Groundwater Potential Analysis Using the Geoelectrical Schlumberger Configuration Method

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Abstract

This study analyzes the groundwater potential using the geoelectric resistivity method with a Schlumberger configuration. The main objective of this research is to identify subsurface lithology and the presence of aquifers as a solution to seasonal drought problems. Measurements were carried out along three survey lines, each 100 meters in length, and the resistivity data were processed using IPI2WIN software to produce one-dimensional (1D) subsurface models. The interpretation results indicate subsurface lithology consisting of clay, sandy clay, and sandstone. Potential aquifer layers were identified at depths of 2–7 meters with resistivity values ranging from 67–106 Ωm, interpreted as unconfined to semi-confined aquifers. The overall resistivity values obtained in the study area ranged from 1 to 13,991 Ωm. The existence of these layers indicates groundwater potential that can be utilized to meet the needs of the surrounding community.The Schlumberger configuration proved effective in mapping subsurface lithology and determining potential aquifer zones. The information obtained from this study can serve as a basis for sustainable groundwater resource management area.

Keyword : geoelectric, Schlumberger, resistivity, aquifer, groundwater, lithology

1. INTRODUCTION

Groundwater is one of the most important natural resources for sustaining life, especially in regions with limited surface water availability. In developing areas, groundwater plays a vital role in meeting domestic, agricultural, and industrial needs. However, seasonal droughts and uneven groundwater distribution often lead to a decrease in well yields, which ultimately affects the stability of social, economic, and environmental activities.

The lack of comprehensive subsurface information, particularly regarding lithology and aquifer distribution, remains a major challenge in achieving sustainable groundwater management. Conventional groundwater exploration methods often face limitations in terms of accuracy and cost efficiency. In contrast, geophysical methods—particularly the geoelectrical resistivity method using the Schlumberger configuration—offer a reliable and non-destructive approach to identifying subsurface conditions. This method enables the detection of lithological variations and the delineation of aquifer zones based on resistivity values.

To enhance the accuracy of interpretation, geoelectrical survey data must undergo further processing and modeling. In this study, the IPI2WIN software was used to perform one-dimensional (1D) inversion, which converts field measurement data into subsurface models that describe the depth, thickness, and resistivity of each layer. These models serve as the basis for identifying aquifer systems and estimating groundwater potential in the study area.

By applying the Schlumberger configuration in combination with modeling using IPI2WIN, this research aims to provide a more accurate assessment of subsurface lithological conditions and groundwater potential in the study area. The results are expected to serve as an important reference for sustainable groundwater management and support the development of technology-based areas.

Based on this background, this study aims to identify the subsurface lithological conditions and determine the depth of aquifer occurrence within the lithological formations.

1.1. Groundwater

Groundwater is water stored in the saturated zone, moving through soil and rock layers until it emerges as springs or fills other water bodies, with its upper boundary referred to as the water table (Fetter, 1994). To this day, groundwater remains the primary source of water supply for communities, serving needs such as drinking water, household use, irrigation, and industry (Prastistho, 2018). Its availability is influenced by topography, climatic conditions, porosity, permeability, and vegetation.

Although groundwater plays an essential role in environmental balance, excessive exploitation can reduce both its quality and quantity. Naturally, groundwater movement is controlled by geological and hydrogeological factors, with fractures and discontinuities functioning as secondary storage, while its hydraulic conductivity is influenced by pressure, depth, and rock conditions. Factors such as temperature, cementation, rock age, and weathering may further decrease permeability. Therefore, understanding aquifer geological structures is crucial to support sustainable groundwater management. In addition, the groundwater recharge process refers to precipitation infiltration into the saturated zone, while discharge is the process by which groundwater reaches the surface and flows outward (Barkah, 2021).

1.2. Geolistric

The geoelectrical method is one of the most commonly used geophysical methods in shallow exploration because it can detect variations in rock resistivity related to water content, porosity, and mineralization (Reynolds, 1997). Essentially, this method is approached using the concept of electric current propagation in a homogeneous isotropic medium, where the electric current flows equally in all directions. Therefore, if there is any deviation from the ideal condition (homogeneous isotropic), this deviation (anomaly) is what is actually observed. The resistivity value of rocks is related to their physical properties, including the degree of water saturation, porosity, permeability, and rock formation. Interpreting measurements in the geoelectrical method, the Earth is assumed to be homogeneous and isotropic, meaning that each layer has the same resistivity. The basic principle of the geoelectrical method is to measure the response in the form of potential at a potential electrode resulting from electric current injected into the ground through a current electrode. Therefore, the theoretical formulation of the geoelectrical method is based on the principle of calculating electrical potential in a given medium due to a current source applied at the Earth's surface. If a current (I) is injected into a homogeneous and isotropic medium through a single electrode, the electric current will spread in all directions along equipotential surfaces in the form of hemispherical surfaces, as illustrated in Figure 1 (Telford, 1990).

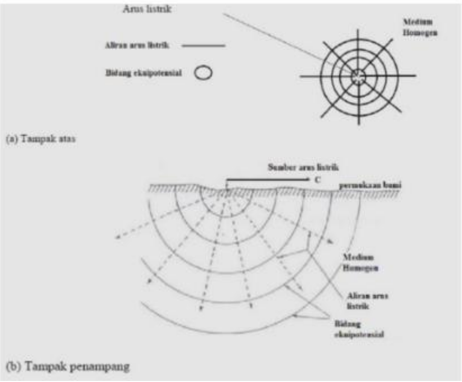


Fig.1 Electric Current Flow and Equipotential Surfaces

1.3. Schlumberger configuration

The Schlumberger configuration is a measurement technique carried out by placing electrode points at varying distances from one another. The spacing of the current electrodes can be adjusted to be different from the spacing of the potential electrodes. The arrangement of the Schlumberger configuration for the geoelectrical method can be seen in Figure 2.

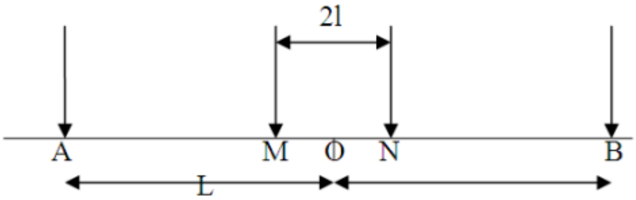


Fig.2 Current electrodes and potential electrodes in the Schlumberger configuration

In this configuration, A and B are the current electrodes that inject electrical current into the ground, with distance L measured from electrode A to the central point O. The potential difference resulting from the injected current is measured using electrodes M and N, where the distance l is measured from electrode N to the central point O. The value of K is obtained from the equation:

$$K = \frac{\pi(L^2 - l^2)}{2l} \qquad (1)$$

Where:

K = Geometric factor (m)

L = Distance of the current electrode from the central measuring point (m)

l = Distance of the potential electrode from the central measuring point (m).

The resistivity formula is expressed as:

$$\rho = k \frac{V}{I} \qquad (2)$$

Where:

ρ = Resistivity value (ohm-m)

K = Geometric factor (m)

I = Current value (ampere)

V = Potential value (volt)

The Schlumberger configuration has the advantage of detecting rock layers with non-homogeneous properties near the surface. This interpretation is achieved by comparing the apparent resistivity values when the spacing of the potential electrodes is varied. The Schlumberger configuration is considered one of the most effective methods for identifying subsurface anomalies or intrusions (Loke, 2000).

1.4. Lithology

Lithology is defined as the description of rocks in an outcrop based on their characteristics, such as color, mineral composition, grain size, synonyms, and petrography (Bates and Jackson, 1985). Lithology is one of the factors that influence seismic wave velocity. Different types of rocks will exhibit different velocity ranges. Each rock layer has a different level of hardness. These differences in hardness affect a rock's ability to return to its original shape and size when subjected to force. The varying elasticity of rocks causes seismic waves to propagate through rock layers at different velocities (Setiawan, 2008). There are various types of rocks on Earth, such as sedimentary rocks and bedrock. Sedimentary rocks are formed as a result of the compaction of loose deposits, which are formed from the accumulation of materials derived from the breakdown of pre-existing rocks or from chemical or biological activity, which are then deposited on the Earth's surface and eventually lithified (Pettjohn, et al., 1975).

1.5. Rock Resistivity

Resistivity is the ability of a rock to impede the flow of electric current. It is measured in Ohm-m and is the inverse of a rock's conductivity. Two physical properties that influence a rock's resistivity value are porosity and permeability. A rock's resistivity decreases when: Porosity is greater and the rock is saturated with water.The concentration of dissolved electrolyte substances is higher.

Rock Permeability

Permeability is a measure of how easily a fluid can flow through a porous medium. Permeable rock layers have interconnected pores, allowing fluids to pass through. The size of these pores and the properties of the fluid determine the rock's permeability. The smaller the rock's constituent particles, the smaller its pores, which results in lower permeability.

Table 1. hydraulic conductivity

Material	Hydraulicconductivity (m/day)	Type of measurement
Gravel, coarse	150	R
Grave, Medium	270	R
Gravel, fine	450	R
Sand, coarse	45	R
Sand, Medium	12	R
Sand, Fine	2.5	H
Silt	0.08	H
Clay	0.0002	V
Sandstone, fine-grained	0.2	V
Sandstone, Medium - grained	3.1	V
Limestone	0.94	V
Dolomite	0.001	V
Dune Sand	20	V
Loess	0.08	V
Peat	5.7	V
Schist	0.2	V
Slate	0.00008	V
Till, predominantly sand	0.49	R
Till, predominantly gravel	30	R
Tuff	0.2	V
Basalt	0.01	V
Gabbro, weathered	0.2	V
Granite, weathered	1.4	V

Source: (Todd, 2005).

Table 2. Resistivity of various rocks and sediments

Rock Type	Resistivity Range (Ωm)
Granite porphyry	4.5×10^3 (wet) – 1.3×10^6 (dry)
Feldspar porphyry	4×10^3 (wet)
Syenite	$10^2 - 10^5$
Diorite porphyry	1.9×10^3 (wet) – 2.8×10^4 (dry)
Porphyrite	$10 - 5 \times 10^4$ (wet) – 3.3×10^3 (dry)
Carbonatized porphyry	2.5×10^3 (wet) – 6×10^4 (dry)
Quartz diorite	$2 \times 10^4 - 2 \times 10^6$ (wet) 1.8×10^5 (dry)
Porphyry (various)	$60 - 10^4$
Dacite	2×10^4 (wet)
Andesite	4.5×10^4 (wet) – 1.7×10^2 (dry)
Diabase (various)	$20 - 5$ x 10^7
Lavas	$10^2 - 5 \times 10^4$
Gabbro	$10^3 - 10^6$
Basalt	$10 - 1.3 \times 10^7$ (dry)
Olivine norite	$10^3 - 6 \times 10^4$ (wet)
Peridotite	3×10^3 (wet) – 6.5×10^3 (dry)
Hornfels	8×10^3 (wet) – 6×10^7 (dry)
Schists (calcareous and mica)	$20 - 10^4$
Tuffs	2×10^3 (wet) – 10^5 (dry)
Graphite schist	$10 - 10^2$
Slates (various)	$6 \times 10^2 - 4 \times 10^7$
Gneiss (various)	6.8×10^4 (wet) – 3×10^6 (dry)
Marble	$10^2 - 2.5 \times 10^3$
Skarn	2.5×10^2 (wet) – 2.5×10^8 (dry)
Quartzites (various)	$10 - 2 \times 10^8$
Consolidated shales	$20 - 2 \times 10^3$
Argillites	$10 - 8 \times 10^2$
Conglomerates	$2 \times 10^2 - 10^4$
Sandstones	$1 - 6.4 \times 10^8$
Limestones	$50 - 10^7$
Dolomite	102
Unconsolidated wet clay	20
Marl	3 – 70
Clays	1 – 100
Oil sands	4 – 800

Source : (Telford et al., 2004)

2. METHOD

2.1. Research Design

Data analysis using quantitative techniques essentially aims to transform research results into a more structured numerical form, making them easier to understand. The collected data is then processed and presented in the form of numerical descriptions, such as tables, diagrams, or percentages, so that the information obtained can be read and interpreted more clearly (Hikmawati, 2020). This research is a quantitative study, in which field measurements were conducted to estimate the presence of groundwater aquifers using the geoelectrical method with a Schlumberger configuration. The measurement data were then interpreted to identify the hydrogeological cross-section in the study area. Based on this interpretation, the location and depth of potential drilling points can be determined to obtain the maximum potential from the groundwater aquifer.

2.2. Project Technical Data

The case study in this research is the analysis of groundwater potential using the geoelectrical method with a Schlumberger configuration.

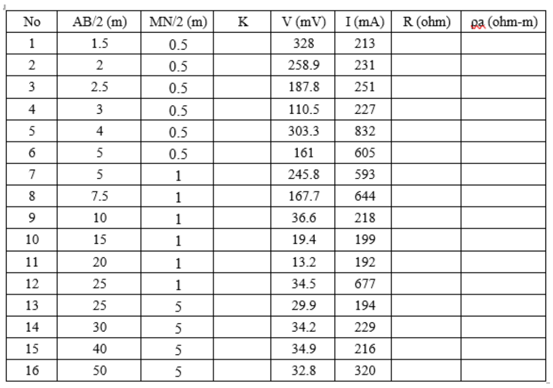
This research was conducted on three measurement lines, each with a length of 100 meters. Each line was selected based on the morphological conditions and topographic characteristics of the study area. In general, the soil conditions at the research site tend to be sloping, influenced by the natural contour of the area. The study area is located at an elevation of approximately 866 meters above sea level, indicating that the region is part of a highland area with significant variations in lithology and aquifer potential. The sloping topography also affects surface water flow and water infiltration into the soil layers, which are important factors in analyzing groundwater potential.

3. RESULTS AND DISCUSSION

3.1.1. Interpretation of the first measurement trajectory Results

The first research line is located at an elevation of 866 meters with a total length of 100 meters. The existing condition of the first line consists of a garden area covered with grass, several small soil mounds, and a relatively flat surface.

Table 3.Interpretation of the first measurement trajectory Results



No	AB/2 (m)	MN/2 (m)	K	V (mV)	I (mA)	R (ohm)	ρa (ohm-m)
1	1.5	0.5		328	213		
2	2	0.5		258.9	231		
3	2.5	0.5		187.8	251		
4	3	0.5		110.5	227		
5	4	0.5		303.3	832		
6	5	0.5		161	605		
7	5	1		245.8	593		
8	7.5	1		167.7	644		
9	10	1		36.6	218		
10	15	1		19.4	199		
11	20	1		13.2	192		
12	25	1		34.5	677		
13	25	5		29.9	194		
14	30	5		34.2	229		
15	40	5		34.9	216		
16	50	5		32.8	320		

3.1.2. Interpretation of the 2nd measurement trajectory

The second research line is located at an elevation of 866 meters with a total length of 100 meters. The existing condition of the second line consists of a garden area covered with grass, several small soil mounds, and a relatively flat surface.

Table 4.Interpretation of the 2nd measurement trajectory

No	AB/2 (m)	MN/2 (m)	K	V (mV)	I (mA)	R (ohm)	ϱa (ohm-m)
1	1.5	0.5		361.6	193		
2	2	0.5		261.3	224		
3	2.5	0.5		161.1	202		
4	3	0.5		142.5	248		
5	4	0.5		62.6	181		
6	5	0.5		184.2	827		
7	5	1		137.5	249		
8	7.5	1		54.1	262		
9	10	1		90	811		
10	15	1		37	1012		
11	20	1		6	283		
12	25	1		22.3	929		
13	25	5		111.4	869		
14	30	5		92.4	876		
15	40	5		54.6	662		
16	50	5		40.2	582		

3.1.3. Interpretation of the 3rd measurement trajectory

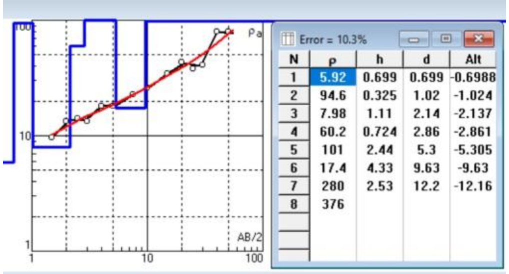
The third research line is located at an elevation of 866 meters with a total length of 100 meters. The existing condition of the third line consists of a garden area covered with grass, several small soil mounds, and a relatively sloping surface.

Table 5. Interpretation of the 3nd measurement trajectory

No	AB/2 (m)	MN/2 (m)	K	V (mV)	I (mA)	R (ohm)	ϱa (ohm-m)
1	1.5	0.5		113.1	19		
2	2	0.5		36.1	17		
3	2.5	0.5		30	28		
4	3	0.5		45	59		
5	4	0.5		29.8	65		
6	5	0.5		32.4	54		
7	5	1		47.4	58		
8	7.5	1		22	52		
9	10	1		11.7	46		
10	15	1		4.8	33		
11	20	1		2.5	34		
12	25	1		1.5	73		
13	25	5		47.1	71		
14	30	5		29.9	67		
15	40	5		17.1	106		
16	50	5		12.8	161		

3.2 Interpretation of IPI2WIN resultsCapacity Curve

Based on the modeling results using IPI2Win software, the first, second and third trajectories are shown in the following image.

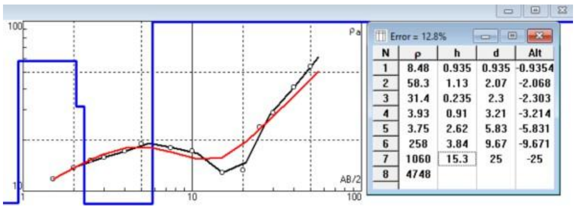


Error = 10.3%

N	ρ	h	d	Alt
1	5.92	0.699	0.699	-0.6988
2	94.6	0.325	1.02	-1.024
3	7.98	1.11	2.14	-2.137
4	60.2	0.724	2.86	-2.861
5	101	2.44	5.3	-5.305
6	17.4	4.33	9.63	-9.63
7	280	2.53	12.2	-12.16
8	376			

Fig. 3. IPI2WIN results track 1

The interpretation of the geoelectrical data in the figure shows eight subsurface layers with an inversion error of 10.3%, indicating that the model fit is reasonably accurate. The resistivity values range from 5.92 Ωm in the first layer to 376 Ωm in the deepest layer. The depth of the layers varies from approximately 0.699 m in the first layer to more than 12.2 m in the seventh layer, with increasing thickness observed in the deeper layers. These results provide an overview of the vertical distribution of resistivity and layer thickness in the subsurface, which can be used as a basis for further interpretation of lithology and groundwater potential.

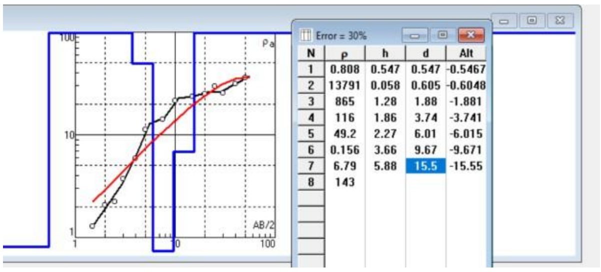


Error = 12.8%

N	ρ	h	d	Alt
1	8.48	0.935	0.935	-0.9354
2	58.3	1.13	2.07	-2.068
3	31.4	0.235	2.3	-2.303
4	3.93	0.91	3.21	-3.214
5	3.75	2.62	5.83	-5.831
6	258	3.84	9.67	-9.671
7	1060	15.3	25	-25
8	4748			

Fig. 4. IPI2WIN results track 2

The interpretation of the geoelectrical data in this figure shows eight subsurface layers with an inversion error value of 12.8%. The resistivity (ρ) values range from 8.48 Ωm in the first layer to 4748 Ωm in the deepest layer. The depth of the layers ranges from approximately 0.935 m in the first layer to more than 15.3 m in the sixth layer, with layer thickness generally increasing at greater depths. The curve graph shows significant resistivity variations at certain depths, indicating changes in the subsurface material composition. These results provide an overview of the vertical distribution of resistivity and layer thickness, which can serve as a basis for lithological interpretation and the identification of potential groundwater zones in further analysis.



Error = 30%

N	ρ	h	d	Alt
1	0.808	0.547	0.547	-0.5467
2	13791	0.058	0.605	-0.6048
3	865	1.28	1.88	-1.881
4	116	1.86	3.74	-3.741
5	49.2	2.27	6.01	-6.015
6	0.156	3.66	9.67	-9.671
7	6.79	5.88	15.5	-15.55
8	143			

Fig 5. IPI2WIN results track 3

The interpretation of the geoelectrical data in this figure shows eight subsurface layers with an inversion error value of 30%. The resistivity (ρ) values range from 0.808 Ωm in the first layer to 143 Ωm in the deepest layer. The layer depths range from approximately 0.55 m in the first layer to more than 15.5 m in the seventh layer. The layer thickness varies, with relatively thin layers at shallow depths and thicker layers at intermediate to deeper depths. The resistivity curve shows a clear upward trend at certain depths, indicating changes in the subsurface material composition. These results provide an overview of the vertical resistivity distribution, which can be used for lithological interpretation and further evaluation of groundwater potential

3.3 Lithology layer

Based on the IPI2WIN interpretation, lithology results will be obtained through interpretation with geological data, as shown in the image below.

Table 6.Lithology layer 1

Lintasan 1							
Layer	Tahanan jenis	Kedalaman Tanah			Ketebalan Tanah	Litologi	Hidrogeologi
1	5.92	0	-	0.699	0.699	Clays	
2	94.6	0.699	-	1.02	0.321	Clays	
3	7.98	1.02	-	2.14	1.12	Clyas	
4	60.2	2.14	-	2.89	0.75	Clays	
5	101	2.89	-	5.31	2.42	Oil sand	Akuifer
6	17.4	5.31	-	9.63	4.32	Clays	
7	280	9.63	-	12.2	2.57	Oil sand	Akuifer
8	376	12.2	<			Oil sand	Akuifer

Table 6 shows the division of several subsurface layers with varying depths and resistivity values. The differences in color or pattern in each layer represent resistivity variations that can be interpreted as different lithological materials, such as clay, sand, or hard rock. In general, the top layer appears thin with low resistivity values, which likely represents a soil cover or clay layer. Beneath it, the resistivity values increase, possibly indicating the presence of sand or other porous materials. At greater depths, the resistivity becomes even higher, which generally represents hard rock layers.

Table 7.Lithology layer 2

Lintasan 2					
Layer	Tahanan jenis	Kedalaman Tanah	Ketebalan	Litologi	Hidrogeologi
1	9.95	0 - 0.935	0.935	Clays	
2	97.9	0.935 - 2.07	1.135	Clays	
3	33.1	2.07 - 2.3	0.23	Clays	
4	3.31	2.3 - 3.21	0.91	Clays	
5	4.87	3.21 - 5.83	2.62	Clays	
6	140	5.83 - 9.67	3.84	Sand	Akuifer
7	1305	9.67 - 25	15.33	Limestone	
8	5850	25 <		Limestone	

Table 7 shows several subsurface layers with varying depths and resistivity values. The upper layer has low resistivity, which may indicate topsoil or clay. The layers below have higher resistivity values, suggesting sandy or more porous material. At greater depths, resistivity becomes even higher, indicating compact or hard rock material.

Table 8.Lithology layer 3

Lintasan 3					
Layer	Tahanan jenis	Kedalaman Tanah	Ketebalan	Litologi	Hidrogeologi
1	0.808	0 - 0.547	0.547	-	
2	13791	0.547 - 0.605	0.058	limestones	
3	865	0.605 - 1.88	1.275	limestones	
4	116	1.88 - 3.74	1.86	oil sand	Akuifer
5	49.2	3.74 - 6.01	2.27	clays	
6	0.156	6.01 - 9.67	3.66	clays	
7	6.79	9.67 - 15.5	5.88	Clays	
8	143	15.5 <		oil sand	Akuifer

Table 8 shows the division of several subsurface layers with varying depths and resistivity values. The top layer has moderate resistivity, likely representing the surface soil layer. The next layers show higher resistivity values, which may indicate materials such as sand or gravel. At greater depths, the resistivity values become even higher, which likely represents bedrock layers.

4 CONCLUSIONS

Based on the analysis results, the following conclusions can be drawn:

1. Based on the interpretation of geoelectrical data from the three survey lines, the presence of aquifers was identified in several layers, indicated by relatively high resistivity values and lithology consisting of oil sand, clay, and limestone.
2. From the geoelectrical interpretation, aquifers on the first survey line were identified in the 5th layer at depths of 2.86–5.31 m and in the 7th layer at depths of 9.63–12.2 m. On the second line, aquifers were found in the 6th layer at depths of 5.83–9.67 m, while on the third line, aquifers were identified in the 4th layer at depths of 1.88–3.74 m.

ACKNOWLEDGMENT

This research could not have been completed without the support, guidance, and encouragement of many parties. The author wishes to express profound appreciation to Mardiani, S.Pd., M.Eng., and Drs. Ir. Rakhmat Yusuf, M.T., MCE., C.PM., IPM., ASEAN Eng., as academic supervisors, for their exceptional guidance, valuable insights, and constructive suggestions that greatly enhanced the quality of this research. The author is also deeply grateful to colleagues for their continuous support, collaboration, and insightful discussions throughout the research journeysustainably utilized.

REFERENCES

Barkah, M. N., Lisiawan, Y., Nugraha, B., & Hadian, M. S. D. (2021). Modul praktikum hidrogeologi. Adab.

Bates, R. L., & Jackson, J. A. (1985). Glossary of geology (3rd ed.). American Geological Institute.

Fetter, C. W. (1994). Applied Hydrogeology (3rd Edition). Prentice Hall. https://arjzaidi.files.wordpress.com/2015/09/unimasrcom_e7ce669a880a8c4c70b4214641f93a02.pdf

Hikmawati, F. (2020). Metodologi penelitian (Cet. ke-4). Depok: PT RajaGrafindo Persada.

Loke, M. H. (2000). Electrical imaging surveys for environmental and engineering studies: A practical guide to 2-D and 3-D surveys. Penang, Malaysia: Geotomo Software

Prastistho, B., Pratiknyo, P., Rodhi, A., Prasetyadi, C., Massora, M. R., & Munandar, Y. K. (2018). Hubungan Struktur Geologi dan Sistem Air Tanah (1st ed.). LPPM UPN "Yogyakarta" Press.

Pettijohn, F. J., Potter, P. E., & Siever, R. (1975). Sand and sandstone. Springer-Verlag.

Reynolds, J. M. (1997). An introduction to applied and environmental geophysics. John Wiley & Sons.

Setiawan, B. (2008). Pemetaan tingkat kekerasan batuan menggunakan metode seismik refraksi (Skripsi, Universitas Indonesia). Universitas Indonesia.

Telford, W. M., Geldart, L. P., & Sheriff, R. E. (2004). Applied geophysics (2. ed., [repr.], transferred to digital print). Cambridge Univ. Pr.

Todd, D. K., & Mays, L. W. (2005). *Groundwater hydrology* (3rd ed.). John Wiley & Sons