

Identification of unconfined aquifer using 3D resistivity analysis at Simpang 5 area, Semarang, Central Java, Indonesia

SUPRIYADI^{1,*}, FIANTI¹, DWI RIZKI R¹, AGUS SETYAWAN², RONALDO TALAPESY³

¹ Physics Department, Universitas Negeri Semarang, Indonesia

² Physics Department, Diponegoro University, Indonesia

³ Graduate School Of Science and Technology, Kumamoto University, Kumamoto, Japan

* Corresponding author email address: supriyadi@mail.unnes.ac.id

Abstract: Water is a unique property of the Earth and very important to every living organism. The existence of groundwater is only 0.61% of the total water on earth (oceans, rivers, lakes, polar ice, rain). The purpose of this research is to determine the location and depth of the aquifer by using 2D and 3D modeling. The method of research is resistivity method using Schlumberger configuration, where data is collected according to the survey design with coordinate ranging from X:436100, Y:9226880 to X:436680, Y:9227640, and covered by 7 lines. The modeling results indicate that the present groundwater aquifer potential has low resistivity distribution in this area. The spreading of unconfined aquifer is estimated on the north side to the east of Simpang 5 area. This can be seen from syncing the data of line one to six. But the data on line seven is of different patterns with other lines. The existence of groundwater basin is not easily identified on this line. This may be due to the location of Line Seven being located in the area of Ciputra Mall, Horison Hotel and Tlogorejo Hospital with higher consumption of water, thus the decrease in groundwater condition. This may cause conditions such as land subsidence. The results of interpretation based on the modeling show the possibility of an unconfined aquifer with groundwater level at 10-15 m depth with varied end of border groundwater depth.

Keywords: Alluvium, geoelectric, groundwater, unconfined aquifer, Simpang 5, Semarang

INTRODUCTION

Water is a limited natural resource according to time and place. Processing and preservation is absolutely necessary. Utilization of water for various purposes should be done wisely by taking into account the interests of present and future generations. Water has become a primary need for every living being on earth (Nazaruddin, *et al.*, 2017). Increasing population of living creatures has decreases the water supply. Most human generally need about 300 liters of clean water for everyday purposes (Lateef, 2016). Water is found in many parts of the world including oceans, rivers, lakes, polar ice, rain, and ground water. In addition to oceans and polar ice, ground water is another most important source (Ofterdinger *et al.*, 2020). Sub-surface information is one of the most important components of earth-related activities. This information includes the geological structure, type, and physical properties of rocks, array of rocks below the surface, depths, thickness, and distribution, including the condition of aquifers containing ground water.

The city of Semarang as the capital of Central Java province has various geographical characteristics. Semarang City which continues to experience growth both in the field of industry and property makes Simpang 5 area became the center of growth and development in the

city. This is because the location of Simpang 5 Semarang is at a very strategic area, easily accessible from all over the city. It also makes the growth of economic, trade and tourism activities very rapid in the region. Rapid growth in the Simpang 5 area requires the availability of clean water sources to support all these activities that are taking place in the region. Water users in Simpang 5 area are increasing with the presence of several hotels, such as Horison Hotel, Citra Land, Graha Santika, Holiday Inn, Luis Kiene, and several malls in the area.

The condition of groundwater extraction in Semarang City, especially Simpang 5 area can be said to have reached a condition that exceeds the balance between ground water supply and the number of taking. It can be seen from the groundwater infiltration data which states that the amount of absorption lost in Semarang City is 5,281,564 m³ (Shen *et al.*, 2020). The amount indicates a large volume, where if the situation continues, will cause negative impacts on groundwater conditions such as the decrease of groundwater level, quantity, and quality. Taking into account the condition of Simpang 5 area, it is necessary to know the potential of groundwater well in the area so that groundwater management can be carried out in an integrated and sustainable condition. The geophysical method is an appropriate tool for

characterizing the geology and sub-surface hydrology (Ibuot *et al.*, 2013). In this research, systematic planning and management to predict the groundwater potential using modern techniques is applied for proper use, protection and management of vital resources (Sultan *et al.*, 2017). The role of geophysical methods in groundwater survey is to understand the adequately and accurately hidden hydrogeological conditions. The basis of any geophysical method is to measure the contrast between the target physical and environmental properties (Saad *et al.*, 2012). A good appreciation of geology is essential in groundwater development programs because geology determines where, how, and how much groundwater quantity and quality are available (Ewusi *et al.*, 2009).

The geophysical method uses an approach based on the contrast of conductivity or resistivity to determine the conductivity distribution or resistivity of the subsurface Earth material, so this method is particularly suitable for identifying lithology units and variations of lithologic units as well as for the study of groundwater and aquifers (Redhaounia *et al.*, 2016; Shen *et al.*, 2020). In addition, this geophysical method is also a popular method because of its low operation cost, simple process, and efficiency in areas with low contrast resistivity (Muchingami *et al.*, 2012). There are several kinds of geoelectric methods, one of which is the resistivity method. It follows the basic principle that each of the rock layers has different resistivity values. The resistance values of each type of rock is determined by their constituent material types, water content, chemical properties of water, and rock porosity (Nakashima & Kawabata, 2020). So by knowing the resistance value of the type of rock layers, we can study the types of rock material, subsurface, and distribution of groundwater in the area. Geoelectric surveys of mapping and sound resistivity methods resulted in information of variations in resistivity rates both laterally and vertically (Luo *et al.*, 2019). At the present time, the resistivity method has become an important and useful tool in hydrogeological studies, mining and mineral mining (Aizebeokhai, 2010).

MATERIAL AND METHOD

Geophysical methods provide an efficient tool for characterizing subsurface geology and hydrology (Ibuot *et al.*, 2013). Geological and geophysical surveys were conducted in the research area to identify potential groundwater in the area. The geological survey aims to identify and map geomorphological and geological features, especially the unit of land and lithologic units exposed in the study area. For geophysical investigations, resistivity survey is an effective method for groundwater investigation.

Resistivity method is a geophysical approach based on the conductivity or contrast resistivity used to determine the conductivity distribution or resistivity of

the Earth's substances below the surface, so this method is particularly suitable for identifying lithology units and variations in lithology units as well as for groundwater and aquifer studies (Redhaounia *et al.*, 2016). Moreover it is one geophysical method that is low in cost, simple operation, and is efficient in areas with low contrast resistivity (Muchingami, 2012).

The principle of the resistivity method is to inject an electric current to the earth through the current electrode (a pair of electrodes) and the response received in the form of a potential difference is measured through two potential electrodes. Each measurement uses four electrodes, following Ohm's Law, interrogating the effective point beneath the surface (Cardenas & Markowski, 2010). From the measurement of the differential current and electric potentials, we can obtain variations of electrical resistance in the layer below the measurement point (Supriyadi *et al.*, 2017; Suski *et al.*, 2010). Multi-electrode resistivity survey was conducted using S-Field resistivity resistance. The system is connected to 16 stainless steel electrodes, which are placed in a straight line with a constant distance through a multi-core cable. The Schlumberger configuration is used in this study (Figure 1). The resistivity survey was conducted with a 10 m electrode spacing that provided a spreading length of about 150 m with the deepest penetration of approximately 50 m. The location of the study is shown in Figure 2.

Based on the measured physical quantities, the Schlumberger electrode arrangement aims to measure the electrical potential gradient. The geometric factor for this Schlumberger electrode arrangement corresponds to Equation 1, while the magnitude of the Geometry Factor (K) for the Schlumberger configuration is shown in Equation 2.

$$K = 2\pi((1/r_1 - 1/r_2) - (1/r_3 - 1/r_4)) \quad (1)$$

$$K = \pi (b^2/a - a/4) \quad (2)$$

The research steps include the measurement of path, determining the width between electrodes (a), installing electrodes based on the electrode arrangement used in the Schlumberger configuration, and activating the resistivity meter device which will inject the electrical current into the ground through the geoelectric cables.

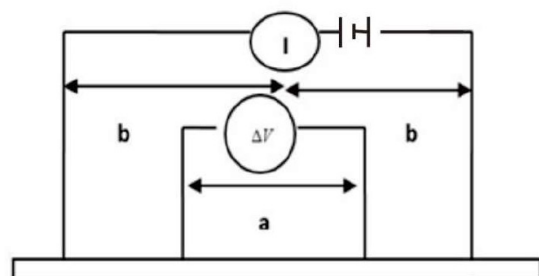


Figure 1: Schlumberger electrode configuration (modified after Hermawan, 2016).

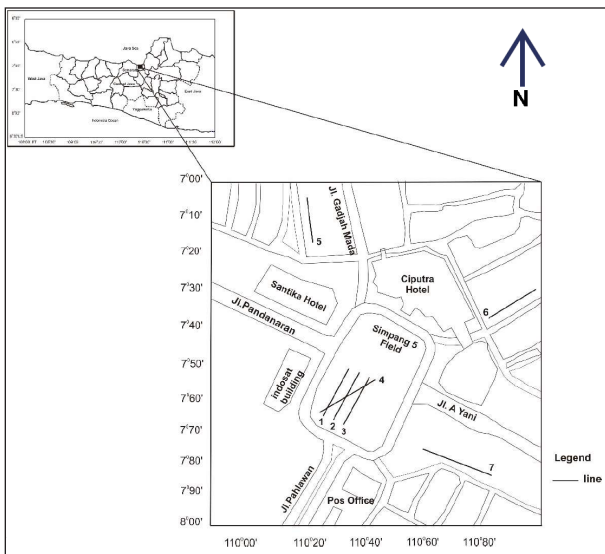


Figure 2: Survey design at the research location Simpang 5, Semarang.

Data was obtained in the form of primary data of the measured results using Ms.Excel. The measured parameters are voltage (V) and current strength (I). The magnitude of the voltage value (V) and the current strength (I) is used to determine the apparent resistivity value, as shown in Equation 3.

$$\rho_a = k \Delta V / I \quad (3)$$

where ρ_a is apparent resistivity, k is geometry factor, ΔV is different of potential (V_{MN}), and I is Current Flow (I_{AB}). ΔV and I are based on Figure 1.

RESULTS AND DISCUSSION

The 3D resistivity modeling was processed using Rockwork software. The distribution of resistivity values obtained from the inversion of Res2Dinv software processing is used as the beginning of 3D cross-section processing using Rockwork Software. From the range of resistivity values, the existence of groundwater at the research location can be determined. Figure 3 shows the distribution of control points modeled from the data obtained at the time of measurement.

The 3D modeling used only 4 trajectories which are scattered in the Simpang 5 field, that is the first, second, fourth and third track as cross sections based on 2-D and 3-D electrical imaging surveys tutorial (Loke, 2004). The next three trajectories are not included in the 3D modeling as they are only used as a comparability path for the accuracy of data. The distance of Simpang 5 Field with the track that is on the fifth, sixth, and seventh tracks is considered less accurate for modeling because it will cause considerable interpolation.

The 3D cross-section is modeled in a block shape, so that it can be observed more clearly from all sides. The coordinates of this box are at the maximum position of X

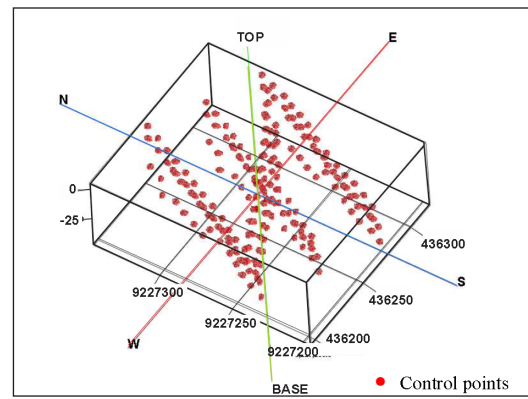


Figure 3: Control points distribution using Rockwork software.

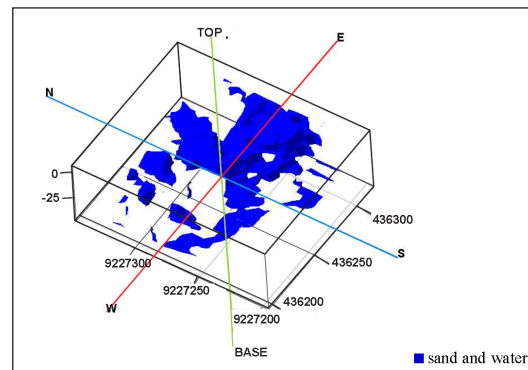


Figure 4: 3D imaging of the anomaly results in 0.25-1 Ωm resistivity range.

436320 and Y 9227345, as well as the minimum positions X 436195 and Y 9227195. The elevation modeled on the 3D cross section is from 6 m to -50 m from the ground. The distribution of resistivity values according to rock type is shown in Table 1.

The study area generally consists of several layers with different resistivity values. The results of 3D processing using Rockwork software on the restriction value of 0.25-1 Ωm which predicted ground water obtained results are shown in Figure 4. Restriction of resistivity value is done in order to get the distribution of groundwater basin in the location clearly.

The distribution of a larger number of resistivity is shown in the northeast of the Simpang 5 field. This is reinforced by the sixth track located in the East Pekunden Road area. The sixth track shows that at its southern side, there is more groundwater distribution, and this position is close to the northeastern part of Simpang 5 Square.

The first trajectory precisely in the western part of Simpang 5 Square showed less groundwater distribution than the other paths. From another study, a decrease between 0.2-0.4 m/year in groundwater level that occurred at Graha Santika Hotel located at Simpang 5 was reported (Chen *et al.*, 2010). The decrease in the groundwater level indicates the reduced distribution of groundwater.

Table 1: The values of resistivity (Telford *et al.*, 1990).

Materials	Resistivity (Ωm)
Air	0
Sea Water	0,21
Ground Water	0.25-200
Clay	1-100
Sand	1-1000
Copper	1-1,7
Magnesium	4,2
Iron	0,1-25
Alluvium	10-800
Mangan	44-160
Gravel	100-600
Sandstone	200-8000
Limestone	50-1x10 ⁷
Carbon	3000
Saltstone	30-1x10 ¹³
Quartz	4x10 ¹⁰ -2x10 ¹⁴
Andesite	17x10 ¹ -45x10 ³

However, the range of decline is still categorized as low-grade (Zhou *et al.*, 2020).

Simpang 5 area consists of 3 main land layers, namely the first layer of top soil (0 to 10 m) composed of soil. The second layer with a depth of between 10 and 45 m is in the form of sand layer, which indicated the location of aquifer (surface water source). The third layer is a clay layer at a depth of 45 to 80 m. The results of modeling using Rockwork software shows the presence of groundwater distribution at a depth of 15 m below the surface. This layer is identified as a sand layer which is thought to be the site of an aquifer. Furthermore, this layer where the range of resistivity values tend to be small i.e. 0.25-1 Ωm is included in the conductive zone as it is a layer that is easy to conduct electrical current. Based on the resistivity value of the aquifer being less than 1 Ωm , this indicates that it is salty water, caused by intrusion. Therefore, this aquifer is not suitable for consumption such as for drinking or cooking. The location of the groundwater depth in the study area is shown in Figure 5. 3D modeling results using 0.25-1 Ωm resistivity range indicates a volume of $\pm 55950 m^3$, the figure represents only 20 % of all volume modeled using Rockwork software.

CONCLUSION

The 3D modeling results indicate the presence of groundwater potential in the study site. In this model, the groundwater resistivity range is between 0.25-0.940 Ωm and indicated an unconfined aquifer because the very salty water may be caused by sea water intrusion. The

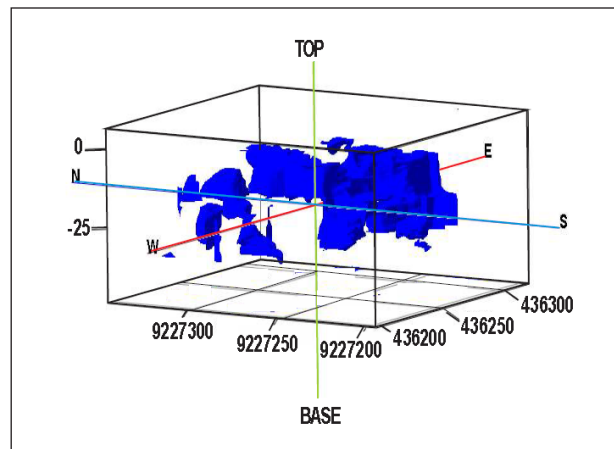


Figure 5: 3D imaging showing the depth of the free aquifer basin in the 0.25-1 Ωm resistivity range, as seen from the southwest.

measured volume is $\pm 55950 m^3$, representing only 20% of all volume modeled using the Rockwork software.

The results of data processing of each measurement path indicate the presence of groundwater layer at Simpang 5 Field, and the potential of ground water tends to be in the north. The seventh location in the Sejora Selatan area has different conditions from other trajectories, presumably this location is experiencing a decrease in groundwater level, caused by the loading of hotels located in the region such as Horison Hotel, Ciputra Mall, and Hotel Santika.

ACKNOWLEDGEMENT

Thanks are conveyed to the UNNES's Rector who has founded the research grant DIPA UNNES with contract number : 1.26.3/UN37/PPK.3.1/2018.

REFERENCES

Aizebeokhai, A.P., 2010. 2D and 3D geoelectrical resistivity imaging: Theory and field design. *Scientific Research and Essays*, 5(23), 3592-3605.

Cardenas, M.B. & Markowski, M.S., 2010. Geoelectrical imaging of hyporheic exchange and mixing of river water and groundwater in a large regulated river. *Environmental Science & Technology*, 45(4), 1407-1411.

Chen, C.H., Wang, C.H., Hsu, Y.J., Yu, S.B. & Kuo, L.C., 2010. Correlation between groundwater level and altitude variations in land subsidence area of the Choshuichi Alluvial Fan, Taiwan. *Engineering Geology*, 115(1-2), 122-131. <https://doi.org/10.1016/j.enggeo.2010.05.011>.

Ewusi, A., Kuma, J. S. & Voigt, H. J., 2009. Utility of the 2-D multi-electrode resistivity imaging technique in groundwater exploration in the Voltaian sedimentary basin, Northern Ghana. *Natural resources research*, 18(4), 267.

Hermawan, O.R. & Putra, D.P.E., 2016. The Effectiveness of Wenner-Schlumberger and Dipole-dipole Array of 2D Geoelectrical Survey to Detect The Occurring of Groundwater in the Gunung Kidul Karst Aquifer System, Yogyakarta, Indonesia. *Journal of Applied Geology*, 1(2), 71-81.

Ibuot, J.C., Akpabio, G.T. & George, N.J., 2013. A survey of the

- repository of groundwater potential and distribution using geoelectrical resistivity method in Itu Local Government Area (LGA), Akwa Ibom State, southern Nigeria. *Central European Journal of Geosciences*, 5(4), 538-547.
- Lateef, A.T., 2016. Geophysical Investigation for Groundwater Using Electrical Resistivity Method-A Case Study of Annunciation Grammar School, Ikere Lga, Ekiti State, South-Western Nigeria. *JOAP*, 2(1), 01-06.
- Loke, M.H., 2004. Tutorial: 2-D and 3-D electrical imaging surveys. Geotomo Software, Malaysia.
- Luo, X., Gong, S., Huo, Z., Li, H. & Ding, X., 2019. Application of Comprehensive Geophysical Prospecting Method in the Exploration of Coal Mined-Out Areas. *Advances in Civil Engineering*, 2019(4), 1-17. <https://doi.org/10.1155/2019/2368402>.
- Muchingami, I., Hlatywayo, D.J., Nel, J.M. & Chuma, C., 2012. Electrical resistivity survey for groundwater investigations and shallow subsurface evaluation of the basaltic-greenstone formation of the urban Bulawayo aquifer. *Physics and Chemistry of the Earth, Parts A/B/C*, 50, 44-51.
- Nakashima, M. & Kawabata, J., 2020. Research, business activities and industry-government-academia collaboration of the Japanese Association of Groundwater Hydrology. *Journal of Groundwater Hydrology*, 62(1), 15-24. DOI: <https://doi.org/10.5917/jagh.62.15>.
- Nazaruddin, D.A., Amiruzan, Z.S., Hussin, H. & Jafar, M.T.M., 2017. Integrated geological and multi-electrode resistivity surveys for groundwater investigation in Kampung Rahmat village and its vicinity, Jeli district, Kelantan, Malaysia. *Journal of Applied Geophysics*, 138, 23-32.
- Ofterdinger, U., MacDonald, A.M., Comte, J.C. & Young, M., 2020. Groundwater in Fractured Bedrock Environments: Managing Catchment and Subsurface Resources. Geological Society of London, UK. 250 p. DOI: <https://doi.org/10.1144/SP479-2018-170>.
- Redhaounia, B., Bédir, M., Gabtni, H., Batobo, O.I., Dhaoui, M., Chabaane, A. & Khomsi, S., 2016. Hydro-geophysical characterization for groundwater resources potential of fractured limestone reservoirs in Amdoun Monts (North-western Tunisia). *Journal of Applied Geophysics*, 128, 150-162.
- Saad, R., Nawawi, M.N.M. & Mohamad, E.T., 2012. Groundwater detection in alluvium using 2-D electrical resistivity tomography (ERT). *Electronic Journal of Geotechnical Engineering*, 17, 369-376.
- Shen, D., Guna, A. & He, X., 2020. Water use control sytem in China. *International Journal of Water Resources Development*, 36(4), 590-609. <https://doi.org/10.1080/07900627.2019.1676202>.
- Sultan, S.A., Essa, K.S.A.T., Khalil, M.H., El-Nahry, A.E.H. & Galal, A.N.H., 2017. Evaluation of groundwater potentiality survey in south Ataq-northwestern part of Gulf of Suez by using resistivity data and site-selection modeling. *NRIAG Journal of Astronomy and Geophysics*, 6(1), 230-243.
- Supriyadi, Khumaedi & Putro, A.S.P., 2017. Geophysical and Hydrochemical Approach for Seawater Intrusion in North Semarang, Central Java, Indonesia. *International Journal of Geomate*, 12(31), 134-140. DOI: 10.21660/2017.31.50405.
- Suski, B., Brocard, G., Authemayou, C., Muralles, B.C., Teysier, C. & Holliger, K., 2010. Localization and characterization of an active fault in an urbanized area in central Guatemala by means of geoelectrical imaging. *Tectonophysics*, 480(1-4), 88-98.
- Telford, W.M., Sheriff, R.E. & Geldart, L.P., 1990. *Applied Geophysics*, 2nd edition. Cambridge University Press, New York. 770 p.
- Zhou, C., Gong, H., Chen, B., Gao, M., Cao, J., Duan, L., Zuo, J., & Shi, M., 2020. Land Subsidence Response to Different Land Use Types and Water Resource Utilization in Beijing-Tianjin-Hebei, China. *Remote Sensing Journal*, 12, 457. doi:10.3390/rs12030457.

Manuscript received 1 June 2020
Revised manuscript received 9 October 2020
Manuscript accepted 9 November 2020