Assessment of Aquifer Systems for The Sustainable Development of Groundwater Use in The Batutua Groundwater Basin

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Abstract. Groundwater exploration is an alternative to meet raw water needs because of the increasing water demand and the dwindling surface water availability. Water use continues to increase along with the rate of population growth in the Rote Ndao Regency. Therefore, an initial assessment of the presence of groundwater can be carried out by identifying the groundwater basin area. Batutua is one of the groundwater basin areas occupied by the most population because it is the capital of Rote Ndao Regency. This study aims to identify aquifer systems and flow patterns as the basis for groundwater exploration in the Batutua groundwater basin area. The method used in this groundwater aquifer system study is the Vertical Electrical Sounding (VES) method. The VES method is a geoelectrical method used to investigate the layers of an aquifer by interpreting the current that penetrates the soil using two electrodes and the potential response. Geoelectrical investigations were carried out at 8 points in the Batutua groundwater basin area. The aquifer is found in water-containing coral limestone areas where water flows through fractures as secondary permeability. The groundwater flow direction was obtained by measuring the groundwater levels in 14 dug wells and 24 springs. The research’s area aquifer system is formed by upper shallow aquifer as an unconfined aquifer with a thickness less than 20 m and lower shallow aquifer as a semi-confined aquifer that has clay or marls on upper layer and limestone in below with the flow direction from the East to the West and the North part of the study area.

Keywords: groundwater, aquifer system, Batutua groundwater basin

1. Introduction

Rote Island is one of the southernmost islands and is designated as the small outermost island and the territorial boundary of the Indonesian state[1]. Based on data from the Central Statistics Agency, the area of Rote Island is 1,280.10 km², with a total population of 172,104 people in 2019. The population growth rate in Rote Ndao Regency was recorded to increase by 3.80% from 2018 to 2019 and 30.33% from 2010 to 2019[2]. As the population increases, the water demand is also increases, especially for domestic and agricultural use on Rote Island. Due to the limited availability of surface water because of the low rainfall where the rain only occurs for four months in one year[3] and the increasing of water use by the community, it is necessary to explore groundwater to meet water needs on Rote Island.

Groundwater exploration is carried out to determine the presence of groundwater which is reviewed based on the area of the groundwater basin[4]. The division of the groundwater basin area is stated in the Minister of Energy and Mineral Resources Regulation No. 02/ 2017, where Rote Island is divided into non-groundwater basin areas and three groundwater basin areas, namely Batutua, Nembrala, and Rote. Batutua groundwater basin is one of the groundwater basin areas occupied by the most population because it is the capital of Rote Ndao Regency.
The study area is in the Batutua groundwater basin, Rote Ndao Regency, East Nusa Tenggara Province (Figure 1). Geographically, it is located at 123° 0’ 4,1” - 123° 16’ 31,4” East Longitude and 10° 41’ 43,5” - 10° 50’ 47,5” South Latitude. The area of Batutua groundwater basin is 229 km² which is located in 5 sub-districts, namely Lobalain, Rote Selatan, Rote Tengah, Rote Barat Laut, and Rote Barat Daya sub-districts. The topography of the study area is between 0 - 450 masl, with a slope between 0% - 166%. The higher slope is in the East area and is getting flattered to the West, South, and North of the study area.

Based on regional geological maps, geological conditions in the Batutua groundwater basin area consist of coral limestone formations, Noele formations, and alluvium deposits[5]. The coral limestone formation area seems to dominate the Batutua groundwater basin, so it is suspected that the water in this area is flowing in the limestone fractures. Meanwhile, the hydrogeological conditions in the Batutua groundwater basin area based on the hydrogeological map are local productive aquifers with flows through fissures, fractures, and dissolution channels[6]. From these two conditions, the Batutua groundwater basin is inevitably a karst aquifer.

Karst is an area with unique hydrogeological conditions because it is composed of soluble rock, and has secondary porosity[7]. Karst hydrogeology is formed from a combination of high rock dissolution with integrated porosity[8]. Karst areas are usually composed of limestone, which has rock properties that allow surface water to pass through gaps or fractures, resulting in water shortages in the dry season due to loss of surface water[9]. Karst areas have characteristics such as rare or no drainage, underground caves and closed basins of various sizes with different shapes[10]. In addition to this, the karst area is an area that has abundant groundwater storage and is a rock that can drain water so that it...
is included in the aquifer layer\cite{11}. Therefore, it is essential to carry out groundwater exploration, especially in the karst area, to detect groundwater's presence and assess the aquifer layer in the area.

In groundwater exploration activities, five technologies can be used to detect the presence of water below the surface, namely, (1) hydrogeological maps; (2) Remote sensing from aerial photography and technology program results; (3) Sampling of soil or rock; (4) Geophysical Survey on the ground surface, and; (5) Geophysics in boreholes\cite{12}. The results of the groundwater exploration method will be maximized if more than one method is used. However, the limitations of these methods are the difficulty of obtaining data, and having little definite information because it is interpretive. Therefore, this research will combine three technologies of hydrogeological maps, remote sensing, and a geophysical survey method on the ground surface which will be validated with hydrogeological observations. Remote sensing techniques are used to identify potential groundwater zones and to thoroughly view systems on earth via satellite\cite{13}. This technology is an advancement to support various fields, especially the field of geology such as geological mapping, groundwater exploration, and the introduction of rock materials in geology.

One of the geophysical methods used is the one-dimensional (1D) geoelectric method of Vertical Electrical Sounding (VES), which will produce resistivity values from rocks below the surface\cite{14}. The VES method is a geoelectric method used to investigate the layers of an aquifer by interpreting the current that penetrates the soil using two electrodes and the potential response. The results of these values will be interpreted into sub-surface according to the resistivity values. Then, the lithology layer will be analyzed to be an aquifer system in Batutua groundwater basin. The resistivity value has been used extensively to explore groundwater and determine sub-surface geological sequences. This method has been used in many groundwater exploration studies\cite{15,16,17}. However, it has never been implemented in the Batutua groundwater basin. This study aims to identify aquifer systems and flow patterns direction as the basis for groundwater exploration in the Batutua groundwater basin area.

2. Methods
The methods used in this research are by observing the conditions on the surface and conducting subsurface investigations to find out the description of the hydrogeological system in the research area.

2.1. Field Observation
Hydrogeological observations in the study area were chosen to measure the groundwater level in groundwater sources like springs and wells. Groundwater level observations were carried out at 24 existing springs, and 14 dug wells to identify groundwater levels in the study area. The groundwater level depth in the springs is measured using a rolling meter calculated from the groundwater level to the ground surface. The global positioning system (GPS) device measures station coordinates and the land surface elevation above the sea. The hydrogeological observation data were analyzed using the GIS Software and presented as groundwater flow pattern maps.

2.2. Sub-surface Investigation
Analysis of the groundwater aquifer system using the geoelectrical method on the groundwater-surface aims to investigate the electrical flow below the surface. Geoelectrical is one of the methods in geophysics that studies the nature of the flow of electricity in the earth by detecting above the earth's surface, which includes measuring potential, current, and electromagnetic fields that occur naturally and injecting currents into the earth\cite{18}. The VES method is one of the most widely used methods because it is considered suitable and straightforward to apply to areas with limited land\cite{19}.

Two current electrodes were used to pass the current into the subsurface, and it will cause potential difference values ($\Delta V$)$^{20}$. The resistance of the ground ($R$) is obtained from the ratio between the potential difference values ($\Delta V$) and the electric current ($I$) below the surface (equation 1).

\[
R = \frac{\Delta V}{I}
\]  

(1)

This configuration will be used to calculate the apparent resistivity value ($\rho_a$) obtained from the geometrical factor depending on the type of electrode array (K) and the resistance of the ground ($R$) using Ohm's law (equation 2).

\[
\rho_a = K R
\]  

(2)

The apparent resistivity ($\rho_a$) is related to the sub-surface resistivity. In general, linear electrode configurations are used for measuring resistivity like Wenner, Schlumberger, and Dipole-dipole. The VES method mainly uses the symmetrical Schlumberger configuration where the current electrodes
AB move outward and the MN voltage electrodes are closely spaced and fixed to the array’s center[19]. The Schlumberger configuration was known to have the ability to measure the variation of resistivity is deeper compared to the Wenner method[21]. The resistivity value is used to interpret rock types. The rock resistivity values for sedimentary rocks are presented in Table 1.

Data points of VES has performed in the Batutua groundwater basin were used to measure the resistivity data beneath the surface. The location of the VES data points is in the villages of Daleholu and Busalangga, each with 4 points (Figure 2). The geoelectric parameters were further refined using a resistivity interpretation program to obtain the true resistivity and thickness of the various layers. The data that has been processed, produces 1-dimensional data and interprets the rock type. After that, it is processed again using the RockWorks 2021 Version 8.5 software, which produces 2-dimensional data to describe the subsurface structure.

### Table 1. Resistivity value of sediments rock (Telford et al., 1990)

| Rock type            | Resistivity range (Ωm)          |
|----------------------|---------------------------------|
| Consolidated shales  | $2 - 2 \times 10^4$              |
| Argilites            | $10 - 8 \times 10^2$            |
| Conglomerates        | $2 \times 10^3 - 10^4$          |
| Sandstones           | $1 - 6.4 \times 10^8$           |
| Limestones           | $50 - 10^3$                     |
| Dolomite             | $3.5 \times 10^2 - 5 \times 10^3$|
| Unconsolidated wet clay | 20                             |
| Marls                | 3 - 70                          |
| Clays                | 1 - 100                         |
| Oil sands            | 4 - 800                         |

3. Result and Discussion

3.1. Hydrogeological Observation

Groundwater level measurements are carried out to determine the elevation of the groundwater level and the direction of groundwater flow. Based on groundwater level measurements in the Batutua groundwater basin area, the groundwater level is between 28.74 - 369 masl. The lowest groundwater level is at the Batutua spring, located in the Southwest part of the Batutua groundwater basin, with an elevation of 28.74 masl. The highest groundwater level is at the Nggaehu spring, an elevation of 369 masl, located in the East part. The groundwater level analysis was carried out using GIS Software which produced the contour (equipotential line) and the direction of groundwater flow (Figure 3). From the analysis results, it can be concluded that groundwater flows from the East to the West, North, and South of the study area.
3.2. **Sub-surface Investigation**

The geoelectrical investigation was conducted in 8 locations to represent sub-surface conditions with VES Method. Based on the analysis of field data from the geoelectric test results using a resistivity interpretation program, the resistivity values at each sounding point were obtained. The interpretation results of rock layers are presented in Figure 4. The interpretation results show that the lithology of the research area is composed of limestones, clays, and marls. The geological map of the research area also indicates that Batutua Groundwater Basin is dominated by limestone lithology. The result was found that the aquifers existed at different depths between points in Daleholu and Busalangga.

The resistivity value in Daleholu is between 0.121 – 8062 Ωm and interpreted as limestone at the depth between 0 – 62 m interspersed with marls at 10 – 58 m, and clay at 44 – 85 m. While in Busalangga, the resistivity value is between 0.631 – 2493 Ωm and composed of limestones at the depth between 0 – 79 m interspersed with marls at 1.7 – 13 m and clays at 10 – 75 m. The depth of each point can be seen in Figure 4. Those limestone layers have the potential aquifer as secondary porosity and permeability.
3.3. **System Aquifer**

The determination of the aquifer system in the Batutua groundwater basin is based on the interpretation of rock types at the VES point. The groundwater basin is located in the limestone lithology area, which is a karst aquifer. The hydrogeological map also states that the Batutua groundwater basin is local productive aquifers with flows through fissures, fractures, and dissolution channels which is a characteristic of karst aquifers. The summary of aquifer type at the VES point is presented in Table 2.
Table 2: Summary of aquifer type at VES point

| VES Point | Elevation (masl) | Depth (m) | Thickness (m) | Aquifer Type |
|-----------|------------------|-----------|---------------|--------------|
| Daleholu-1| 309              | 0 - 14.545| 14.545        | Aquiclude    |
|           | 294.455          | 14.545 - 18.735 | 4.19          | Aquifer      |
|           | 290.265          | 18.735 - 46.665 | 27.93         | Aquifer      |
|           | 262.335          | 46.665 - 79.265 | 32.6          | Aquiclude    |
| Daleholu-2| 309              | 0 - 36.007 | 36.007        | Aquifer      |
|           | 272.993          | 36.007 - 79.277 | 43.27         | Aquiclude    |
| Daleholu-3| 309              | 0 - 10.526 | 10.526        | Aquifer      |
|           | 298.474          | 10.526 - 21.646 | 11.12         | Aquiclude    |
|           | 287.354          | 21.646 - 62.786 | 41.14         | Aquifer      |
|           | 246.214          | 62.786 - 79.286 | 16.5          | Aquiclude    |
| Daleholu-4| 309              | 0 - 3.496   | 3.496         | Aquifer      |
|           | 305.504          | 3.496 - 4.364 | 0.868         | Aquiclude    |
|           | 304.636          | 4.364 - 44.95 | 40.586        | Aquifer      |
|           | 264.05           | 44.95 - 83.75 | 38.8          | Aquiclude    |
| Busalangga-1| 134            | 0 - 1.702   | 1.702         | Aquifer      |
|           | 132.298          | 1.702 - 2.866 | 1.164         | Aquiclude    |
|           | 131.134          | 2.866 - 10.579 | 7.713         | Aquifer      |
|           | 123.421          | 10.579 - 47.8 | 37.221        | Aquiclude    |
|           | 86.2             | 47.8 - 75.029 | 27.229        | Aquifer      |
| Busalangga-2| 134            | 0 - 2.921   | 2.921         | Aquifer      |
|           | 131.079          | 2.921 - 4.119 | 1.198         | Aquiclude    |
|           | 129.881          | 4.119 - 10.499 | 6.38          | Aquifer      |
|           | 123.501          | 10.499 - 48.519 | 38.02         | Aquiclude    |
|           | 85.481           | 48.519 - 75.119 | 26.6          | Aquifer      |
| Busalangga-3| 131            | 0 - 1.053   | 1.053         | Aquifer      |
|           | 129.947          | 1.053 - 13.878 | 12.825        | Aquiclude    |
|           | 117.122          | 13.878 - 39.058 | 25.18         | Aquifer      |
|           | 91.942           | 39.058 - 75.848 | 36.79         | Aquiclude    |
| Busalangga-4| 135            | 0 - 1.025   | 1.025         | Aquifer      |
|           | 133.975          | 1.025 - 12.327 | 11.302        | Aquiclude    |
|           | 122.673          | 12.327 - 22.707 | 10.38         | Aquifer      |
|           | 112.293          | 22.707 - 46.877 | 24.17         | Aquiclude    |
|           | 88.123           | 46.877 - 79.477 | 32.6          | Aquifer      |

The aquifer system in the Daleholu area has a layer of limestone as an aquifer with an aquifer thickness between 3.5 m - 40.5 m with the flow direction from East to west. The aquifer in the Busalangga area has a layer of limestone with alternating marl and clay on the second and fourth layers with aquifer thickness between 1.7 - 36.7 m with the flow direction from East to west and north of the study area. The cross-section of the aquifer system in the Daleholu and Busalangga areas is presented in Figure 5.
The Figure 5 clearly shows the succession of lithology, the changes of aquifer thickness, and the aquifer configuration. In general, the aquifer is under to karst aquifer that is composed of limestone. Based on the resistivity value classification, the research’s area aquifer system is formed by (from surface to the base), the first aquifer (upper shallow aquifer as an unconfined aquifer) with a thickness less than 20 m. The second and third aquifer (lower shallow aquifer as a semi-confined aquifer) has clay or marls on upper layer and limestone in below.

**4. Conclusion**

Based on the analysis results, the research’s area aquifer system is formed by (from surface to the base), the first aquifer or upper shallow aquifer as an unconfined aquifer with a thickness less than 20 m. The second and third aquifer or lower shallow aquifer as a semi-confined aquifer that has clay or marls on upper layer and limestone in below with the flow direction from the East to the West and the North part of the study area. So it can be concluded that the Batutua groundwater basin area is a karst aquifer that can store and drain groundwater. Therefore, the result of this study can be considered a basis for exploring groundwater in the research area to meet the community's water needs. However, it is essential to remember the importance of conserving groundwater to maintain the sustainability of groundwater sources.

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