Identification of Groundwater Potential Using Wenner Configuration 2D Resistivity Method (Kupang, Nusa Tenggara Timur)

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Abstract. Kupang is the capital of the Indonesian province of Nusa Tenggara Timur, and has an estimated population in 2019 of 434,972. It is the biggest city and port on the island of Timor. The geology of Kupang is located on the Batu Gamping Koral Formation which composed by coral limestone, which is physically barren and dry. So that local residents often have some problems with water availability. Therefore, needed the information about potential and depth of groundwater aquifers in the area. Measurement of the Wenner configuration 2D resistivity method has been carried out to identify the subsurface to determine the potential for groundwater. Inversion were performed using the method of Least-Square Smoothness Constraint. The result of the interpretation shows that the subsurface resistivity value in the area ranges from 0.4-13.108 Ω m, and groundwater aquifer potential lies at trajectories KPG 01, 02, 03, 04, 14, 15. In the Batu Gamping Koral Formation there is groundwater potential in depth between 0-85 m with a resistivity value of 25.6-205 Ω m, and its constituent rocks are limestone sand and sand. In the Alluvium Formation, the groundwater potential in depth between 0-20 m with resistivity value of 25.6-410 Ω m, and its constituent rock is sand. Whereas in Bobonoro Formation, there is no groundwater potential.

1. Introduction

Areas that are dominated by limestone are usually physically dry and barren areas. One example of limestone dominated areas is Kupang, East Nusa Tenggara. The city of Kupang is the capital of the Indonesian province of East Nusa Tenggara, and had an estimated population in 2019 of 434,972. It is the biggest city and port on the island of Timor. The geology of Kupang is located on the Batu Gamping Koral Formation which composed by coral limestone, which is physically barren and dry. So that local residents often have some problems with water availability. The needs for groundwater is urgent in Kupang. Therefore, needed the information about potential and depth of groundwater aquifers in the area. In an effort to obtain the composition of the earth's layers, activities must be carried out through underground investigation, so that the presence or absence of a water-carrying layer (aquifer) can be known, its thickness and depth.

Groundwater is stored in a container in the form of an aquifer, which is a geological formation that is saturated with water and has the ability to store and pass water to a sufficient and economical amount [1]. The formation of ground water follows the cycle of water circulation on earth called the hydrological cycle [2]. The flow and amount of ground water in a rock is influenced by permeability and porosity. Permeability is the ability of rocks to pass water through rock pores [3]. While porosity is a measure of empty space in a rock or a comparison between the pore volume and the overall rock
Volume [4]. Classification of rocks based on the ability to drain ground water and its porosity, divided into 4, including aquifers, aquiclud, aquitards, and aquifug. An aquifer is a layer of water-saturated rock below the surface of the soil that can store and carry water in sufficient quantities, such as sand. Aquiclud is a layer of rock that can store water but is unable to release it, for example clay. Aquitard is a layer of rock that can store water but can only pass a limited amount of water. While aquifug is a waterproof rock layer that is unable to store and carry on water, for example granite [5]. Based on rock lithology, groundwater aquifers can be divided into 2 types, as follows [5]: free aquifer (unconfined aquifer) is a water-saturated aquifer whose lower boundary layer is a waterproof layer while the upper layer is a ground water level, and confined aquifer (a stressed aquifer) is an aquifer where groundwater is located below the impermeable layer and has a greater pressure than the atmosphere. In this aquifer, the upper and lower layers of the boundary are water impermeable formations.

2. Method

2.1. Geology

The city of Kupang is located at coordinates 123°31'35"-123°41'00" East Longitude and 10°07'40"-10°17'39" South Latitude. With an area of 180.27 km², and a coastline of ± 27 km (Marina Beach City). Kupang City consists of 6 districts and 51 villages. The geological condition of Kupang City is included in the Kupang-Atambua geology sheet, which is then modified as shown in Figure 1. Based on the map, the study area can be divided into 4 geological formations. These formations are the Alluvium (Qa) Formation, the Coral Limestone Formation (Ql), the Noele Formation (QTn), and the Bobonaro Formation (Tmb) [6]. The Coral Limestone Formation (Ql) is formed on reef limestone and slightly marl. The Alluvium (Qa) Formation is formed by the deposition of rivers, lakes and beaches in the form of clay, gravel, silt and mud and coral reefs. The Bobonaro Formation (Tmb) consists of scaly clay and rocky rock. The Noele Formation (QTn) is formed on sandy marbles intermittently with sandstones, conglomerates and a small amount of tuff.

2.2. Research Location

This research was carried out in Kupang and Surrounding areas, East Nusa Tenggara (NTT). Map of the location of data collection can be seen in Figure 2. Data was collected at 7 measurement points with a measurement length of 710 m.

Figure 1. Geological Map of the Research Location [6]
2.3. Methodology

The geoelectric method is one of the methods in geophysics that studies the nature of electric currents in the earth [7]. While the resistivity method is used to describe subsurface conditions by studying the electrical resistivity of rock layers in the earth, where the earth is composed of rocks that have different electrical conductivity [8]. Resistance is the electrical resistance of a material that is electrified. For the same material, the resistance is directly proportional to the length (L) and inversely proportional to the cross-sectional area (A). While resistivity is the ability of a material to conduct electricity, resistivity does not depend on the size of the material but the nature of the material [9]. The relationship of resistance to resistivity is shown in Equation (1).

\[ R = \frac{\rho L}{A} \]  

where \( R \) is the resistance (Ω), \( \rho \) is the resistivity (Ω m), \( L \) is the length (m) and \( A \) is the cross-sectional area (m²) [9].

In resistivity measurement, it is assumed that the earth has isotropic homogeneous properties, but actually the earth consists of layers with different resistivity. Therefore, the measured resistivity value is apparent resistivity [10]. If there are two layers that have different resistivities namely \( \rho_1 \) and \( \rho_2 \), then it is assumed to be one layer that has a resistivity value of \( \rho_a \) [9]. The apparent resistivity produced by each configuration will be different, even though the distance between the electrodes is the same.

The geoelectric method that will be used in this study is the Wenner configuration geoelectric method. Wenner configuration is used because this configuration is considered to produce better resolution of potential electrodes and stronger signals because in the study area there are many underground iron pipes which are considered as noise. The Wenner configuration is a configuration in the resistivity method that uses the same spacing [11]. The distance between the current electrodes is three times the distance between the potential electrodes. If the distance between the current electrodes is widened, the distance between the potential electrodes must also be changed. The potential distance to the sounding point is \( a / 2 \), while the current distance to the sounding point is \( 3a / 2 \). The depth target that this method can achieve is \( a / 2 \) [12].

Geometry factors in the Wenner configuration can be explained as follows:
The apparent resistivity data is inverted to produce subsurface resistivity values. Inversion was carried out using the Least-Square Smoothness Constraint algorithm method. This method is used because it can produce smooth subsurface model. Where the data is iterated over and over again to get the smallest error value in order to get an underground section close to the original.
Figure 3. Interpretation results in KPG 01

Table 1. Stratigraphy KPG 01 from 2D Resistivity Interpretation Result. The area is included in the Coral Limestone Formation

| Layer                | Thickness | Resistivity      |
|----------------------|-----------|------------------|
| Limestone            | 15 m      | 51.2-205 Ω m     |
| Coral limestone      | 40 m      | 205-1638 Ω m     |
| Limestone            | 15 m      | 51.2-205 Ω m     |
| Sand                 | 15 m      | 25.6-51.2 Ω m    |
| Sandy                | 50 m      | 12.8-25.6 Ω m    |

Figure 3 is a 2D resistivity cross section of KPG 01 path. The cross section shows that the resistivity value is in the range of 12.8-1638.38m. The area is included in the Coral Limestone Formation. Meanwhile, based on data from the wellbore at KPG 01, at a depth of 0-60 m is coral limestone and at 60-62 m is sand. Thus, the Path can be interpreted to consist of 5 layers (Table 1). The first layer is fractured limestone which has a resistivity value of 51.2-205 Ω m with a layer thickness of 15 m. The second layer is coral limestone with resistivity values 205-1638 Ω m and has a thickness of 40 m. The third layer is fractured limestone with a resistivity value of 51.2-205 Ω m and has a thickness of 15 m. The fourth layer is thought to be sand with a range of values 25.6-51.2 Ω m with a layer thickness of 15 m, and the fifth layer is thought to be sandy with a resistivity range of 12.8-25.6 Ω m with a layer thickness of 50 m. If reviewed based on hydrogeological maps, the KPG 01 trajectory is a type of aquifer with flow through fissures, fractures and channels with high to moderate productivity. Therefore, at KPG 01 trajectory, the layer that is indicated as groundwater aquifer is the limestone and sand layer at depth 0-15 and 55-85 m.
Table 2. Stratigraphy KPG 02 from 2D resistivity interpretation result. This track is in the Coral Limestone Formation, but also across from the Noele Formation.

| Layer             | Thickness | Resistivity       |
|-------------------|-----------|-------------------|
| Sandy limestone   | 35 m      | 25.6-205.5 Ω m    |
| Maritime sand     | 60 m      | 6.4-25.6 Ω m      |
| Marl              | 40 m      | 1.6-6.4 Ω m       |

Figure 4 is a 2D resistivity cross section of KPG 02 path. The resistivity value in this path is in the range of 1.6-205 Ω m. This track is in the Coral Limestone Formation, but also across from the Noele Formation. When viewed in a transverse incision on the geological map, the Coral Limestone Formation is above and piled up the Noele Formation. Thus, the KPG 02 pathway is interpreted to have 3 layers of soil (Table 2). In the first layer with a resistivity range of 25.6-205.5 Ω m and a thickness of 35 m layer is indicated as sandy limestone. Whereas the second layer has a resistivity range of 6.4-25.6 Ω m and a thickness of 60 m which is indicated as maritime sand. Whereas in the third layer with a value range of 1.6-6.4 Ω m and a thickness of the 40 m layer is indicated as marl. Based on hydrogeology, this trajectory is in the aquifer zone with moderate productivity through cracks, fissures and channels. Thus, in this lane, sandy limestone is thought to be a shallow aquifer at a depth of 0-35 m.

Figure 5 is a resistivity cross section for KPG trajectory 03. The figure has a resistivity range of 1.6-13108 Ω m. This track is still in the Coral Limestone Formation. So, it is interpreted that there are 5 layers of rock on this path (Table 3). Namely, the first layer is a sandy marl with a resistivity value of 6.4-25.6 Ω m and a layer thickness of 15 m. In the second layer is interpreted as coral limestone with a resistivity value of 205-13108 Ω m with a layer thickness of 15 m. In the third layer in the form of sandy limestone with resistivity range of 25.6-205 Ω m and a layer thickness of 10 m. In the fourth layer is a maritime sand with a range of values of 6.4-25.6 Ω m with a layer thickness of 15 m. And the fifth layer is thought to be marl with resistivity values ranging from 1.6-6.4 Ω m with a thickness of 85 m. Based on hydrogeology, this trajectory is in the aquifer zone with moderate productivity through cracks, fissures and channels. Thus, on this path, sandy limestone is suspected to have potential as groundwater aquifer with a depth of 30-40 m.

Table 3. Stratigraphy KPG 03 from 2D resistivity interpretation result. This area has a resistivity range of 1.6-13108 Ω m. This track is in the Coral Limestone Formation.

| Layer            | Thickness | Resistivity           |
|------------------|-----------|-----------------------|
| Sandy marl       | 15 m      | 6.4-25.6 Ω m          |
| Coral limestone  | 15 m      | 205-13108 Ω m         |
| Sandy limestone  | 10 m      | 25.6-205 Ω m          |
Table 4. Stratigraphy KPG 04 from 2D resistivity interpretation result. The resistivity value in this trajectory is in the range 1.6-410 \( \Omega \) m. This track is in the Alluvium Formation.

| Layer                      | Thickness | Resistivity       |
|----------------------------|-----------|-------------------|
| Sand with a little gravel  | 20 m      | 25.6-410 \( \Omega \) m |
| Clay                       | 20 m      | 1.6-6.4 \( \Omega \) m |
| Sandy loam                 | 60 m      | 6.4-25.6 \( \Omega \) m |
| Clay                       | 40 m      | 1.6-6.4 \( \Omega \) m |

Figure 6 is a 2D resistivity cross section of KPG 04 trajectory. The resistivity value in the trajectory is in the range 1.6-410 \( \Omega \) m. This track is in the Alluvium Formation. Thus, the KPG 04 trajectory is interpreted to have 4 layers of soil (Table 4). In the first layer with a resistivity range of 25.6-410 \( \Omega \) m and a thickness of 20 m, the layer is indicated as sand with a little gravel. The second layer has a resistivity range of 1.6-6.4 \( \Omega \) m and a thickness of 20 m, which is indicated as clay. In the third layer, it is assumed that sandy loam with a resistivity range of 6.4-25.6 \( \Omega \) m and a layer thickness of 60 m. While in the fourth layer, it is suspected that the clay with resistivity range of 1.6-6.4 \( \Omega \) m and the thickness of the layer is 40 m. If it is reviewed based on its hydrogeology, this path is in the zone of moderate productive aquifer with a wide distribution of types of flow through inter-grain space. Thus, at this point, sand is suspected to have potential as groundwater aquifer at a depth of 0-20 m.
Table 5. Stratigraphy KPG 05 from 2D resistivity interpretation result. The resistivity value in the trajectory is in the range of 1.6-25.6 $\Omega$ m. This track is in the Bobonoro Formation.

| Layer      | Thickness | Resistivity |
|------------|-----------|-------------|
| Clay       | 140 m     | 1.6-25.6 $\Omega$ m |

Figure 8. Interpretation results in KPG 14

Table 6. Stratigraphy KPG 14 from 2D resistivity interpretation result. The cross section shows that the resistivity value is in the range 6.4-13108 $\Omega$ m. The area is included in the Coral Limestone Formation.

| Layer                  | Thickness | Resistivity        |
|------------------------|-----------|--------------------|
| Coral limestone        | 35 m      | 205-13108 $\Omega$ m |
| Sandy limestone        | 25 m      | 25.6-205 $\Omega$ m |
| Sandy marble           | 80 m      | 6.4-25.6 $\Omega$ m |

Figure 7 is a 2D resistivity cross section of KPG 05 trajectory. The resistivity value in the trajectory is in the range of 1.6-25.6 $\Omega$ m. This track is in the Bobonoro Formation. Thus, KPG 05 trajectory is interpreted to have 1 layer of soil (Table 5). I.e the range of resistivity values of 1.6-25.6 $\Omega$ m at 140 m and the thickness of the layer is indicated as clay. Clay on this track is a type of aquiklud which is a layer that can store water but is unable to release it or continue. If it is reviewed based on its hydrogeology, this track is in a rare groundwater zone with low productivity. Thus, in this path there are no layers that have the potential to be aquifers.

Figure 9. Interpretation results in KPG 15
Table 7. Stratigraphy KPG 15 from 2D resistivity interpretation result. The cross section shows that the resistivity value is in the range 0.4-819 Ω m. The area is included in the Coral Limestone Formation. In the napal layer there is a low resistivity value reaching 0.4 Ω m, presumably due to sea water intrusion.

| Layer     | Thickness | Resistivity   |
|-----------|-----------|---------------|
| Coral limestone | 10 m     | 205-819 Ω m   |
| Sandy limestone  | 10 m     | 25.6-205 Ω m  |
| Napal         | 120 m    | 6.4-25.6 Ω m  |

Figure 8 is a 2D resistivity cross section of the KPG trajectory 14. The cross section shows that the resistivity value is in the range 6.4-13108 Ω m. The area is included in the Coral Limestone Formation. Thus, the KPG 14 track is interpreted to have 3 layers (Table 6). The first layer is coral limestone which has a resistivity value of 205-13108 Ω m with a thickness of 35 m. Whereas the second layer is sandy limestone with resistivity value of 25.6-205 Ω m with a layer thickness of 25 m, and the third layer is sandy marbles with a resistivity value of 6.4-25.6 Ω m with a thickness of 80 m. If viewed based on hydrogeological maps, this path is a type of aquifer with flow through fissures, fractures and channels with high productivity. Thus, on KPG 14 trajectory, the layer that has the potential as a groundwater aquifer is sandy limestone at a depth of 35-60 m.

Figure 9 is a 2D resistivity cross section of the KPG pathway. The cross section shows that the resistivity value is in the range 0.4-819 Ω m. The area is included in the Coral Limestone Formation. Thus, the KPG 15 path is interpreted to have 3 layers (Table 7). The first layer is coral limestone which has a resistivity value of 205-819 Ω m with a layer thickness of 10 m. Whereas the second layer is sandy limestone with resistivity value of 25.6-205 Ω m with a thickness of 10 m, and the third layer is napal with a resistivity value of 6.4-25.6 Ω m with a thickness of 120 m. In the napal layer there is a low resistivity value reaching 0.4 Ω m, presumably due to sea water intrusion. If viewed based on hydrogeological maps, this path is a type of aquifer with flow through fissures, fractures and channels with high productivity. Thus, on KPG 15 trajectory, the layer that has the potential as a groundwater aquifer is sandy limestone at a depth of 10-20 m.

The results of the interpretation of groundwater aquifer potential indicate that in the Coral Lime Formation, layers that have the potential to be groundwater aquifer are in the sand and sandy limestone layers with resistivity values of 25.6-205 Ω m and a depth range between 0-85 m. Whereas in the Alluvium Formation the potential layer as an aquifer is sand with a resistivity value of 25.6-410 Ω m at depths between 0-20 m. While the layers in the Bobonoro Formation have no potential as groundwater aquifers.

4. Conclusion
Based on data analysis and discussion, it can be concluded that:
1. The subsurface resistivity value in the study area ranges from 0.4 to 13108 Ω m.
2. Potential groundwater aquifers are located in the trajectory of KPG 1, 2, 3, 4, 14 and 15 with sand and sandy limestone constituent layers.
3. In the Coral Limestone Formation there is the potential for ground water at a depth of 0-85 m with a resistivity value of 25.6-205 Ω m and the constituent rocks are sand and sand limestone. In the Alluvium Formation, the groundwater potential is at a depth of 0-20 m with a resistivity value of 25.6-410 Ω m and its constituent rocks are sand. Whereas in the Bobonoro Formation there is no groundwater potential.

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