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RESEARCH ARTICLE

Groundwater Resilience Study for Sustainable Tourism Development Through Electrical Sounding Method in Mansinam Island, Manokwari Regency, West Papua, Indonesia

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Abstract

The sustainable exploitation of groundwater must be understood based on an understanding of geology and hydrogeological conditions. Water availability on small islands has limited reserves and is vulnerable to contamination. In addition, groundwater resources are vulnerable to decreasing groundwater levels in high abstraction without good management practices. Mansinam Island is one of the islands administratively located in Doreri Bay – Manokwari Regency for sustainable tourism development, which has an area of 410.97 Ha. The purpose of this research is to determine the condition and potential of groundwater in the Mansinam Island area. The geoelectric method is a technique that is widely used to characterize groundwater resources, which aims to identify the physical parameters of the subsoil and acquire information about its natural properties. The resistivity values obtained from the field measurement are thus interpreted and determined to be further correlated with geological characteristics as well as aquifer characteristics. On 11 geoelectric paths, good results are presented with a measurement depth of 20 – 23m. The northern area of the measurement on Mansinam Island has a resistivity value of 58.6 - 100Ωm for an aquifer layer containing groundwater potential with a groundwater level (MAT) of 12-20m and aquifer thickness of 3-8m. Meanwhile, the southern area of the geoelectric measurement has a resistivity value of 25.5-100Ωm for an aquifer layer containing groundwater potential, with a groundwater level of 6-12m and aquifer thickness of 8-16m. The southern segment of Mansinam Island has better potential for groundwater, with a relatively shallower depth and thicker aquifer than the northern segment.

Keywords: Geoelectric, Small Island, Hydrogeology, Groundwater potential, Sustainable Tourism Development

1. Introduction

Mansinam Island is an island that is administratively registered as the Manokwari Regency area. This island is located in Doreri bay, with 410.97 Ha area coverage (Agapa et al., 2014). Masinam Island has become a religious tourism destination with an average of 15,000 annual visitors (Wakeburi & Tungka, 2016). However, the number of proper sanitation facilities is quite limited in this area (Agapa et al., 2014), and one of the important aspects of a sanitation program is to ensure the availability of a clean water supply (Poedjiastoeti & Karmilah, 2008).

According to Indonesia regulation No. 7 / 2004 about Water Resources, Mansinam Island is categorized as a small island with an area coverage of less or equal to 2000 km^2 (Figure 1). Because of this condition, Mansinam Island has a small water catchment area that leads to a lack of recharge and directly affects the clean water reserve of the island. Furthermore, based on WHO standards, basic clean water needs are around 60 L per person per day. Therefore, a lack of clean water supply will also affect the small island resident's environment and health conditions.

Sustainable groundwater exploration should consider based on the geological understanding and aquifer condition (Lenkey et al., 2005; Juandi & Syahril, 2017; Juandi, 2020). Thus, this study aims to determine the groundwater condition and potency in Mansinam Island.

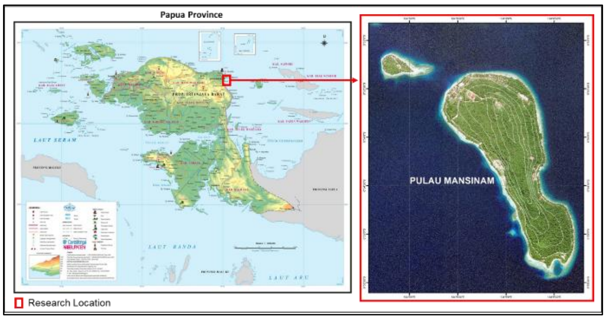


Fig 1. Research Location Area

The water source in the small island is commonly from the precipitation process that infiltrates the subsurface layer and fills in the aquifer or groundwater lenses (Febriarta et al., 2015; Fetter, 2014). In addition, the small island area faces a limited water reserve and is prone to contamination as a result of continuous exploitation without proper management (Acworth, 2019). Hence, geology, morphology, and climate condition are among the dominant factors that control the groundwater resource of an island (Delinom & Robert, 2007).

A qualitative and quantitative approach could be conducted to study and understand the groundwater potential of a small island. Groundwater quantity is closely related to the capability of the aquifer system and is influenced by topography, weather, hydrology, geology, and hydrogeological conditions (Min et al., 2016). Thus, the result of this research is expected to be used as a reference for taking an initial step toward developing sustainable groundwater management on Mansinam Island.

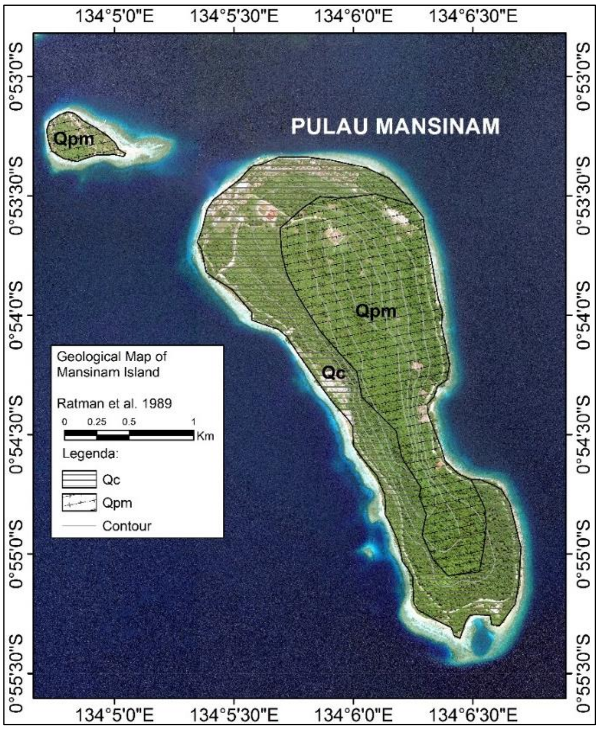


Fig 2. Geology Research Area of Mansinam Island

2. Literature Review

2.1 Geology

According to Ratman et al. (1989), the geology of Mansinam Island (Figure 2) consists of two geological units, from older to younger age, called Qpm (Manokwari formation) and Qc (uplifted coral reef). Manokwari formation comprises coral limestone, calcirudite, calcarenite, sandstone, conglomerate, and breccia. Then, the uplifted coral reef unit includes coral limestone and forams, bio-calcarenite, and bio-calciduirite.

Another geological study indicates that the geological formation on this island consists of a finely layered carbonate sandstone, clay, and cross-bedding lamination sediment. The relative age of this formation is Miocene – Pleistocene (Restu, 2017).

2.2 Hydrogeology

An Aquifer is a saturated layer or zone in the subsurface caused by the water penetration in the infiltration process (Healy, 2012; Tesfaldet et al., 2019). Equally important, determining the water level fluctuation in an aquifer is vital in sustainable groundwater resource management (Tesfaldet et al., 2019). In addition, the groundwater level will provide information on the aquifer system and its relationship with the groundwater reserve, recharge, and discharge system (Jayakumar, 2015). Moreover, there are five types of aquifers such as confined, unconfined, leaky, perched, and multi-layers leaky aquifer systems (Kovelevsky et al., 2004). Conversely, other geological terms related to groundwater regimes must also be considered. In particular, it is commonly known as an aquitard, a permeable geology unit that does not yield water sufficiently, and an aquiclude, an impermeable layer that does not permit water flow (Kruseman & Ridder, 1994). In the case of Mansinam Island, the aquifer system on this island is characterized by limestone lithology, in which the water can flow through the fracture systems (Pryambodo et al., 2016).

In Masinam Island, the water needs to accommodate a clean water supply for 730 residents, and religious tourism activities approximately reach 1.74 L/s (PU, 2014). Therefore, to facilitate the water needs and maximize the groundwater potential for domestic consumption, the government built a program called SPAM (Sistem Penyediaan Air Minum / Drinking Water Supply System) through the Ministry of Public Works and Public Housing.

2.3 Climate and Precipitation Rate

An environmental temperature study using 2012 data from two decades shows the temperature of the Manokwari area significantly rose and is responsible for the lower environmental comfort level than the previous period (Winarsa et al., 2012). The temperature increased due to global warming and could lead to climate change (IPCC, 2012). The temperature change of an environment implies global temperature rise that can cause other transformations, such as the amount and precipitation pattern (Fox, 2007). In the Manokwari area, the temperature was recorded as 27.6°C in 2018 and 27.7°C in 2019-2020, with a 0.1°C increment.

A scientific study indicated that precipitation patterns in Indonesia were influenced by the monsoon, semi-monsoon, and local (Aldrian, 2003). The precipitation data in 2018 (Table 1) shows an average monthly rate of 203.84 mm^3/month. It increased in 2019 to 239.56 mm^3 and slightly decreased in 2020 to 229.08 mm^3. A national report shows the Manokwari area experienced a higher precipitation rate than average, around 248mm^3 (Meteorology, Climatology, and Geophysical Agency, 2019).

Table 1. Rainfall and Climate Value in 2018 – 2020 of Manokwari Region (BPS. 2020)

Month	2018		2019		2020	
	Temperature (C)	Rainfall (mm3)	Temperature (C)	Rainfall (mm3)	Temperature (C)	Rainfall (mm3)
January	27.8	141	27.2	482.4	27.2	176.6
February	27.2	323.5	27	463	27.5	384.1
March	27.4	417.1	27.3	305	27.4	485.1
April	27.6	235	27.7	311.6	27.6	406.5
May	27.8	104	28.9	215.1	28.5	243.3
June	27.4	135.8	27.6	342.9	27.8	82.5
July	27.8	206.5	27.2	154.8	27.8	137.5
August	27.5	81.9	28	85.1	27.6	110.1
September	27.8	75.1	28.1	42	28.2	65.5
October	27.4	125.7	27.9	95.4	28.3	87
November	27.6	278.1	28.2	86.3	27.8	328.4
December	27.9	322.4	28	291.2	27.6	242.4
Average	27.6	203,8416667	27,75833	239,5666667	27,775	229,083333

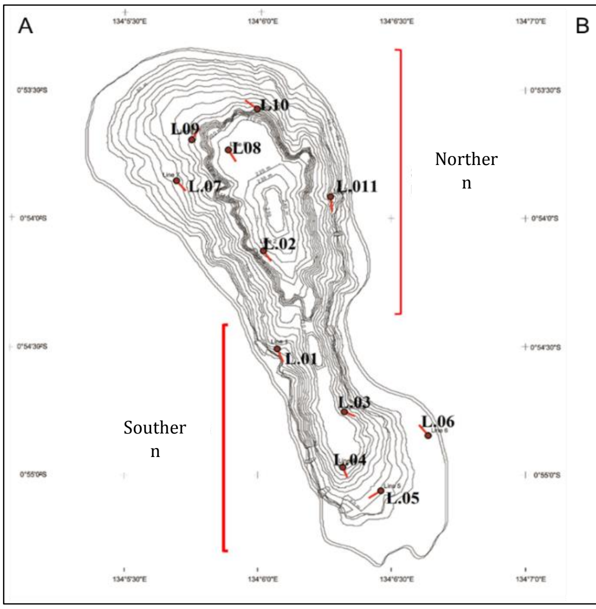
In Mansinam Island, the climate data, such as temperature and rainfall rate, would be able to give a comprehensive result to the groundwater volume analysis. The average temperature of Mansinam Island from 2018-2020 was 27.6 (Statistics Indonesia, 2020). In 2018, the precipitation rate decreased from January to December, as in the following years, 2019 and 2020. During December each year, the rainfall intensity tends to be increased for the next five months until April of the following year. The most intense in 2018 was in March, with 417.1 mm^3, and the least was in September, with 75.1 mm^3. September experienced the lowest precipitation in 3 years, as it was also recorded in 2019 and 2020, with 42 mm^3 and 65.5 mm^3, respectively. The highest rainfall rate in 2019 was in January (482.4 mm^3), two months earlier than the 2018 highest intensity, and in March with 485.1 mm^3 for 2020.

2.4 Geophysical Data Acquisition (2D Geoelectric)

Geoelectric is a method employed to characterize groundwater resources, as it has a sensitivity to the groundwater and identifies the physical parameters of subsurface structures (Lenkey et al., 2005; Boughriba et al., 2006; Binley et al., 2015; Faqihi et al., 2019). In addition, a geoelectric method provided information about the subsurface resistivity value and its distribution as the response from the rock to the electrical current (Mehmood et al., 2020). Moreover, the resistivity value is an important aspect that could assist in locating an aquifer and describing its potency (Adenji et al., 2013, Mehmood et al., 2020).

Eleven Electrical Resistivity Imaging (ERI) lines were obtained from the survey along Mansinam Island (Figure 3), divided into two segments: the north and the south. The result of the ERI survey in each location was classified into low, mid, and high resistivity zones.

Previous studies about the relationship between resistivity, limestone, and groundwater occurrence were visualized in Figure 4. The literature studies show that the resistivity value of limestone ranged from ±30 Ωm to 1000 Ωm. Meanwhile, water-contained limestone has resistivity values ranging from ±30 Ωm to 130 Ωm. The variation of resistivity values of a rock formation was influenced by rock characteristics and weathering grades (Portal et al., 2017). Other aspects that could govern the resistivity values are rock mass, rock fractures, and volume of fluid (Charles et al., 2018; Mutebi et al., 2020).



B

Indeks Lintasan	Resistivity zone	Depth (m)	Resistivity Value (Ωm)
Lintasan 1	High	18.72 – 21.8	0.17 - 0.79
	Middle	5.13 – 21.8	0.79 - 7.7
	Low	0 – 12.7	7.7 - 34.8
Lintasan 2	High	17.00 – 21.8	0.064 - 0.79
	Middle	17 – 21.8	0.79 - 34.2
	Low	0 – 12.7	34.2 - 420
Lintasan 3	High	12.7 – 17	1.5 - 6.2
	Middle	8.72 – 12.7	6.2-51.1
	Low	0 – 8.72	51.1 - 209
Lintasan 4	High	0 – 17	0.35 - 1.5
	Middle	0 – 17	1.5 - 13
	Low	0 – 8.72 & 17 – 21.8	13 - 54.2
Lintasan 5	High	5.13 – 17	1.1 - 22.8
	Middle	0 – 17	22.8 - 174
	Low	0 – 21.8	174 - 1337
Lintasan 6	High	5.13 – 17	1.2 - 22.4
	Middle	0 – 17	22.4 - 413
	Low	0 – 21.8	413 - 1091
Lintasan 7	High	17 – 21.8	3.1 - 15.2
	Middle	17 – 21.8	15.2 - 164
	Low	0 – 17	164 - 796
Lintasan 8	High	17 – 21.8	6.4 - 25.9
	Middle	5.13 – 17	25.9 - 209
	Low	0 – 12.7	209 - 844
Lintasan 9	High	5.13 – 21.8	15.5 - 44.1
	Middle	5.13–12.7 & 17- 21.8	44.1 - 212
	Low	0 – 12.7	212 - 605
Lintasan 10	High	17 – 21.8	5.2 - 17.7
	Middle	0 – 21.8	17.7 - 110
	Low	0 – 12.7	110 - 369
Lintasan 11	High	5.13 – 17	7.6 - 29.7
	Middle	0 – 21.8	29.7 - 228
	Low	0 – 21.8	228 - 889

Southern Segment
Northern Segment

Fig 3. [A] Figure of the ERI Method of Geoelectrical Measurement Trajectory Distribution. [B] Table of Resistivity Values and Class Division of Field Measurement Results on Mansinam Island.

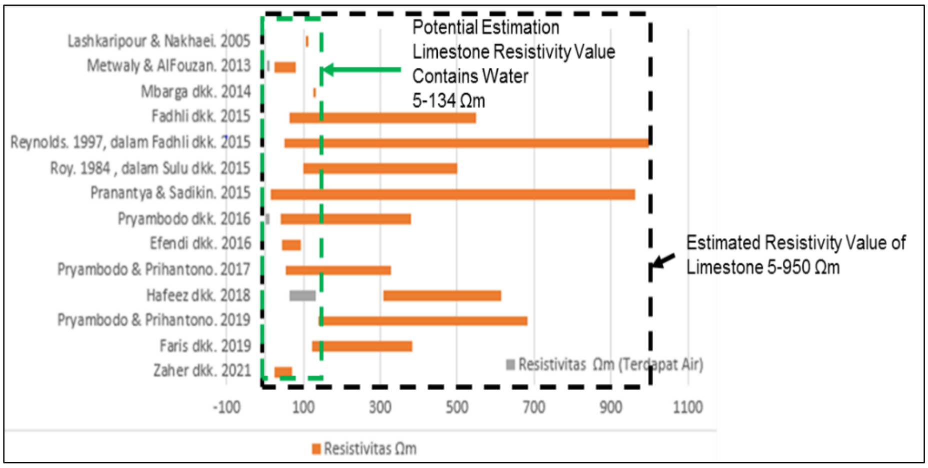


Fig 4. Graph of the Average Resistivity of Limestone from Several References

3. Methodology

Quantity analysis of groundwater in the aquifer was conducted using the volume estimation using the following formula (Bailey, 2010, modified by Marganingrung, 2018).

…… (1)

V = volume (m^3)

P = average annual precipitation (m/year)

A = area (m^2)

H = aquifer thickness or average aquifer depth (m)

K_h = hydraulic conductivity (m/day)

The aquifer thickness was identified based on the resistivity values obtained from 2D ERI surveys. Geoelectric estimation is one of the methods that can identify the aquifer's material through geometry and aquifer configuration (Todd, 1980; Zohdy, 1989; Santosa and Adji, 2006). The electrical method is called a passive method when it detects the potential field, electromagnetic field, and electrical current naturally in the subsurface or as an active method when it utilizes an injection current. This study applied the dipole-dipole electrode configuration to measure the electrical resistivity value (Figure 5).

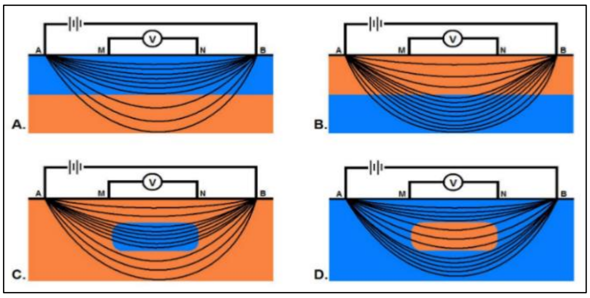


Fig 5. Variations in subsurface current density and their relationship to variations in the earth's resistivity where current flow is affected by subsurface heterogeneity.

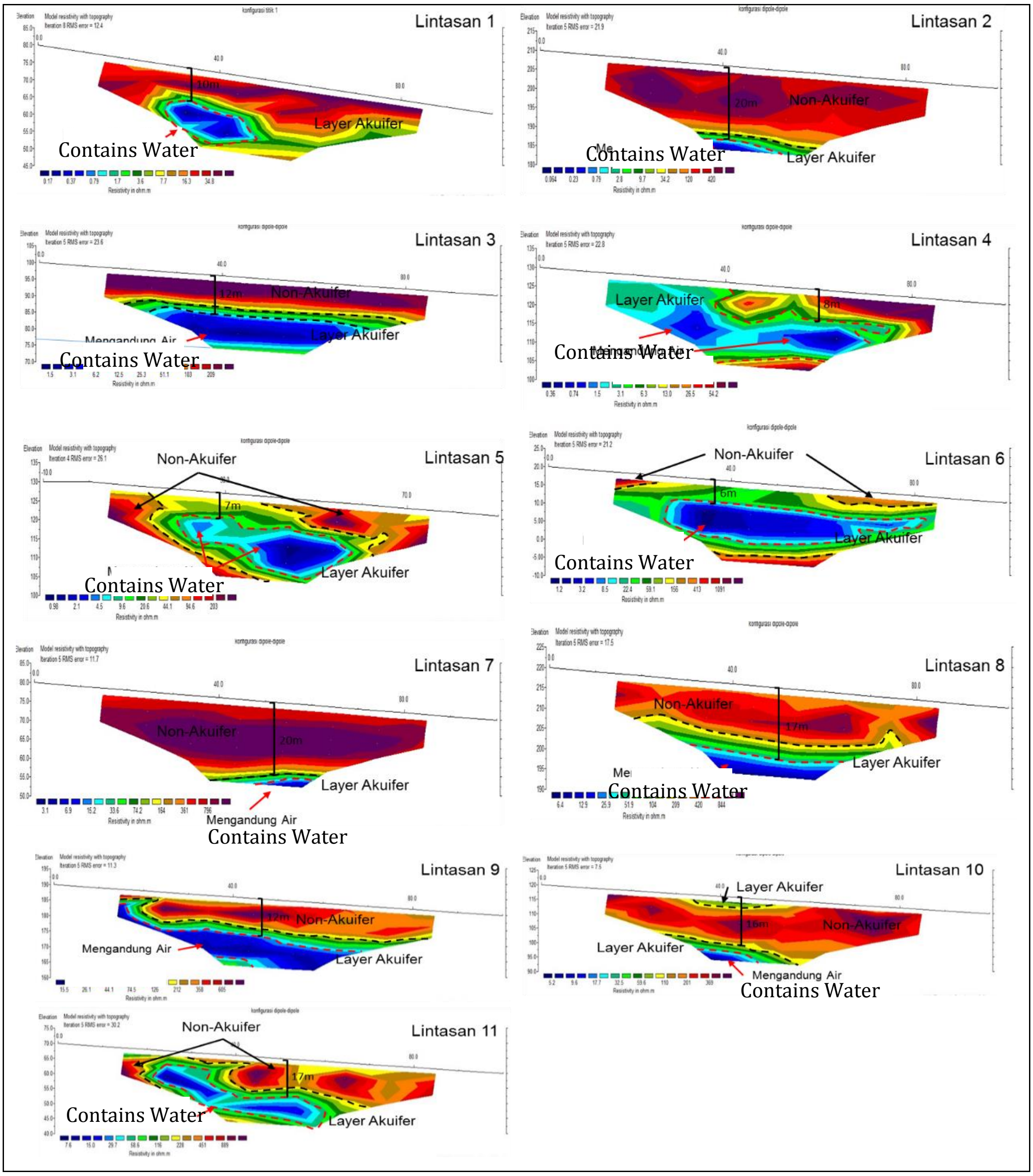


Fig 6. Results Interpretation of subsurface resistivity values on rock characters as aquifers and non-aquifers

4. Result and Discussion

4.1 Geoelectrical Identification

The result identified the resistivity value on each geoelectrical line and provided information on the geological units and the groundwater level of Mansinam Island (Figure 6, Figure 7).

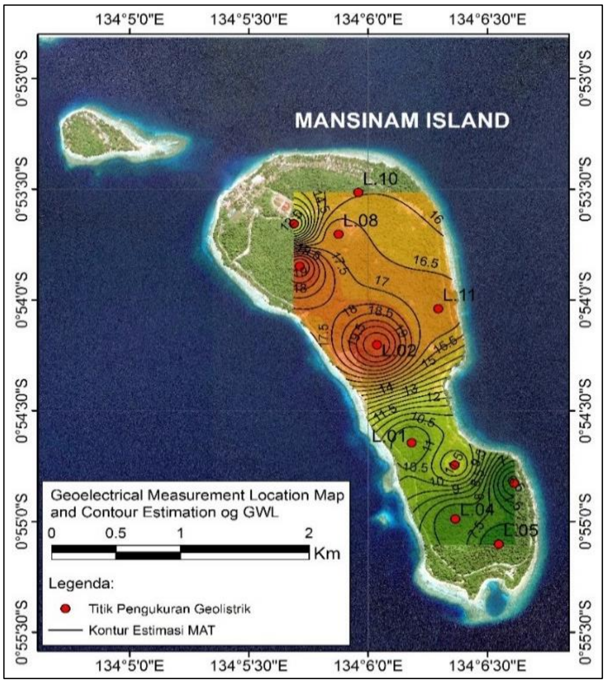


Fig 7. Distribution of GWL Elevation Contour Values Result of Resistivity Data Interpretation

4.1.1 Section 1

Line 1 (L01) is located in the southern part of Mansnam Island, extending from the northwest to the southeast direction. The resistivity value for L01 ranges from 0-74 Ωm, giving the information of a geological unit characterized as the groundwater aquifer. Thus, it was interpreted that the groundwater level is 10m deep, and the layer was classified as a perched aquifer.

4.1.2 Section 2

Line 2 (L02), line 7 (L07), line 8 (L08), line 9 (L09), and line 10 (L10) are located in the northern part of the island, while line 3 (L03) is located in the southern region. The direction of L02, L07, L08, and L10 is northwest-southeast, L09 is northeast-southwest, and L03 is from the west-east. The resistivity values of these lines are relatively similar and range from 0-130 Ωm. Hence, it is interpreted as the aquifer layers with distinguishing characteristics. While the resistivity value of 0-100 Ωm is determined as an aquifer, the 100-130 Ωm value is an aquitard layer. On the other hand, the layer with a resistivity value greater than 130 Ωm is identified as the aquiclude. The groundwater level in this section is 12-20 m below the surface, with a confined aquifer character. And the impermeable layer in this section is 10-20m thick.

4.1.3 Section 3

Line 4 (L04), line 5 (L05), and line 6 (L06) are the measurement lines that were located at the southern segment of Mansinam Island. The direction of L04 is northwest-southeast, L05 is northeast-southwest, and L06 is northwest-south-east, and these lines have similar resistivity variation. Hence, the resistivity of 0-130 Ωm is interpreted as the aquifer layer, and greater than 130 Ωm is considered a non-aquifer layer. In addition, based on the resistivity value, the subsurface layers in this section are divided into an aquifer (0-25.5 Ωm), an aquitard (25.5-130 Ωm), and an aquiclude (>130 Ωm). As a result, the groundwater level is 6-8 m below the surface and is characterized as an unconfined aquifer.

4.1.4 Section 4

Line 11 (L11) is a measurement line that is located in the northern segment of Mansinam Island, extended from the north-south direction. The resistivity values found in this section are 0-130 Ωm, interpreted as the aquifer layer, and greater than 130 Ωm as the non-aquifer layer. Moreover, the layer with 0-58.6 Ωm is identified as an aquifer, and the one with >58.6 Ωm is an aquiclude.

In the shallow depth along the L11 line, a resistivity variation, classified as the aquitard, is related to the surface potential to absorb water. A steep topography has a relatively higher resistivity value, while a low slope tends to have a relatively lower value. Based on the resistivity interpretation, the groundwater level in this section was found at 17m deep, with an aquifer thickness of 4m, and classified as a leaky aquifer.

The resistivity variation in L11 shows different aquifer characteristics and different groundwater depths. As in the southern part, the groundwater level is relatively shallow (6-12m), while the northern part is somewhat deeper (12-20m). Thus, this variation is influenced by several factors, including topography (Muhlis et al., 2016), precipitation rate, groundwater pumping rate, and hydrogeological condition (Maggirwar & Umrikar, 2011; Prihartanto, 2020; Krogulec et al., 2020).

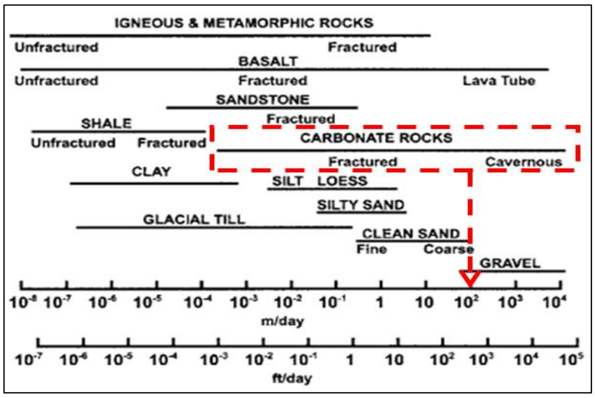


Fig 8. Modification of Distribution of Hydraulic Conductivity Values in Different Materials (Anderson and Woessner. 1992; in Wight. 2008)

4.2 Groundwater Volume Potential

The volume of water in the aquifer was calculated using Bailey's method (2010), modified by Marganingrung (2018). Precipitation data that will be used are the annual average of 2018, 2019, and 2020 data. The area estimation is the surface area of Mansinam Island with a similar value for each aquifer. In addition, the aquifer thickness is an average value from the 11 electrical geophysics survey lines. Meanwhile, the hydraulic conductivity value was obtained from the literature study related to the conductivity of limestone (Figure 8). Mansinam Island consists of coral limestone from the Manokwari formation (Qpm) and the uplifted coral reef of a younger limestone formation (Qc). Hence, the water volume estimation was calculated for the different aquifer types assuming that each aquifer has the same area, average annual rainfall, and hydraulic conductivity.

5. Conclusion

The electrical geophysics investigation and measurement in Mansinam Island provided important information on groundwater potential. The resistivity value was interpreted, identified, and correlated with the geological formation and aquifer characteristics as the water storage. Several types of aquifers were identified from the 11 ERT survey lines: perched, confined, unconfined, and leaky. The subsurface depth was found at 20-23m from the ERT result. The limestone from the Manokwari formation (Qpm) and the uplifted coral reef formation (Qc) has variable resistivity values. The northern segment shows a resistivity value of 58.6-100 Ωm for the aquifer layer that potentially contains groundwater. The groundwater level in this segment was relatively deep, with 12-20m and an aquifer thickness of 3-8m. Meanwhile, the southern part shows a resistivity value of 25.5-100 Ωm for the potential aquifer layer. The groundwater level was found at 6-12m depth, relatively shallow compared to the northern part. In addition, the average aquifer thickness is 8-16m.

It is found that the southern part of Mansinam Island has a higher potential for groundwater resources, which is shown by the shallow depth and thicker aquifer compared to the northern segment. However, further study needs to be conducted to obtain more comprehensive information on the groundwater condition in Mansinam Island, such as climate study, hydrology, and conceptual hydrogeology modelling.

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