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Groundwater Aquifer Analysis Using the Schlumberger Configuration Vertical Electrical Sounding Resistivity Method with Dar Zarrouk Parameters in the Komplek Perkantoran Gunung Merah Sentani

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ABSTRACT

A study has been conducted using the Vertical Electrical Sounding (VES) method of Schlumberger configuration and Dar Zarrouk parameters which aims to determine the range of resistivity values of the subsurface layer, the depth of the groundwater aquifer layer, the thickness of the water aquifer layer and the range of Dar Zarrouk parameter values at the research site. The research location is in the office complex of Gunung Merah Sentani, Jayapura Regency as many as four sounding points with a maximum length of 175-300 meters. The results of this research show that the VES 1 point has two aquifer layers with a depth range of 4 - 7 meters and 14-31 meters. which is a fragment of Gneiss rock containing sand, gravel and clay. The resistivity values of each aquifer layer are 26-45 Ωm and 16 Ωm respectively. At VES point 2, the inversion model parameters show that there are three aquifer layers in the depth range of 2 - 4 meters, 7 - 13 meters and 30 - 91 meters. And the resistivity values of each aquifer are 6, 13 and 35 Ωm. At VES point 3, the inversion model parameters show that there are two aquifer layers in the depth range of 5 - 16 meters and 25 - 66 meters with resistivity values for each aquifer layer of 15 and 22 Ωm respectively. At VES point 4, the inversion model parameters show that there are two aquifer layers in the depth range of 3 - 5 meters and 7 - 20 meters with the resistivity values for each aquifer layer being 24 and 7 Ωm respectively.

Keywords: Aquifer; Geoelectricity; Schlumberger.

1. Introduction

Clean water is one of the basic human needs [1]. Humans use clean water for drinking, cooking, bathing, and washing. In addition, water is also used in economic activities such as agricultural irrigation and fisheries [2]. Residents in Jayapura Regency need clean water, which the Jayapura Regency PDAM serves. The water source used by the Jayapura Regency PDAM comes from surface water in the form of rivers from the Cyclops Mountains. Clean water from the Jayapura Regency PDAM has several main problems, namely limited service coverage, so not all houses in Sentani have access to PDAM clean water. In addition, PDAM services are also limited due to damage to supporting infrastructure caused by flooding that is increasingly occurring in Sentani Jayapura. The limitations of PDAM in providing clean water make it necessary to find alternative sources of clean water for Sentani residents, especially in the Gunung Merah office complex. One alternative source of clean water is groundwater.

Groundwater is stored in the layer containing groundwater, called an aquifer, which has pore spaces between the particles of the rock layer. Due to the groundwater content, the electrical properties of the aquifer layer are conductive so that the existence of the aquifer layer can be determined using geophysical methods, especially the resistivity geoelectric method of the Vertical Electrical Sounding (VES) Schlumberger configuration.

In the VES Schlumberger configuration geoelectric method, electric current is injected through a pair of current electrodes, and the electrical response of the subsurface layers is detected in the form of a potential difference measured using a pair of potential electrodes [3].

The Dar Zarrouk parameter is a derived parameter obtained from the Schlumberger VES data inversion modeling results, which are the thickness and resistivity of each layer. This parameter is used to determine an aquifer's protective capacity.

Based on the remote sensing geological map of the Dondai sheet, Papua, the Gunung Merah Office Complex is located in the Cyclops Gneiss Unit (Mzmc), which is in contact with the

Quaternary Alluvium (Qa) in the East, West, and South as shown in Figure 1. The Cyclops Gneiss Unit (Mzmc) consists of Gneiss rocks that are around 150 million years old (Mesozoic era). This unit occupies most of the Cycloops mountains, which are characterized by mountains with relatively blunt peaks, parallel flow patterns with moderate density, and deep and rather steep valley shapes [4]. Quaternary Alluvium (Qa) is a surface deposit and is Holocene in age (11,700 years to the present). Quaternary Alluvium (Qa) consists of loose material of clay, sand, gravel, and gravel in the form of river deposits, alluvial fan deposits, and flood deposits. Generally flat, meandering flow patterns with fine textures and wide and shallow valley shapes [4].

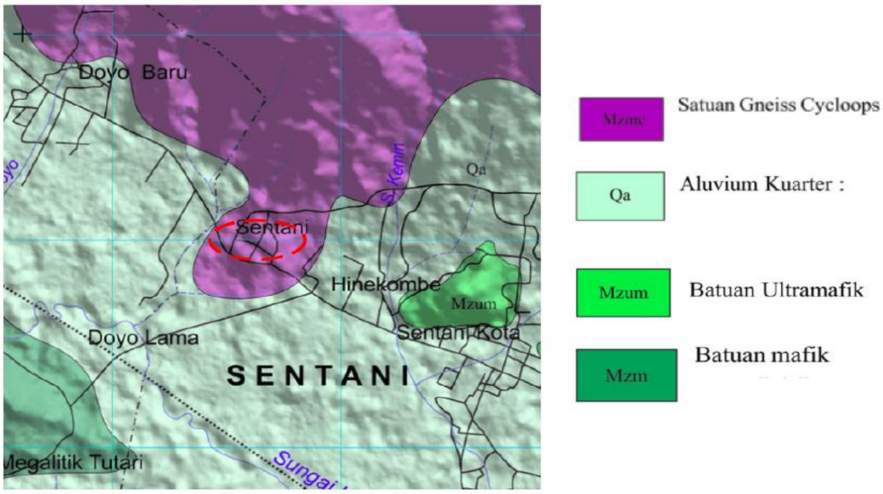

Figure 1. Remote sensing geological map of Dondai Papua sheet, scale 1:50,000

Groundwater is defined as water found beneath the earth's surface. As an alternative source of clean water, groundwater is stored in water-saturated geological formations (called aquifers) that are able to accommodate and pass water in sufficient and economical quantities [5]. One of the main sources is rainwater that seeps below the surface through pores between soil grains. The porosity and permeability properties of the aquifer quantify the ability of aquifers to accommodate and pass water.

Three important parameters determine the characteristics of aquifers, namely aquifer thickness, permeability, and porosity [6]. Aquifer thickness is measured from the groundwater table to a semi-impermeable layer, including aquicludes and aquifuges. Aquifer permeability is largely determined by the texture and structure of minerals, such as pa, articles, or grains that make up the aquifer. The coarser the texture with a loose structure, the higher the ability of the rock to pass a certain amount of groundwater. Conversely, the finer the texture with a more irregular or more compact structure, the lower the ability of the rock to pass a certain amount of groundwater. Thus, each type of rock will have a different permeability value from other types of rock.

1. Aquifer layer that can store and flow water in sufficient and economical quantities. Examples: sand, gravel, sandstone, fractured limestone.
2. An impermeable aquifer layer of rock cannot store and flow water, such as crystalline rock and Cycloop Gneiss rock.
3. An aquitard layer of rock that can store water and flow in limited quantities, such as sandy clay.
4. Aquiclude layer that can store water but cannot flow water in significant quantities. For example, clay and shale.

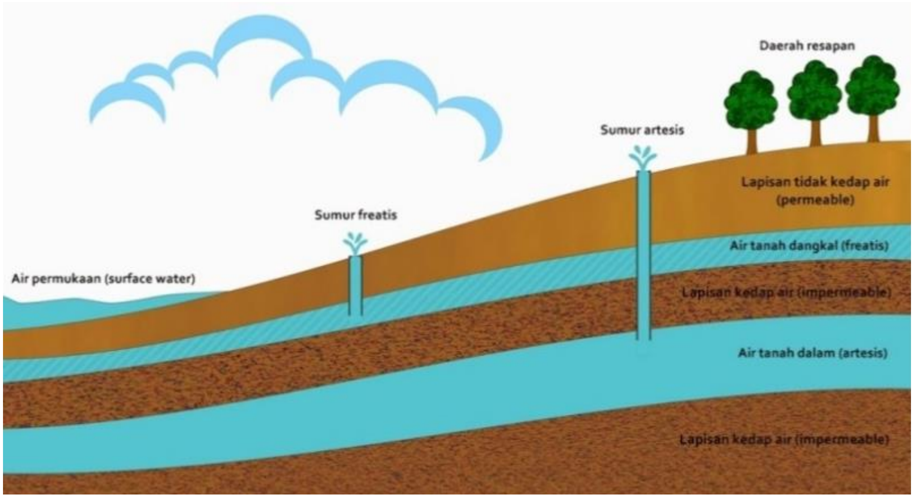

Figure 2. Unconfined aquifers (unconfined) and confined aquifers (source: https://akupintar.id)

There are several types of aquifers, as follows:

1. Confined aquifers are aquifers whose upper and lower parts are bounded by aquifuge or aquiclude layers (Figure 2)
2. Unconfined aquifers are aquifers bounded by a watertight layer below them, but there is no cover layer on top (Figure 2)

The resistivity geoelectric method is one of the active geophysical methods that study the subsurface of the earth based on the electrical properties of rocks, such as resistivity and conductivity [7]. This method is called an active geophysical method because it uses an artificial source in the form of a battery. In the resistivity geoelectric method (Figure 3), electric current is injected into the subsurface through a pair of current electrodes (electrodes C_1 and C_2), and the response of geological material below the surface will be measured by a pair of potential electrodes (electrodes P_1 and P_2)

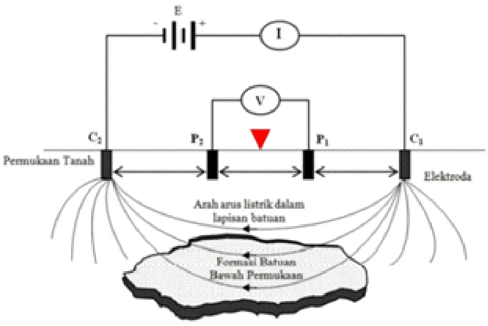

Figure 3. Schematic of resistivity geoelectric method measurement.

Ohm's Law states that the magnitude of electric current I flowing through a conductor is always directly proportional to the potential difference V, which is mathematically expressed by the following equation

$$V = I R \quad (1)$$

The equation above can also be written as electric field strength **E** (volt/meter) and current density **J** (A/m^2).

$$\rho = \frac{E}{j}(\Omega m) \quad (2)$$

True resistivity is defined as: $\rho = \frac{v}{I}\frac{A}{L}$ (3)

The Schlumberger configuration is the most frequently used in the VES method. This configuration's advantage is the ease of field data collection. Only the current electrode pair is moved at each measurement, while the potential electrode pair is only moved when the potential difference decreases drastically (called potential drop). However, a mathematical inequality governs the distance between the potential electrode and the current electrode, as in the following equation [8].

$$C_1C_2 > 5\, P_1P_2 \text{ dan } C_1C_2 < 30\, P_1P_2 \quad (4)$$

The field data sampling rate is logarithmic, with six samples per cycle [9]. This means that there are six data samples between the current electrode spacing of 1 to 10 meters, six data samples between the current electrode spacing of 10 meters to 100 meters, six data samples between the spacing of 100 to 1000 meters, and so on.

The following equation gives the apparent resistivity value of the VES method using the Schlumberger configuration.

$$\rho_a = \frac{\pi a^2}{b}\left[1 - \frac{b^2}{4a^2}\right]\left[\frac{v}{I}\right] \quad (5)$$

Where the distances a and b are given in Figure 4

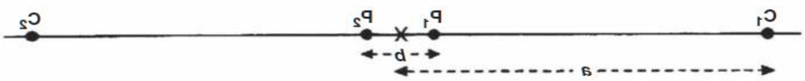

Figure 4. Schlumberger configuration. The distance between potential electrodes is b, and half the distance between current electrodes is a [4].

Table 1. Resistivity of several types of rocks [10-11]

No	Rock	Resistivitas (Ωm)
1	Granit	$300 - 1.3 \times 10^6$
2	Granit (terlapuk)	$30 - 500$
3	Diorit	$10^4 - 10^5$
4	Gabbro	$10^3 - 10^6$
5	Basalt	$10 - 1.3 \times 10^7$
6	Batupasir	$1 - 7.4 \times 10^8$
7	BatuGamping	$50 - 10^7$
8	Lempung	$1 - 100$
9	Aluvial dan pasiran	$10 - 800$
10	Laterit	$800 - 1500$
11	Tanah laterit	$120 - 750$

Dar Zarrouk parameters are used to measure the characteristics of aquifers, which consist of Transverse Resistance T (Ωm^2) and longitudinal Conductance S (Ωm^{-1}). The use of Dar Zarrouk parameters for hydrogeological parameter detection is based on the assumption that groundwater flow is influenced by the same petrophysical factors that affect the flow of electric current, namely porosity, water saturation, and permeability. Dar Zarrouk's parameters are given by the equation below.

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + \cdots \frac{h_n}{\rho_n} \quad (6)$$

Table 2. Protective capacity categories based on the range of total longitudinal conductance values

Protective Capacity Category	Total Longitudinal Conductance
Poor	$< 0,1$
Weak	0,1 – 0.19
Moderate	0,2 – 0,69
Good	0,7 – 4,9
Very Good	5 – 10
Excellent	> 10

2. Method

This study used the field survey method. Data collection was carried out using the geoelectric resistivity method Vertical Electrical Sounding (VES) Schlumberger configuration, type HV 500 AK. Data processing was using IPI2WIN software. Data obtained from measurements are in the form of current values and potential difference values.

a. Research Equipment

The equipment used is as follows:

1) resistivity unit
2) 2. 4 roll cables with a length of 300 meters
3) 3. 4 electrodes
4) 4. 4 hammers
5) 5. Battery
6) 6. 4 Handy Talkies
7) 7. one GPS unit
8) 8. Laptop or PC installed with IPI2Win, MS Excel, and QGIS

b. Time and Location of the Research

Figure 5. Research Location Map

This research was conducted for eight months, from November 2023 to June 2024. The location is in the Gunung Merah Sentani Office Complex, Jayapura Regency. It is located at four points: the Health Office, Regional Revenue Service, Regent's Office, Gunung Merah Sentani PU Office, and Jayapura Regency. The research location map can be seen in Figure 5.

c. Research Procedure

1) Data Collection Stages

The stages in this study are as follows:

a) Before data acquisition using the Schlumberger configuration geoelectric method, first study the local and regional geological studies of the local measurement area. This will determine the research target and the number of measurement points and facilitate the interpretation of data obtained in the field.
b) Create a survey design to determine the location of the measurement point and the length of the path in the acquisition of the geoelectric method.
c) After the measurement location point has been determined, the measurement path is determined at each measurement point.
d) Determine the zero point, then determine the length of the path; the length of the path used is 300 meters, as much as one path at four measurement points
e) Install one electrode at the zero point as a reference for installing the roll meter.
f) Install the connecting cable from the tool to the electrode connecting cable and install the clamp from the tool to the accumulator. When installing the clamp to the accumulator, it is preferable to install the negative pole first and then the positive pole.
g) Plug all electrodes into the configuration used.
h) Look at the analog current display. If the needle shows less than half, repeat the electrode assembly by moving the electrode to another place or inserting the electrode deeper.
i) Install the connecting cable to the current source (battery).
j) Observe and record the current value and potential difference on the resistivity meter.
k) Use the Dar Zorrouk parameter to calculate the transversal and longitudinal values to obtain the media resistivity value and the subsurface anisotropy coefficient

2) Data Processing Stages

The data obtained from the measurements are current values (I) and potential differences (V).

a) Calculating the apparent resistivity value based on field measurement data using equation 2.5
b) Data in the form of electric current and potential obtained after conducting field measurements are then calculated to obtain the apparent resistivity value (ρa) by dividing the potential value by the current and multiplying it by the Schlumberger geometry factor (K)
c) The calculated data obtained in the field is then processed using IPI2WIN software to obtain the actual resistivity value and the subsurface layer structure pattern.
d) The resistivity value obtained is then calculated based on the anisotropy concept and Dar Zorrouk parameters

3) Data Interpretation Stages

a) Data interpretation is done by looking at the resistivity value table generated from the IPI2WIN software modeling and the Dar Zorrouk parameter calculation
b) Next, analyze the resistivity value based on the resistivity table obtained, determine the type of rock in each layer, and then determine the depth and potential of the existing groundwater aquifer.

3. Result and Discussion

The results of the inversion modeling of the apparent resistivity value $\boldsymbol{\rho_a}$ calculated using equation (5) at points VES 1, VES 2, VES 3, and VES 4 using the IPI2Win software are given in Tables 3, 4, 5, and 6 below.

Table 3. Resistivity Values and thickness of each layer at point VES 1

No Layer	$\boldsymbol{\rho(\Omega m)}$	$\boldsymbol{h(m)}$
1	434	0.5
2	63	0.5
3	300	1
4	214	2
5	27	1
6	45	2
7	748	7
8	16	17
9	11.637	infinite

Table 4. Resistivity Values and thickness of each layer at point VES 2

No Layer	$\boldsymbol{\rho(\Omega m)}$	$\boldsymbol{h(m)}$
1	147	2
2	6	2
3	161	3
4	13	6
5	313	17
6	35	62
7	2.397	infinite

Table 5. Resistivity Values and thickness of each layer at point VES 3

No Layer	$\rho(\Omega m)$	$h(m)$
1	19	0.5
2	226	0.5
3	12	1
4	108	3
5	14	11
6	199	9
7	21	41
8	2.095	infinite

Table 6. Resistivity Values and thickness of each layer at point VES 4

No Layer	$\rho(\Omega m)$	$h(m)$
1	630	0.5
2	2	0.5
3	204	2
4	24	1
5	113	4
6	7	13
7	132	infinite

The following table 7 gives Dar Zarrouk parameters at VES 1, VES 2, VES 3, and VES 4 points determined using equation 6 and Tables 3, 4, 5, and 6.

Table 7. Dar Zarrouk Parameters

No VES	No Akuifer	Longitudinal Conductance S (Ω^{-1})	Aquifer Protection Capacity Category
1	Akuifer 1	0,02	Poor
	Akuifer 2	0,1	Weak
2	Akuifer 1	0,01	Poor
	Akuifer 2	0,37	Moderate
	Akuifer 3	0,88	Moderate
3	Akuifer 1	0,14	Weak
	Akuifer 2	0,97	Good
4	Akuifer 1	0,51	Moderate
	Akuifer 2	0,59	Moderate

a. Determination of Groundwater Aquifers

At VES 1 point, the inversion model parameters show that there are two aquifer layers, namely aquifer one at a depth of 4-7 meters, which is a Gneiss rock fragment with sand, gravel, and silt-sized material inserts. The groundwater content at this depth is very dependent on the season, so it is unstable. During the dry season, groundwater will run out, while during the rainy season, groundwater will be very abundant. Aquifer 2 is at a depth of 14-31 meters, which is a Gneiss rock fragment mixed with sand and silt-sized material. The bedrock at VES 1 point is Gneiss rock, which is part of the Gneiss Cyclops (Mzmc) unit. Mixed with sand and silt-sized material. The bedrock at VES 1 point is at a depth of more than 31 meters and is Gneiss rock, which is part of the Gneiss Cyclops (Mzmc) unit.

b. Aquifer Protection Capacity

Aquifer layer one at VES 1, VES 2, and VES 3 points is not protected from pollution (poor and weak category); this is due to the thin layer above it (overburden) and low resistivity values indicating good conductivity. However, aquifer one at VES 4 is more protected from pollution (moderate category), which is caused by the thickness of the layer above it (overburden), and is more resistive. Aquifer layer two at VES points 2 and 4 is somewhat more protected from the threat of pollution (moderate category). Aquifer 2 at VES 3 is most protected from the threat of pollution (good category). Meanwhile, aquifer two at VES 1 is not protected from the threat of pollution. Namely, aquifer 1 at a depth of 4 - 7 meters, which is a Gneiss rock fragment with sand, gravel, and silt material inserts. The groundwater content at this depth is very dependent on the season, so it is unstable. During the dry season, groundwater will run out.

4. Conclussion

The resistivity value of the aquifer layer at the research location is between 7 - 45 Ωm, which is thought to be a fragment of Gneiss rock intercalated with sand and gravel. The number of aquifers at each VES point is between 2 - 3. The shallowest depth is 2 meters at the VES point, and the deepest is 90 meters at VES point 2. The range of aquifer thickness at the research location is 2 - 66 meters. The Dar Zarrouk parameter value, in the form of longitudinal conductance S, at the research location is between 0.01 and 0.97.

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