Determination of Priority Areas for Groundwater Development by Using the Analytic Hierarchy Process Method in Rote Island

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Abstract. This study aims to determine other exploration targets related to priority areas for groundwater utilization development on Rote Island. In arranging priority areas for groundwater development, remote sensing data and Geographical Information Systems (GIS) are integrated with the Analytic Hierarchy Process (AHP) method. The parameters used are lineament (F), lithology (L), slope (T), drainage density (D), and rainfall (R). F, T, and D were obtained from DEM map analysis. L was obtained from regional geological maps. Moreover, R was obtained from annual rainfall data from the rain station of the study area. All parameters were overlaid using GIS and assign weights using the AHP method. The results will be compared to the locations of springs and wells scattered in the study area. There are five classifications of potential groundwater areas on Rote Island, namely very high is 34 km² in the East part; high is 383.25 km² in the South, East, and Northeast part; moderate is 549.50 km² in the North and South part; low is 246.50 km² and very low is 2.198 km² in the West part of the research area. Considering the existing observation springs in Rote Island using average yields in each classification area confirms the correctness of the potential groundwater areas.

Keywords: groundwater potential, rote island, GIS, AHP

1. Introduction
The increased population on Rote Island is one of the factors that increase the amount of water use. The increasing factor of water use is caused by a reasonably high population growth rate in Rote Ndao Regency, which is 30.33% in a period of ten years (2010 - 2019) and 3.80% within one year (2018 – 2019) [1].

The projected water demand until 2033 in the Noelmina River Basin area for household-urban, industrial, and irrigation needs is 949.23 million m³. Therefore, it is essential to develop water resources because if it is not carried out, it is estimated that the Noelmina River Basin will experience a water shortage of 550.93 million m³ [2].
Rote Island is one of the small outermost islands in the southern part of the Indonesian territory based on the Presidential Decree of the Republic of Indonesia Number 6/2017 concerning Designation of Outermost Small Islands and drought-prone areas [3]. The determination of drought-prone areas based on rainfall intensity in Indonesia is generally relatively high, ranging from 1000 mm - 6000 mm on average per year. Some areas experience high rainfall intensity, but certain regions experience minimal rainfall of less than 1000 mm on average per year to experience drought [4]. Prolonged droughts cause drought in some areas, resulting in a lack of surface and groundwater availability. Rote Island is an area that experiences a long dry season where the rainy season only lasts for three to four months and the long dry season lasts for eight to nine months [5].

Hydrogeological areas on Rote Island are the most scarce groundwater area [6]. Therefore, on the groundwater basin map listed in the Minister of Energy and Mineral Resources Regulation No. 02/2017, the area is a non-groundwater basin area. Meanwhile, most of the area on Rote Island is composed of limestone, which can store groundwater [7].

Availability of data and information on inventory results in groundwater basins and data on surface water availability are also needed for groundwater development in an area [8]. Therefore, it is essential to develop groundwater based on groundwater management plans and regional spatial plans by considering the carrying capacity of the aquifer, conditions and environment, protected areas, projected needs, and utilization of existing groundwater.

Figure 1. Research Location

The development of groundwater utilization requires information on groundwater potential. Method to determine areas with the most prospect for groundwater can be predicted using the Analytic Hierarchy Process (AHP) method. The AHP method can support mathematical objectivity to process subjective and personal preferences of individuals or groups in making decisions. The decisions are carried out by developing overall priorities to provide ratings and determined parameters [9]. Applying the AHP...
method that integrates with remote sensing data and a Geographic Information System (GIS) helps improve the accuracy of the results in describing potential groundwater areas [10]. This technique is considered suitable for identifying potential groundwater areas and has been applied in several studies [11] [12] [13] [14] [15] [16].

The AHP method to identify groundwater is carried out by determining the parameters following the research location area. Fracture parameters, lithology, slope, distribution density, and rainfall are suitable for applying the AHP method in limestone areas [14]. Limestone has secondary porosity such as joints, fractures, and bedding planes used as groundwater storage areas. Therefore, the AHP method needs to identify priority areas for groundwater development on Rote Island.

This research was conducted to determine priority areas for the development of groundwater utilization on Rote Island. The resulting map aims to assist in developing systematic use of groundwater resources to meet the increasing water needs of Rote Island.

The research location is in Rote Island, Rote Ndao Regency, East Nusa Tenggara Province. Geographically, it is located at 121º 49’ - 123º 26’ East Longitude and 10º 25’ - 11º 00’ South Latitude. Rote Island has a total land area of 1215.45 km$^2$ which includes 9 sub-districts, namely Rote Barat Daya, Rote Barat Laut, Lobalin, Rote Tengah, Rote Selatan, Pantai Baru, Rote Timur, Landu Leko, dan Rote Barat. The research location is presented in Figure 1.

2. Material and Methods

2.1. Tools and Materials

The tools used in research activities include a global positioning system (GPS), office stationery, a laptop, software for GIS analysis. The materials used to conduct the study were: a Digital Elevation Model (DEM) map obtained from the United States Geological Survey (USGS) website [17], a digital Rupa Bumi map of Indonesia (RBI) got from the Geospatial Information Agency of Indonesia (BIG) website [18], a Regional Geological map [7], and Hydrogeological map [6].

2.2. Data Analysis

Analysis of groundwater priority areas used five parameters considered the most influential in determining groundwater potential: lineament, lithology, slope, drainage density, and rainfall [14][16]. The comprehensive research methods of the groundwater potential evaluation are shown in Figure 2.

Lineaments are tectonic results identified as long, narrow, and relatively straight alignments seen in satellite imagery, representing major faults, faults, joints, long and linear geological formations, straight stream, vegetation alignment, or topographic linearity [19][20]. Lineaments have secondary permeability and provide clues to groundwater movement and storage [21]. Therefore, lineament is a determining factor for groundwater exploration [22]. The lineament is interpreted using a visual on the DEM map into the straightness density value. Straightness density (Ld) was calculated based on the grid cell method [23][16]. The grid cell size used was 1 km × 1 km. Ld is defined as the total length of all recorded straights divided by the area under consideration [24]. In Equation 1, where $Ld$ is the lineament density, $Li$ is the sum of the lengths of all lineaments (km), and $A$ is the grid area (km$^2$).

$Ld = \frac{\sum_{i=1}^{n} Li}{A} \ (km^{-1}) \quad (1)$

The results of the straightness density are Point data that will be interpolated using the Kriging method of ordinary type with a spherical semi-variogram [12][13][14][16]. Based on the research before, the number of interconnected and longitudinal fractures in an area determines groundwater in the area. On the other hand, if a site has few or no fractures, the smaller the potential for groundwater in that area.
Lithology is the main factor controlling the quality and quantity of groundwater occurrence in an area [23]. Lithology affects aquifer permeability and fracture pattern distribution [16]. It is related to rock layers with different characteristics in the studied area. Limestone is considered an essential groundwater storage medium because it has secondary porosity such as joints, fractures, bedding planes. In contrast, shale and marl are considered the least important for groundwater storage because the more clay content, the lower the permeability [14]. Hard rock with less clay content will rank higher in groundwater storage capacity than soft rock with more clay content [24].

The slope is an essential factor for the classification of groundwater potential zones. The slope affects the water movement on the ground surface due to the influence of gravity [25]. Areas that are flat to gentle slopes support infiltration and groundwater recharge. Meanwhile, areas with steep slopes support surface runoff. Areas with high groundwater potential are located in areas with a gentle to flat slope [26]. Higher slope levels result in rapid runoff and increased erosion rates with insufficient fill potential [27]. Alluvial plains, floodplains, or highlands are more favorable for groundwater occurrence because of the longer duration of the journey. The time it takes for water to reach downstream provides sufficient water infiltration into the soil [13]. Groundwater will be easily stored in areas with gentle slopes. Surface water on steep slopes will tend to flow into surface runoff rather than seep into groundwater.

The AHP method supports mathematical objectivity to process subjective and personal preferences of individuals or groups in making decisions. The AHP method works by developing priorities for alternatives and the parameters used to assess options. These parameters are determined and selected by the decision-maker [9]. The parameters stresses are obtained from the pairwise comparison matrix to assign weights to each parameter to get the best alternative [33]. Pairwise comparison matrices were compiled to bring priority values using the importance levels based on thematic layers to identify groundwater potential [11]. The comparison matrix uses a number of Saaty’s 1-9 fundamental scale (Table 1) to determine the level of importance or the parameter that dominates [9].

| Scale | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|-------|---|---|---|---|---|---|---|---|---|
| Importance | Equal importance | Weak | Moderate importance | Moderate plus | Strong importance | Strong plus | Very strong or demonstrated importance | Very, very strong | Extreme importance |

\[ Dd = \sum_{i=1}^{n} \frac{D_i}{A} \text{ (km/km}^2) \]
The weight which was assigned to different thematic layers was normalized using the AHP method. Calculation of Consistency Ratio (CR) needs to control and test the consistency and judgment of the assigned weights [16]. The first step to calculate CR is to compute the maximum eigenvalue ($\lambda_{\text{max}}$). Then, calculate the Consistency Index (CI) using equation 3, where $n$ is several factors. CR is resulted by dividing CI by RI (Ratio Index). The value of RI is given based on Saaty’s ratio index (Table 2) [9]. If the value of CR is less than 0.1, the judgment of weights is acceptable and consistent.

$$\text{CI} = \frac{\gamma_{\text{max}} - n}{n - 1}$$

$$\text{CR} = \frac{\text{CI}}{\text{RI}}$$

| N   | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|-----|----|----|----|----|----|----|----|----|----|----|
| Ratio Index | 0  | 0  | 0.52 | 0.89 | 1.11 | 1.25 | 1.35 | 1.40 | 1.45 | 1.49 |

After determining the weight of each parameter, the maps of five parameters were overlaid using GIS software to determine the level of groundwater potential. The result was analyzed using equation 5, where $\text{GWPI}_{\text{AHP}}$ is the groundwater potential index of the AHP method, $n$ is the number of parameters, $W_n$ is the weight of each parameter, and $w_n$ is the weight of each classification on pixel $i$ [12].

$$\text{GWPI}_{\text{AHP}} = \left( \sum_{n=1}^{n} W_n \times w_{n(i)} \right)$$

Sensitivity analysis aims to systematically test subjective predictions of various parameters in the range of interest. Tests are carried out to show priority areas for improvement if the model is to be developed [34]. The most frequently used analysis is based on the variation of factor weights in the testing process, which explains whether there is a change in the results obtained [35]. The sensitivity test for groundwater potential zones can be carried out with the exception technique for each parameter [16]. The exception is removing one of the parameters determining the potential groundwater area and calculating the AHP value without using the excluded parameter. The output raster index values obtained using the GIS software are then analyzed for the standard deviation values of the tested parameters. The standard deviation values are then sorted from the largest to the smallest. The excluded parameter with the most significant standard deviation value is the highest priority scale and sequentially until the smallest standard deviation value is the lowest priority scale. Based on these results, the priority scale can be ordered against the parameters to be used. Suppose the priority order is different from the initial prediction. In that case, it is necessary to process the AHP raster index value again with the results of the priority scale order based on the sensitivity test.

3. Result and Discussion

3.1. Parameters of AHP analysis

Data analysis on each parameter is carried out based on a digital map by giving a weight according to the classification of parameters and will be overlaid to get the value of potential groundwater areas. The weights for each parameter were decided based on the local field experience and expert opinions. The comparison of the importance level of parameters is shown in a pairwise comparison matrix (Table 3). Normalized weight is presented in Table 4.
### Table 3. Pairwise comparison matrix for AHP methods processing

| Parameters | Slope | Rainfall | Lithology | Drainage | Lineament |
|------------|-------|----------|-----------|----------|-----------|
| Slope      | 1     | 2        | 3         | 3        | 5         |
| Rainfall   | 0.50  | 1        | 2         | 3        | 5         |
| Lithology  | 0.33  | 0.50     | 1         | 2        | 3         |
| Drainage   | 0.33  | 0.33     | 0.5       | 1        | 2         |
| Lineament  | 0.20  | 0.20     | 0.33      | 0.50     | 1         |

### Table 4. Normalized weight for parameter of AHP methods

| Parameters | Slope | Rainfall | Lithology | Drainage | Lineament | Normalized Weight |
|------------|-------|----------|-----------|----------|-----------|------------------|
| Slope      | 0.379 | 0.552    | 0.485     | 0.316    | 0.298     | 0.3791           |
| Rainfall   | 0.190 | 0.276    | 0.324     | 0.316    | 0.298     | 0.276            |
| Lithology  | 0.126 | 0.138    | 0.162     | 0.211    | 0.179     | 0.1618           |
| Drainage   | 0.126 | 0.092    | 0.081     | 0.105    | 0.119     | 0.1054           |
| Lineament  | 0.076 | 0.055    | 0.054     | 0.053    | 0.060     | 0.0596           |

### Table 5. Classification and rank for parameter of AHP methods

| Parameters | Weight | Classification                              | Rank |
|------------|--------|--------------------------------------------|------|
| Slope      | 0.3791 | 16.277° - 20.346°                          | 1    |
|            |        | 12.208° - 16.277°                          | 2    |
|            |        | 8.138° - 12.208°                           | 3    |
|            |        | 4.069° - 8.138°                            | 4    |
|            |        | 0° - 4.069°                                | 5    |
| Rainfall   | 0.2760 | 955 – 1013 mm/year                         | 1    |
|            |        | 1013 – 1072 mm/year                        | 2    |
|            |        | 1072 – 1130 mm/year                        | 3    |
|            |        | 1130 – 1189 mm/year                        | 4    |
|            |        | 1189 – 1248 mm/year                        | 5    |
| Lithology  | 0.1618 | Coral Limestone (Ql)                       | 1    |
|            |        | Bobonaro Kompleks (Tmb)                     | 2    |
|            |        | Aitutu Formation (Ra)                      | 3    |
|            |        | Noele Formation (QTn)                      | 4    |
|            |        | Alluvium (Qa)                              | 5    |
| Drainage   | 0.1054 | 0.0069 – 0.0084 km/km²                     | 1    |
|            |        | 0.0055 – 0.0069 km/km²                     | 2    |
|            |        | 0.0041 – 0.0055 km/km²                     | 3    |
|            |        | 0.0026 – 0.0041 km/km²                     | 4    |
|            |        | 0.0011 – 0.0026 km/km²                     | 5    |
| Lineament  | 0.0596 | 0 – 0.498 km/km²                           | 1    |
|            |        | 0.498 – 0.997 km/km²                       | 2    |
|            |        | 0.997 – 1.496 km/km²                       | 3    |
|            |        | 1.496 – 1.994 km/km²                       | 4    |
|            |        | 1.994 – 2.493 km/km²                       | 5    |
Based on the calculation, the Consistency Ratio (CR) of this research is 0.0254, which means that the judgment of the pairwise comparison matrix is consistent. The assigned weight for lineament, lithology, slope, drainage, and rainfall are 0.3791, 0.2760, 0.1618, 0.1054, and 0.0596, respectively. All parameters are then tested for sensitivity so that the standard deviation value is obtained. Based on the order of standard deviation values in the sensitivity test results, the priority order of parameters is accepted, namely slope, rainfall, lithology, drainage density, and the last order is lineament. The assigned weight for lineament, slope, drainage, lithology, and precipitation are 0.3791, 0.2760, 0.1618, 0.1054, and 0.0596, respectively. Ranks were assigned to a different class of the individual themes are presented in Table 5. The thematic maps for all layers are shown in Figure 2.

Figure 2. Five thematics map parameters of AHP methods, (a) Slope map; (b) Rainfall map; (c) Lithology map; (d) Drainage density map; (e) Lineament map.
3.1.1. **Slope.**
Analysis of lineament is using a DEM data that processing into slope map. The slope of the research area ranged from 0º-20.346º that was classified into five classifications shown in Table 5 and Figure 2. The lowest rank is 16.277º-20.346º appeared in the South part of the research area. The highest rank is 0º-4.069º appeared mainly spread all over the island. The analysis result shows that the most of areas in Rote Island are low land areas and flat topography.

3.1.2. **Rainfall.**
Analysis of rainfall was obtained from annual rainfall data (10 years) from the rain station of the research area. There are five rain stations in Rote Island: David Constatijn Saudale, Pantai Baru, Eahun, Keka, and Danau Tua station. Annual rainfall data is then interpolated with Inverse Distance Weighting (IDW) method or the Isohyet method. The rainfall of the research area ranged from 955-1248 mm/year that was classified into five classifications that are shown in Table 5 and Figure 2. The lowest rank is 955-1013 mm/year, which appeared in the West part of the research area. The highest rank is 1189-1248 mm/year appeared in the East part of the research area. The analysis result shows that Rote Island has a low rainfall intensity, so it is categorized as a drought-prone area.

3.1.3. **Lithology.**
Analysis of lithology is using Regional Geological maps. Then field observations were made to determine geological boundaries and digitalized regional maps using GIS software. Rote Island has five rock formations: the Bobonaro Complex, Aitutu Formation, Noelle Formation, coral limestone, and alluvium. The lithology of the research area was classified into five classifications that are shown in Table 5 and Figure 2. The Alluvium is of higher rank because of its higher permeability. The Noelle Formation is composed of sandstone, and tuff has a reasonably high permeability value, so it is placed in rank 4. The Aitutu Formation consists of two layers, the upper part is composed of grayish calcsilutite. In contrast, the lower part is a thin alternation of siltstones, so it is placed in rank 3. The Bobonaro complex comprises scaly clay and mixed tectonic rocks. It is placed in rank two because clay is an aquifer that can absorb water but cannot pass water to be trapped in the layer. The coral limestone has the lowest rank, namely rank 1, because limestone has a small porosity value. Groundwater in limestone comes from water trapped in cracks, so the porosity in limestone is secondary.

3.1.4. **Drainage.**
Analysis of drainage is using DEM data that processing into drainage density data point. Point of drainage density then interpolated with Krigging method of common type with a spherical semi-variogram. The drainage density of the research area ranged from 0.0011-0.0084 km/km², classified into five classifications shown in Table 5 and Figure 2. The higher rank is 0.0011-0.0026 km/km² appeared in the North part of the research area. The lower rank is 0.0069-0.0084 km/km² in the West and East part of the research area.

3.1.5. **Lineament.**
Analysis of lineament is using DEM data that processing into lineament density data point. Then it will be interpolated with the Kriging method of common type with a spherical semi-variogram. The lineament density of the research area is classified into five classifications shown in Table 5 and Figure 2. The lower rank is 0-0.498 km/km² in the Northeast part of the research area. The higher rank is 1.994-2.493 km/km² appeared in the Southeast part of the research area.

3.2. **Groundwater Potential**
Groundwater potential analysis using the AHP method was processed using GIS software. The map overlay parameters for slope, rainfall, lithology, drainage density and lineament are done by inputting Equation 5 into the algebra map tools. The slope, rainfall, and lithology parameters in equation 5 have a higher weight than the other two parameters. The slope, precipitation, and lithology parameters play
an essential role in determining the groundwater potential in the research area. The results of the groundwater potential showed that there were five levels in Rote Island, namely very low, low, moderate, high, and very high levels. Classification of GWPI\textsubscript{AHP} values, level of groundwater potential, and area are presented in Table 6.

### Table 6. Value and level of groundwater potential in Rote Island

| GWPI\textsubscript{AHP} | Level of groundwater potential | Area (km\(^2\)) | Area percentage (%) |
|-------------------------|-------------------------------|-----------------|---------------------|
| 1.774 – 2.359           | Very low                      | 2.198           | 0.18 %              |
| 2.359 – 2.945           | Low                           | 246.50          | 20.28 %             |
| 2.944 – 3.530           | Moderate                      | 549.50          | 45.21 %             |
| 3.530 – 4.116           | High                          | 383.25          | 31.53 %             |
| 4.226 – 4.701           | Very High                     | 34              | 2.80 %              |

Based on Table 6, the very high groundwater potential area is 34 km\(^2\) that appeared in the East part of the research area. The high groundwater potential area is 383.25 km\(^2\), which mainly occurred in the research area's South, East, and Northeast regions. The moderate level is the enormous groundwater potential, distributed widely up to 549.50 km\(^2\) or about half of the island area. It is found in the North and South part of the research area. The low groundwater potential area is 246.50 km\(^2\) and the very low area is 2.188 km\(^2\) that appeared in the West of the research area. Groundwater potential maps using the AHP method are presented in Figure 3.

![Groundwater Potential Map](image)

**Figure 3.** Groundwater potential map using the AHP Method

### 3.3. Groundwater Potential Result Validation

Based on data obtained from the Regional Drinking Water Company of Rote Ndao Regency and the Ministry of Public Works and Public Housing, 43 springs spread over the Rote Island. However, from
43 springs, only 28 springs have water discharge data to validate the results of potential groundwater analysis. Validation of the potential groundwater areas resulting from the existing observation springs is a standard method\[12]\[31]\[16]. The springs yield data was overlaid over the map result. It was found that in the high level of groundwater potential areas delineated, research using the AHP and GIS method can describe potential groundwater areas with springs existence. The average yield rates of springs located in each classification of the groundwater potential map are shown in Table 7. The springs located in high groundwater potential areas have higher yields of 26.354 l/s. The springs located in moderate and low groundwater potential areas have yields of 26.321 l/s and 22.123 l/s.

| Level of groundwater potential | Total Springs | Average yield (l/s) |
|-------------------------------|---------------|---------------------|
| Very low                      | 0             | 0                   |
| Low                           | 6             | 22.123              |
| Moderate                      | 6             | 26.321              |
| High                          | 16            | 26.354              |
| Very High                     | 0             | 0                   |

4. Conclusion
Rote Island has an area of 1215.45 km². Based on the analysis of the AHP method, groundwater potential in Rote Island was divided into five classifications: very low, low, moderate, high, and very high. The very high groundwater potential area is 34 km², which appeared in the research area's East. The high groundwater potential area is 383.25 km², mainly in the research area's South, East, and Northeast parts. The moderate level is the enormous groundwater potential, distributed widely up to 549.50 km² or about half of the island area. It is found in the North and South part of the research area. The low groundwater potential area is 246.50 km², and the very low area is 2.188 km² that appeared in the West of the research area. Validation of the potential groundwater areas results considering the existing observation springs located in Rote Island using average yields in each classification area is confirms the correctness. The high groundwater potential areas have higher average yields of 26.354 l/s. The springs located in moderate and low groundwater potential areas have average yields of 26.321 l/s and 22.123 l/s.

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