



INVESTIGATION OF GROUNDWATER POTENTIAL IN MARSELA AND BULULORA VILLAGES, MASELA ISLAND, SOUTHWEST MALUKU DISTRICT USING VES AND LEM RESISTIVITY DATA

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ABSTRACT

Groundwater has a wider distribution than surface water because groundwater fills all the pores of the rocks and soil beneath the earth's surface. Groundwater is located in a layer of soil called the aquifer layer which can be identified by the resistivity geoelectric method. The hydrogeological survey conducted in this study included the characterization of aquifers such as rock types and aquifer types through the interpretation of subsurface conditions using the geoelectric resistivity mapping (LEM) method with the Wenner-Schlumberger configuration and sounding (VES) with the Schlumberger configuration. The results showed that the MarselaVes-1 (GeoM-01), MarselaVes-2 (GeoM-02), and BululoraVes-1 (GeoB-01) point areas have local aquifers with moderate productivity and wide distribution. These three geoelectric points have the potential for drilling. Meanwhile, the hydrogeology at the BululoraVes-2 (GeoB-2) point has an aquifer with low productivity.

Keywords: aquifer; groundwater; geoelectric mapping; geoelectric sounding

INTRODUCTION

Water is one aspect that is needed by all living things to survive. The population is increasing so it requires an adequate supply of water. Many parts of the world, including Indonesia, are experiencing drought and have difficulty accessing water. The use of groundwater for human consumption and irrigation in the last decade has resulted in a decrease in groundwater in parts of Indonesia ^[1-2]. Groundwater assets are important for humans, especially in the current conditions which are exacerbated by pollution, urbanization, and industrialization ^[3].

Nearly 95% of fresh water available on earth is groundwater stored in aquifers, a geological formation capable of storing water in its pores or fractures, and has permeability/flow with sufficient discharge to be exploited ^[4]. Hydrogeology is a branch of geology that studies the genesis, distribution and movement of groundwater in the soil and rocks in the earth's crust ^[5]. Groundwater has a wider distribution than surface water because groundwater fills all the pores of the rocks and soil beneath the earth's surface. The existence of groundwater in the soil layer is called the aquifer layer which can be identified by the resistivity geoelectric method. Groundwater is water below the surface that fills the pores and rock fractures ^[6], and is in the

saturated zone at the bottom bounded by an impermeable layer and above by the groundwater table. Groundwater is an important part of the hydrologic cycle ^[7].

Most parts of Indonesia are experiencing drought and have difficulty accessing water. Communities in the research area have difficulty getting clean water and only depend on two old wells in their respective villages. During the dry season, the water discharge is very small, and during the rainy season, the community can collect rainwater to meet their clean water needs. So, to meet the clean water needs of the community in the research area, it is necessary to conduct a deep groundwater survey. Thus, the community's need to obtain and access adequate clean water prompted the author to conduct a groundwater survey in the study area. Because there has never been a survey on the hydrogeological system and aquifer characterization in Marsela and Bululora Villages on Masela Island.

This groundwater survey was conducted to help overcome the community's difficulties in obtaining clean water in the research area because, groundwater investigations up to the time this research was conducted had not found deep groundwater because previous groundwater investigations used conventional methods. This study uses the same geoelectric method as previous researchers ^[8-20]. Still, in data acquisition and interpretation, LEM and VES are used to be applied to different research areas to overcome the community's difficulties in obtaining clean water, which will certainly result in different results. The hydrogeological survey conducted in this study included aquifer characterization in the form of rock types and aquifer types through the interpretation of subsurface conditions using geoelectric resistivity mapping and sounding methods ^[21-22]. Measurement of geoelectrical mapping (Lateral Electrical Mapping / LEM) with the Wenner-Schlumberger configuration and geoelectric sounding (Vertical Electrical Sounding / VES) with the Schlumberger configuration ^[23-24] to interpret the distribution of subsurface lithology in the form of depth and thickness of the aquifer layer. The measurement results are estimated to show variations in rock resistivity values ^[25]. From these results, it is possible to map the subsurface layer carrying the aquifer and groundwater potential and to provide a solution for the government in planning the drilling of raw water wells so that the community can overcome the problem of insufficient clean water in the dry season in the village.

MATERIALS AND METHOD

The Study Area

Field data surveys used the resistivity geoelectric method and hydrophysical data acquisition at the water well points in the Marsela and Bululora villages (Figure 1). In general, the geological conditions of the study area are dominated by reef limestone, and the surface rock is tuff breccia rock from weathering of volcanic rocks ^[26]. From a physiographical perspective, the morphology is composed of lowland hills to undulating hills with a slope of up to 40°.

Resistivity geoelectric method

LEM method

The study area is located $\pm$ (0.5 - 2.7) km from the coastline. Lines 1, 2, and 3 are 450 meters long, and line 4 is 200 meters long. Each line lies in the direction of Northeast - Southwest. The spacing of the electrodes on each line using the LEM method is 10 m. Prepare a stacking chart according to the area of the study area and the desired depth in the area that has been previously explored. The LEM geoelectric survey uses the Wenner-Schlumberger configuration ^[27-28]. LEM geoelectrical measurement data are in the form of potential

difference (ΔV), current strength (I), electrode spacing (a), and multiplier factor (n). Then calculate the geometric factor with the formula: $k = \pi n(n+1)a$. To calculate the apparent resistivity value using the equation: $\rho = k \frac{\Delta V}{I}$ [29]. The next stage is the inversion process to estimate the actual resistivity value by paying attention to the smallest possible error [30].

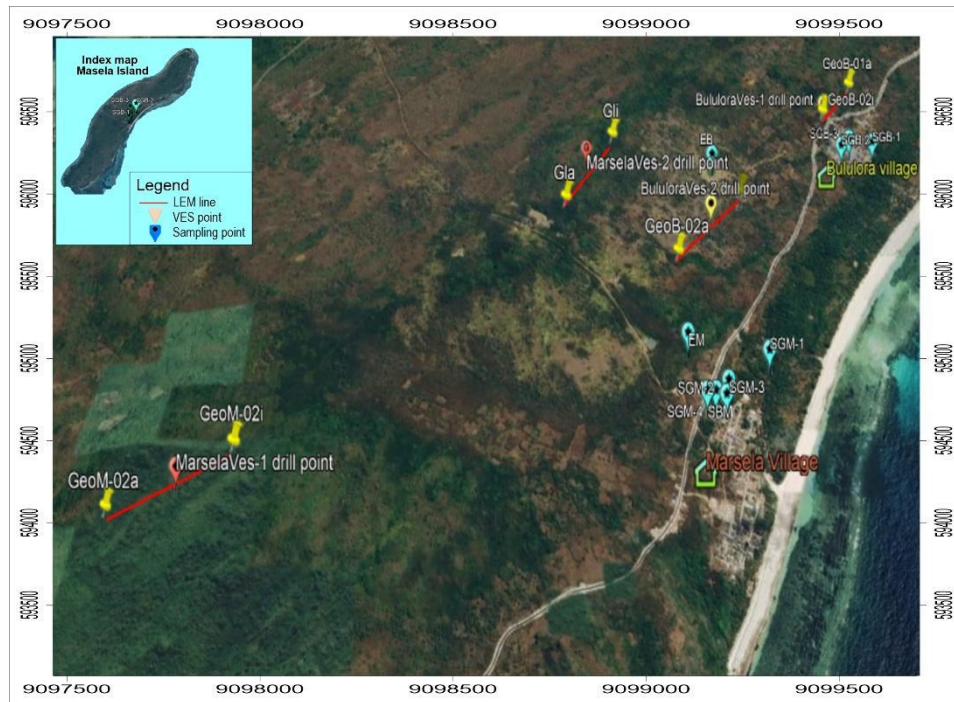


Figure 1. Map of study area (compiled from Google earth, 2025)

VES Method

The length of each sounding point is 450 meters, located at the same position as the LEM method. Geoelectric measurements at four sounding points that are separate and do not intersect. VES geoelectric survey with Schlumberger configuration [31,32] and coordinates. VES geoelectrical measurement data are the potential difference (ΔV) and electric current (I). From these data, the geometry factor is calculated using the formula: $K = \pi \frac{L^2 - l^2}{2l}$ where $L = AB/2$, $l = MN/2$. To calculate the resistivity value, use the equation: $\rho = K \frac{\Delta V}{I}$. Next, the data is processed using a computer program to obtain the most suitable resistivity value.

RESULTS AND DISCUSSION

Hydrogeological conditions of Masela Island

The groundwater basin on Masela Island enters the groundwater basin on Masela Island. The productivity of aquifers on Masela Island is in the form of fracture, fissure, and dissolving aquifer systems with moderate productivity levels.

The raw water survey

The raw water survey was carried out in 9 wells, namely seven dug wells, one drilled well, and two reservoirs. The next step is to measure the depth of the groundwater table and water quality. In coastal areas, the average groundwater level ranges from (0.5 – 2.0) meters. In hilly areas,

the groundwater level is in the range (of 1.0 – 8.0) meters. The results of hydrophysical measurements^[33-35] on nine water samples are shown in Table 1 below.

Table 1. Groundwater hydrophysical data

Types of wells	X	Y	Z (m.asl)	Depth MAT (m)	Temperature		TDS, (mg/L)	EC (S/cm)	pH
					Tw (°C)	Ta (°C)			
SGM-1	9098358	596038	9	1.5	26.5	26.7	1,970	3,200	6.7
SGM-2	9098206	595856	12	0.7	26.7	27.0	1,514	2,436	6.6
SGM-3	9098253	595871	13	0.4	26.7	27.8	413	723	7.2
SGM-4	9098215	595819	13	1.6	26.8	26.9	1,800	2,930	6.4
SGB-1	9099212	596643	11	0.8	26.5	27.0	1,830	2,970	6.8
SGB-2	9099194	596506	14	0.4	26.7	26.6	1,920	3,120	6.7
SGB-3	9099226	596547	13	0.3	26.6	27.7	420	738	7.1
SBM	9098212	595788	17	1.2	26.3	27.2	450	763	7.2
EM	9098401	595744	28	1.3	27.2	28.8	353	628	7.2
EB	9099107	595939	48	1.5	27.1	28.7	348	625	6.9

Where: MAT : groundwater table, SG : dug well, SB : drilled well, E : reservoir,
Tw : water temperature, Ta : air temperature.

Resistivity geoelectric survey

This study uses the VES geoelectric method with the Schlumberger configuration and the LEM geoelectric method with the Wenner-Schlumberger configuration. Geoelectrical data acquisition is carried out at four points/measuring paths that do not intersect. The distance between one measuring point/track and another is estimated to be around (0.5 – 2.0) km.

LEM and VES geoelectric results at the Elewbrene location, Marsela Village

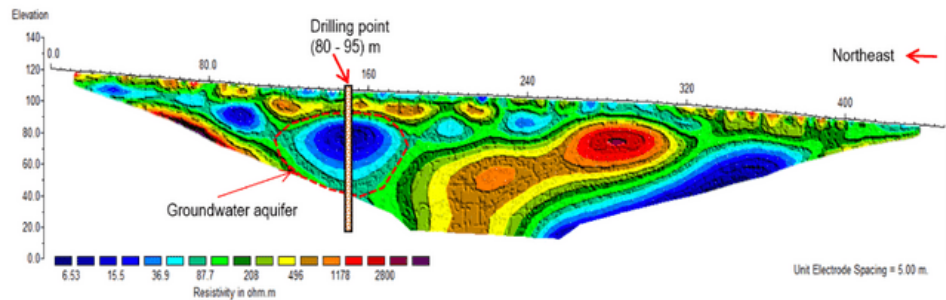


Figure 2. 2D resistivity section with topography on the GeoM-01 line.

The results of modeling with the LEM method on the GeoM-01 lines display the profile of the actual resistivity section resulting from the inversion (inverse model resistivity section). This model already shows the geological conditions of the field as indicated by color degradation as a resistivity pattern during the iteration process (Figure 2).

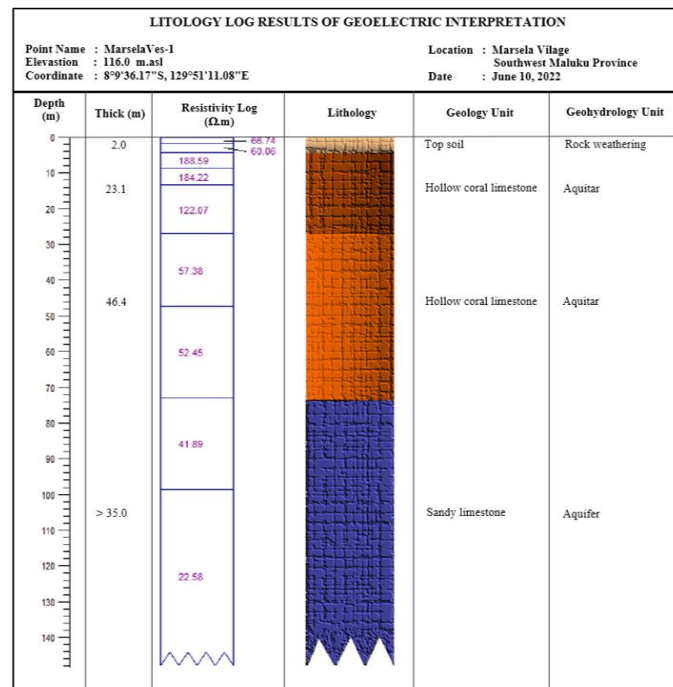


Figure 3. Lithology column results of interpretation of VES geoelectric data at MarselaVes-1.

The VES Geoelectrical method displays a 1D section ^[36] with values for depth, thickness, and type of aquifer at each sounding point. The results of data processing at the MarselaVes-1 (Figure 3) show different rock layers. According to Martins et al. ^[37], the behavior of the conductive layer indicates the upper limit of the water table level, which can be interpreted as the transition between the soil cover and the underlying rock.

LEM and VES geoelectric results at the Eleworamne location, Marsela Village

The results of modeling with the LEM method on the GeoM-02 line, displays the actual resistivity cross-sectional model resulting from the inversion. This model already shows the geological conditions of the field as indicated by color degradation as a resistivity pattern during the iteration process (Figure 4).

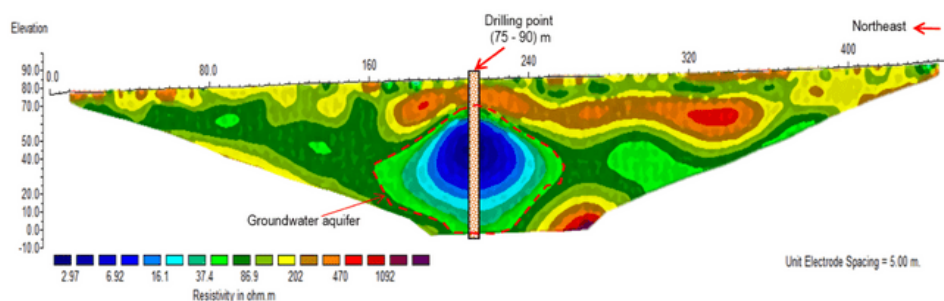


Figure 4. 2D resistivity section with topography on the GeoM-02 line.

The results of VES data acquisition are processed using a computer program to obtain rock resistivity values that are close to actual in the form of resistivity logs. The results of data processing at the MarselaVes-2 (Figure 5) show different rock layers.

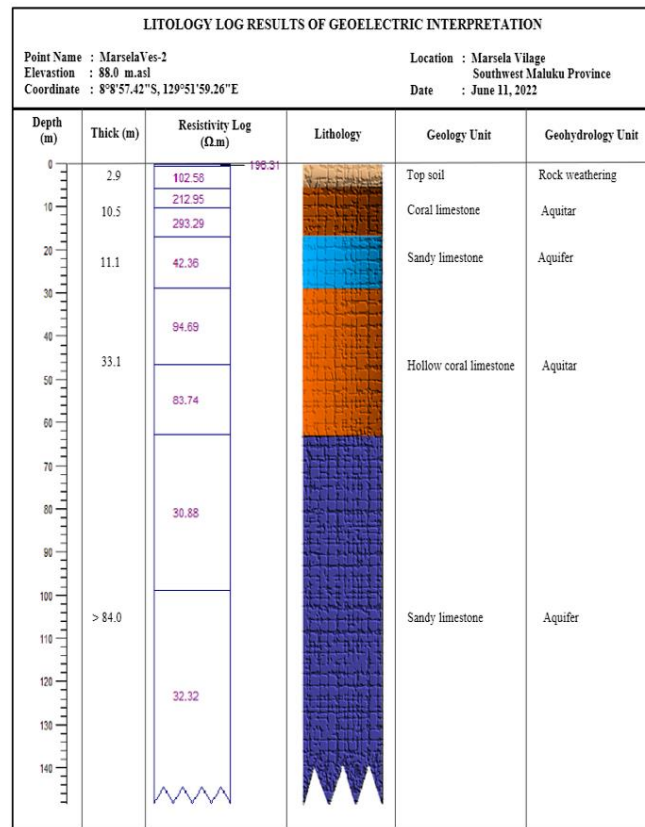


Figure 5. Lithology column results of interpretation of VES geoelectric data at MarselaVes-2.

LEM and VES geoelectric results at Bamboo Trees in Bululora Village

The results of modeling with the LEM method on the GeoB-01 line, displays the actual resistivity cross-sectional model resulting from the inversion (Figure 6).

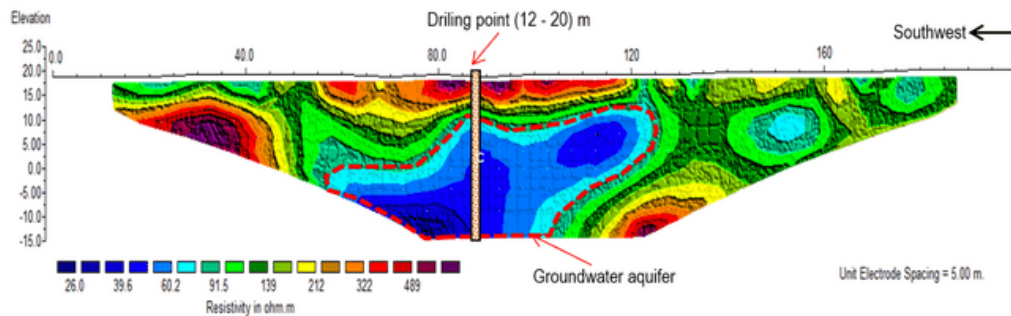


Figure 6. 2D resistivity section with topography on the GeoB-01 line

The results of VES data acquisition are processed using a computer program to obtain rock resistivity values that are close to actual in the form of resistivity logs. The results of data processing at the BululoraVes-1 (Figure 7) show different rock layers.

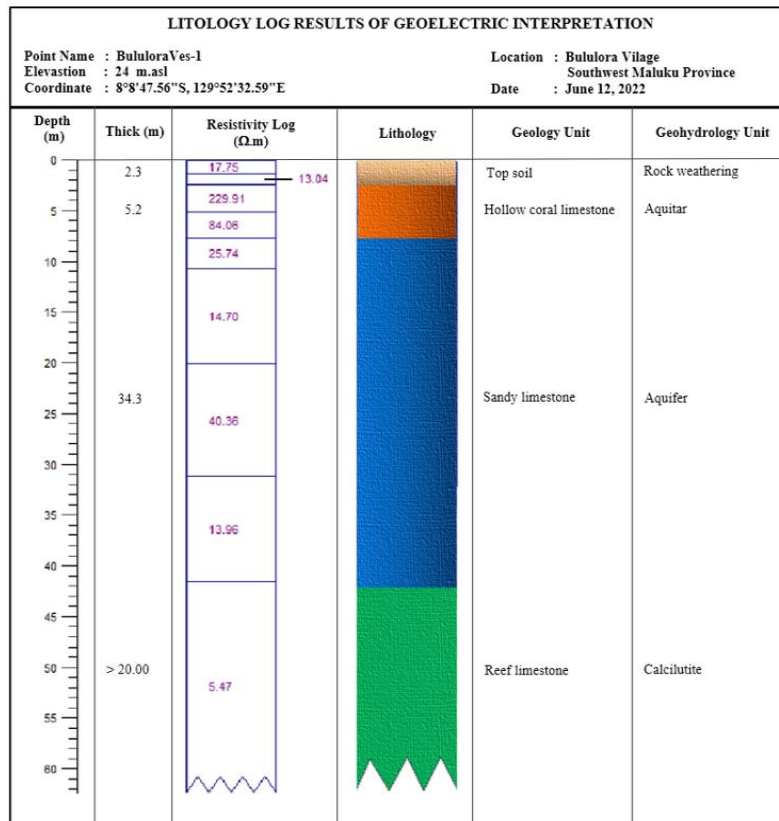


Figure 7. Lithology column results of interpretation of VES geoelectric data at BululoraVes-1.

LEM and VES geoelectric results at locations around the Old Well of Bululora Village

The results of modeling with the LEM method on the GeoB-02 line, displays the actual resistivity cross-sectional model resulting from the inversion (Figure 8).

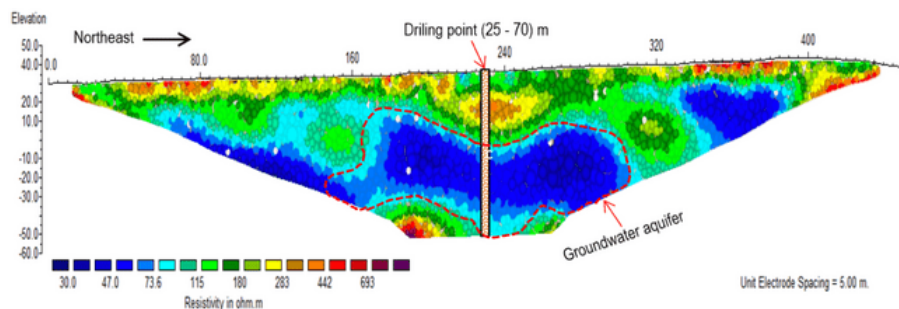


Figure 8. 2D resistivity section with topography on the GeoB-02 line

The results of VES data acquisition are processed using a computer program to obtain rock resistivity values that are close to actual in the form of resistivity logs. The results of data processing at the BululoraVes-2 (Figure 9) show different rock layers.

The results of the geoelectric estimation correlated with quantitative references show that most of the rocks on the measurement path are water-bearing layers with low to moderate resistivity values (20.0 - 150.0) Ω m. The range of resistivity values expressed by Telford et al. [21], Ludman and Coch (1982) in Juanandi [38], Matsui et al. [39] are (20.0-80.0) Ω m, and Aderemi and Bamiro [31] are (30-150) Ω m. The range of resistivity values allegedly is an aquifer layer. Rocks or subsurface layers have varying resistivity values (shown in Blue in Figures 3, 5, 7, and 9). Resistivity is formed based on the type of rock itself. Rock resistivity tends to differ

and decrease (blue) along with increasing porosity, water content (saturation) ^[40], and rock cracks to create additional paths for current strength. A rock formation can accommodate and flow the fluid contained in it. Groundwater estimates based on resistivity values in Figures 3 and 5 are smaller than in Figures 7 and 9 because the rock formation is very porous and can control the flow and amount of groundwater. This type of aquifer is a confined aquifer ^[41]. Generally, water in hard rocks seeps through cracks or fissures in the rock and accumulates to become groundwater ^[42]. Groundwater is generally found at deeper depths, but groundwater in the study area is shallow in fracture systems ^[43].

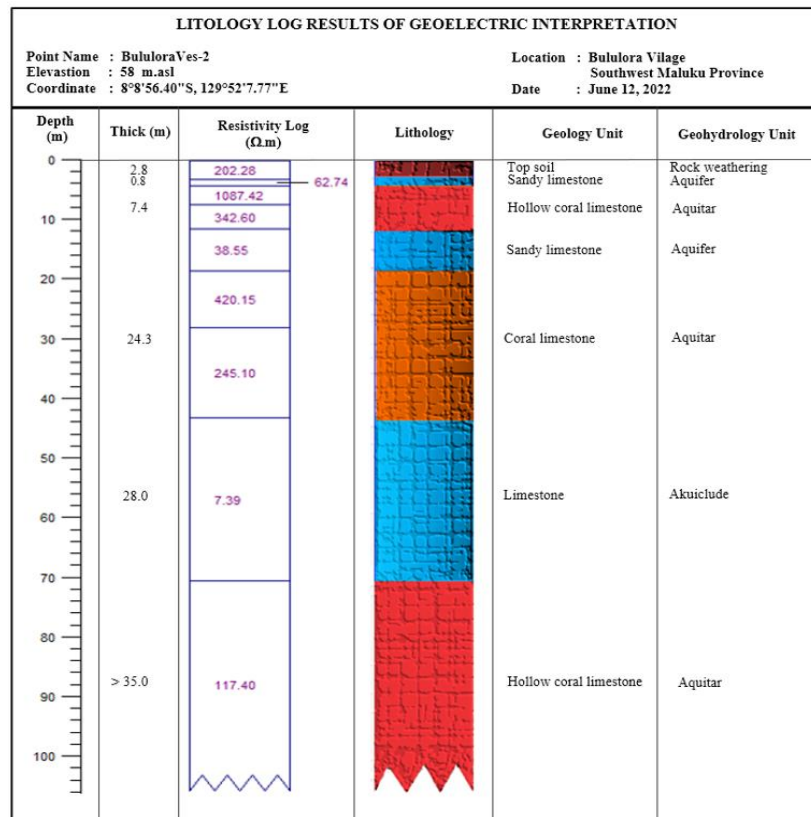


Figure 9. Lithology column results of interpretation of geoelectric data at BululoraVes-2.

Synchronization of aquifer layers at VES Marsela and VES Bululora

The aquifer thickness is estimated from the lithology log (VES method). The aquifer thickness, (t) at the MarselaVes-1 location, is estimated to be 35.0 m, and the aquifer width, (w) 40.0 m with a hydraulic slope, (s) 0.00970 (Figure 3). The aquifer thickness at the MarselaVes-2 location is estimated to be 84.0 m, and the aquifer width is 15.0 m with a hydraulic slope of 0.00679 (Figure 5). The aquifer thickness at the BululoraVes-1 location is 34.3 m, and the width is 10.0 m with a hydraulic slope of 0.00655 (Figure 7). The aquifer thickness at the BululoraVes-2 location is 28.0, and the width is 20, with a hydraulic slope of 0.00623 (Figure 9). The water permeability value (K) in the geological unit of the research area containing the aquifer is 0.94 m/day ^[44]. Thus, the groundwater discharge value for MarselaVes-1 is 446.78 m³/day, MarselaVes-2 is 675.53 m³/day, BuloloraVes-1 is 72.38 m³/day, and BululoraVes-2 is 91.87 m³/day.

The aquifer potential hydrogeological units in the MarselaVes-1 and MarselaVes-2 areas have local aquifers with moderate groundwater productivity and wide distribution. Meanwhile, the hydrogeology of BululoraVes-1 and BululoraVes-2 has an aquifer with low productivity and not a wide distribution. This is due to the presence of aquicludes which do not allow

groundwater to flow up, even though there is a hydraulic gradient. For aquifers with moderate groundwater productivity and wide distribution, the flow through gaps and spaces between grains and the depth of the groundwater table varies greatly. This can be seen in the cross-sections of Figures 3, 5, and 7, which indicate the flow of water flowing between the sand grains and the conglomerate. The thickness of the aquifer in the BululoraVes-2 area is not as thick as that of the MarselaVes-1, MarselaVes-2, and BululoraVes-1 areas.

The interpretation potential aquifer at both ves points has moderate productivity (Figure 10), and its distribution is broad, so it is predicted that the well discharge that can be used is less than 5.0 liters/second. Estimated reservoir size $(6 \times 4 \times 2) \text{ m}^3$. Thus, drilling on MarselaVes-1 is at a distance of 160.0 meters from the initial measurement point or at $8^\circ 9'36.44'' \text{ S}$ and $129^\circ 51'12.10'' \text{ E}$ with a depth of range (80.0-95.0) m. MarselaVes-2 should drill at a distance of 210.0 meters from the starting point of measurement or at the coordinates of $8^\circ 8'58.05'' \text{ S}$ and $129^\circ 51'56.56'' \text{ E}$ with a depth (75.0-90.0) m. Meanwhile, the village of Bululora can be recommended for groundwater drilling (Figure 11) at the Bululoraves-1 point at coordinates $8^\circ 8'47.56'' \text{ S}$ and $129^\circ 52'32.59'' \text{ E}$. Aquifer at this alleged point has moderate productivity, and its spread is not extensive so that it can be predicted the well discharge that can be utilized is less than 2.0 liters/second. The reservoir size is planned $(11 \times 8 \times 2) \text{ m}^3$. While the point of BululoraVes-2 at coordinates $8^\circ 8'56.40'' \text{ S}$ and $129^\circ 52'7.77'' \text{ E}$ has the potential as a water carrier or aquifer layer. The possibility of aquifers in this alleged point has moderate productivity, and its spread is wide so it can be predicted to be used to be less than 2.0 liters/second. The reservoir size is planned $(6 \times 3 \times 2) \text{ m}^3$.

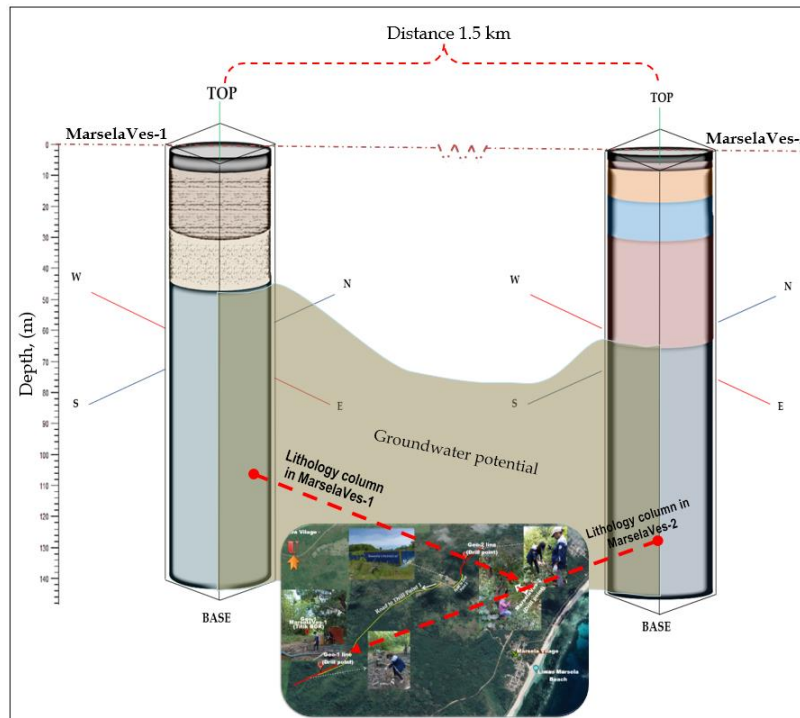


Figure 10. Synchronization of the aquifer layer on MarselaVes-1, and MarselaVes-2.

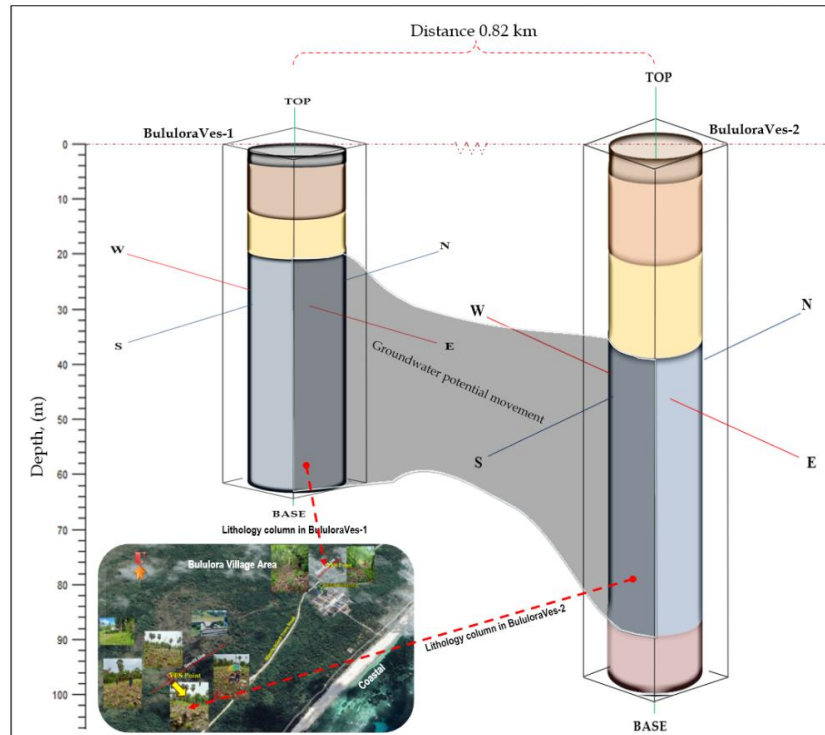


Figure 11. Synchronization of the aquifer layer on BululoraVes-1, and BululoraVes-2.

CONCLUSION

Research and analysis of the potential of groundwater aquifers in the study area have been carried out. The results showed that the MarselaVes-1 (GeoM-01), MarselaVes-2 (GeoM-02), and BululoraVes-1 (GeoB-01) point areas have local aquifers with moderate groundwater productivity and wide distribution. These three geoelectric points have the potential for drilling. Meanwhile, the hydrogeology at BululoraVes-2 (GeoB-2) has an aquifer with low productivity and narrow distribution.

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