Application of the APLIS Method for Groundwater Vulnerability Assessment in Rote Island Karst Areas

H Syafarini\textsuperscript{1,2,*}, H Hendrayana\textsuperscript{3} and S Winardi\textsuperscript{3}

\textsuperscript{1}Magister Program of Geological Engineering, Gadjah Mada University, Yogyakarta, Indonesia
\textsuperscript{2}Ministry of Public Works and Housing, Indonesia
\textsuperscript{3}Department of Geological Engineering, Gadjah Mada University, Yogyakarta, Indonesia

*E-mail: hane.syafarini@mail.ugm.ac.id

Abstract. The karst area on Rote Island dominates more than 60% of the Island. The land surface conditions in karst areas are generally dry, while below the subsurface is the potential for abundant water resources. This study aims to assess groundwater vulnerability using the APLIS (Altitude, Pendiete/Slope, Lithology, Infiltration, and Soils) method that will integrate with Geographic Information System (GIS) technique. The parameters used are elevation, slope, lithology, infiltration zone, and soil type. Slope and elevation are obtained from DEM maps, the soil is obtained from soil type maps, while lithology and infiltration zone are obtained from geological maps. The lithology and the infiltration zone in APLIS method analysis have a high role in determining the level of groundwater vulnerability. The groundwater vulnerability in Rote Island was divided into four classes: very low in the Northeast, low in the South, moderate in the East and North, and high in the East and West part of the Island. It explains that a high level of groundwater vulnerability in Rote Island needs to be used as a groundwater protection zone.

Keywords: karst, groundwater vulnerability, Rote Island, APLIS

1. Introduction

Karst areas have unique geological, hydrogeological, and morphological characteristics than other rock areas [1]. Land surface conditions in karst regions are generally dry, while there is a potential capacity for considerable water resources below the subsurface [2]. The hydrogeology of karst is formed from high rock dissolution with integrated porosity [3]. The cavities resulting from the karstification process cause the rock to have a high permeability value so that groundwater in the karst rock is easily contaminated due to the porous nature of the carbonate rock [4]. Karst also has variations in pore size, shape, origin, and porosity values related to permeability because the pore system in carbonate rocks is not homogeneous [5].

Human activities such as industry, mining, agriculture, and settlements threaten groundwater resources in karst areas. For example, mining activities can stop water infiltration into underground rivers. As a result, underground rivers will dry up, the death of springs, and can cause flooding in the rainy season due to the loss of areas to absorb water [6]. In addition, the use of hazardous chemical fertilizers and pesticides in the agricultural sector around the karst area causes groundwater quality to decline or even become contaminated [7].
The effort to protect karst areas, especially groundwater resources, is by conducting a groundwater vulnerability study in karst areas. The study uses data processed by the APLIS method (Altitude, Pendiete/Slope, Lithology, Infiltration Zone, and Soils) integrated with Geographic Information System (GIS) techniques. This method uses similar variables to measure the level of vulnerability used in the media porous [8]. The APLIS method used to calculate the recharge value in carbonate rock areas has been applied in several studies [4], [8]-[12] but has never been implemented in Rote Island. Therefore, this study aimed to assess the vulnerability of groundwater in karst areas using the APLIS method.

The research location is in Rote Island, Rote Ndao Regency, East Nusa Tenggara Province, Indonesia. 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 1,233,407 km² which includes 9 sub-districts, namely Rote Barat Daya, Rote Barat Laut, Lobalain, Rote Tengah, Rote Selatan, Pantai Baru, Rote Timur, Landu Leko, dan Rote Barat. The research location is presented in Figure 1.

![Figure 1. Research Location in Rote Island, Nusa Tenggara Timur, Indonesia](image)

2. Methods
2.1. Tools and Materials
The tools used in research activities include a global positioning system (GPS), office stationery, laptops, and GIS software analysis. The materials used to conduct the study were: a Digital Elevation Model (DEM) [12], a digital Rupa Bumi map of Indonesia (RBI) map [13], a Regional Geological map [14], and a digital soil types map [15].

2.2. Data Analysis
Data analysis of each parameter is carried out by rating according to the classification [8]. The category and rating of each parameter are presented in Table 1. After rating each parameter, the five maps of parameters were overlaid with GIS software using equation 1 [8] to determine the level of groundwater vulnerability using the APLIS method.

$$R = \frac{(A+P+3L+2I+S)}{0.9}$$

where $R$ is recharge, $A$ is altitude, $P$ is a slope, $L$ is Lithology, $I$ is infiltration zone, and $S$ is soil. The overlay results of five parameters are used as the basis for determining the zoning level of groundwater vulnerability in the karst area. The relationship between the $R$-value and the level of groundwater vulnerability is presented in Table 2.
Table 1. Rating of APLIS parameters

| Rating | Altitude (masl) | Slope (%) | Lithology | Infiltration Zone | Soil |
|--------|----------------|-----------|-----------|-------------------|------|
| 1      | ≤ 300          | >100      | Shales, silts, clays | Scarce Infiltration Landforms | Vertisols |
| 2      | 300 – 600      | 76 – 100  | Plutonic and metamorphic rocks | | Planosols |
| 3      | 600 – 900      | 46 – 76   | Conglomerates | | Chromic luvisols |
| 4      | 900 – 1200     | 31 – 46   | Gravels and sands | | Histosols and luvisols |
| 5      | 1200 – 1500    | 21 – 31   | Limestones and dolostones fissured | | Eutric cambisols |
| 6      | 1500 – 1800    | -         | Limestones and dolostones fissured | | Cambisols |
| 7      | 1800 – 2100    | 16 – 21   | Limestones and dolostones fractured, slighted karstified | | Eutric regosols and solonchak |
| 8      | 2100 – 2400    | 8 – 16    | Limestones and dolostones fractured, slighted karstified | | Calcareous regosols and fluvisols |
| 9      | 2400 – 2700    | 3 – 8     | Limestones and dolostones karstified | | Arenosols and xerosols |
| 10     | > 2700         | < 3       | Limestones and dolostones karstified | | Leptosols and lithosols |

Table 2. Value and level of groundwater vulnerability

| R-Value (%) | Vulnerability Level |
|-------------|---------------------|
| ≤ 20        | Very low            |
| > 20 – 40   | Low                 |
| > 40 – 60   | Medium              |
| > 60 – 80   | High                |
| > 80        | Very high           |

3. Result and Discussion
3.1. Parameter of APLIS analysis

Data analysis on each parameter is carried out based on a digital map by rating according to the classification [8], which will be overlaid to get the value of groundwater vulnerability. The rating was assigned to a different class of each APLIS parameter in Rote Island is presented in Table 3.

Analysis of altitude and slope is using a Digital Elevation Model (DEM) map. DEM data is processing into altitude classification of APLIS methods using GIS software. The elevation of the study area is at an altitude between -36 masl to 450 masl. The slope value of the study area ranged from 0% to 166.3%. Based on table 3, the classification for altitude parameters is divided into two classes. The elevation ≤ 300 masl has an area of groundwater vulnerability 95.8% of the research area, and the elevation of 30 – 600 masl has an area of 4.2% of the research area. The classification for slope parameters is divided into nine classes. The largest area is a slope value of 3% - 8% has an area of 463.551 km² or 37.58% of the research area. The analysis result shows that most of the regions in Rote Island are low land areas and flat topography.

Analysis of lithology is using a Regional Geological map. 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, Limestone, and Alluvium Deposits. The classification for lithology is divided into three classes. Based on the rock composition,
Aitutu Formation and Bobonaro Complex are included in the classification of shales, silts, and clays with an area of 353.375 km² or 28.65% of the research area. Noelle Formation and Alluvium Deposits are included in gravels and sand with an area of 93.437 km² or 7.58% of the research area. Limestone has the highest rating in lithology, with an area of 1113.125 km² or 90.25% of the research area. It is because Limestone has a much higher number of primary pores than sandstone. The infiltration zone is divided into two classes. Many infiltration landform classes are in the Bobonaro Complex and Limestone lithology area, with an area of 1113.125 km² or 90.25% of the research area. Meanwhile, the scarce infiltration landform classes are in the lithology of the Alluvium Deposits, Noelle Formation, and Aitutu Formation with an area of 105.750 km² or 8.57% research area.

Analysis of soil is using a soil type map. The soils control the concentrations of pollutants in the water and harmful effects caused by their permeability characteristics [17]. Soil type on Rote Island is only lithosols.

| Parameters         | Classification                  | Rating | Area (km²) | Area percentage (%) |
|--------------------|---------------------------------|--------|------------|---------------------|
| Altitude           | ≤ 300 masl                      | 1      | 1181.596   | 95.80%              |
|                    | 300 – 600 masl                  | 2      | 51.811     | 4.20%               |
|                    | > 100%                          | 1      | 0.125      | 0.01%               |
|                    | 76% – 100%                      | 2      | 0.312      | 0.03%               |
|                    | 46% – 76%                       | 3      | 3.250      | 0.26%               |
|                    | 31% – 46%                       | 4      | 12.500     | 1.01%               |
|                    | 21% – 31%                       | 5      | 70.248     | 5.70%               |
|                    | 16% – 21%                       | 7      | 98.748     | 8.01%               |
|                    | 8% – 16%                        | 8      | 339.679    | 27.54%              |
|                    | 3% – 8%                         | 9      | 463.551    | 37.58%              |
|                    | < 3%                            | 10     | 244.994    | 19.86%              |
| Lithology          | Shales, silts, clays            | 1      | 353.375    | 28.65%              |
|                    | Gravels and sands               | 4      | 93.437     | 7.58%               |
|                    | Limestones and dolostones       | 10     | 772.063    | 62.60%              |
|                    | karstified                      |        |            |                     |
| Infiltration Zone  | Scarce infiltration landforms   | 1      | 105.750    | 8.57%               |
|                    | Many infiltration landforms     | 10     | 1113.125   | 90.25%              |
| Soils              | Lithosols                       | 10     | 1233.407   | 100%                |

3.2. Groundwater Vulnerability

Groundwater vulnerability analysis using the APLIS method was processed using GIS software. The overlay map parameters for elevation, slope, lithology, infiltration zone, and soil type are input by Equation (1) into the raster calculation tools. The lithology and infiltration zone parameters in equation 1 are higher than the other three parameters [8]. It explains that the lithology and the infiltration zone parameters play an important role in determining groundwater vulnerability [18]. The results of the groundwater vulnerability analysis showed that there were four levels of groundwater vulnerability in Rote Island are presented in Table 4.

| R-Value (%) | Level of groundwater vulnerability | Area (km²) | Area percentage (%) |
|------------|-----------------------------------|------------|---------------------|
| ≤ 20       | Very low                          | 0.5        | 0.041%              |
| > 20 – 40  | Low                               | 103.938    | 8.427%              |
| > 40 – 60  | Moderate                          | 388.063    | 31.463%             |
| > 60 – 80  | High                              | 740.875    | 60.069%             |

Based on table 4, the high level is the most significant groundwater vulnerability area, distributed up to 740.875 km² or 60.069% in the East and West part of the research area. The moderate level area is 388.063 km² or 31.463%, mainly in the East and North part of the research area. The low-level area is
103.938 km² or 8.427% that primarily spread in the South of the research area. Meanwhile, the very low-level area is 0.5 km² or 0.041% in the Northeast of the research area. Areas with a high level of groundwater vulnerability should be designated as groundwater protection zones. The authenticity of the ecosystems in areas of high groundwater vulnerability must be maintained [19]. Human activities that impact groundwater pollution should be limited to areas with a high groundwater vulnerability, such as settlements, agriculture, fisheries, industry, mining, and tourism. In areas with low, very low, to moderate levels of groundwater vulnerability, the community can use groundwater for all types of activities. The thematic map parameters and groundwater vulnerability maps are presented in Figure 2.

![Thematic Map Parameters and Groundwater Vulnerability Map in Rote Island](image)

**Figure 2.** The thematic map parameters and groundwater vulnerability map in Rote Island

### 4. Conclusion

Rote Island has an area of 1,233,407 km². Based on the results of the analysis with the APLIS method, groundwater vulnerability in Rote Island was divided into four classes, namely very low (R-value ≤ 20), low (R-value> 20 - 40), moderate (R-value> 40 - 60), and high (R-value> 60 - 80). The high level is the most significant groundwater vulnerability area, distributed up to 740.875 km² or 60.069% in the East and West part of the research area. The moderate level area is 388.063 km² or 31.463%, mainly in the East and North part of the research area. The low-level area is 103.938 km² or 8.427% that primarily spread in the South of the research area. Meanwhile, the very low-level area is 0.5 km² or 0.041% in the Northeast of the research area. It explains that Rote Island's high groundwater vulnerability area needs to be used as a groundwater protection zone, especially in karst areas.

### References

[1] Veni G, DuChene H, Crawford N C, Groves C G, Huppert G N, Kastning E H, Olson R, and Wheeler B J 2001 *Living With Karst: a Fragile Foundation* (United States: American Geological Institute) p63

[2] Kusumayudha S B 2018 *Mengenal Hidrogeologi Karst (I)* (Yogyakarta: Penerbit Pohon Cahaya) p143

[3] Cahyadi A, Ayuningtyas E A, and Prabawa B A 2013 Urgensi pengelolaan sanitasi dalam upaya konservasi sumberdaya air di kawasan karst Gunungsewu Kabupaten Gunungkidul *Indonesian Journal of Conservation* 23–32

[4] Malawani M N, Cahyadi A, and Hartoyo F A 2014 Analisis kerentanan airtanah terhadap pencemaran sebagai salah satu dasar zonasi kawasan karst *Ekologi Lingkungan Karst Indonesia: Menjaga Asa Kelestarian Kawasan Karst Indonesia* (Yogyakarta: Deepublish) chapter 3 pp 23–26
Ahr W M 2008 Introduction Geology of carbonate reservoirs: the identification, description, and characterization of hydrocarbon reservoirs in carbonate rocks (New Jersey: John Willey &sons, INC) chapter 1 pp 1–12

János M, Klaudia K, Mária S, Andrea K B, András K, László M, Mónika K, and Veronika I 2013 Hazards and landscape changes (degradations) on Hungarian karst mountains due to natural and human effects Journal of Mountain Science 10 16–28

Fikri U, Jati D R, and Marsudi 2014 Pengaruh Pupuk Terhadap Kualitas Air Tanah Di Lahan Pertanian Kawasan Rasau Jaya III, Kab. Kubu Raya Jurnal Teknologi Lingkungan Lahan Basah 2 1–10

Andreo B, Viás J, Durán J J, Jiménez P, López-Geta J A, and Carrasco F 2008 Methodology for groundwater recharge assessment in carbonate aquifers: Application to pilot sites in southern Spain Hydrogeology Journal 16 911–925

Farfán H, Corvea JL, and de Bustamante I 2010 Sensitivity Analysis of APLIS Method to Compute Spatial Variability of Karst Aquifers Recharge at the National Park of Viñales (Cuba) Advances in Research in Karst Media (Berlin: Springer Berlin Heidelberg) chapter 3 pp 19–24

Linggasari S, Cahyadi T A, and Ernawati R 2019 Overview Metode Perhitungan Kerentanan Airtanah Terhadap Rencana Penambangan Prosiding Nasional Rekayasa Teknologi Industri dan Informasi XIV vol 1451

Widiastuti A P 2012 Zonasi Kerentanan Airtanah Bebas terhadap Pencemaran dengan Metode APLIS di Kecamatan Wonosari Kabupaten Gunungkidul Jurnal Bumi Indonesia 1 38–46

Zagana E, Tserolas P, Floros G, Katsanou K, and Andreo B 2011 First outcomes from groundwater recharge estimation in evaporate aquifer in Greece with the use of APLIS method Advances in the Research of Aquatic Environment 22003–04

United States Geological Survey 2014 Digital elevation SRTM 1 arc-second global 1:30.000 p1 https://earthexplorer.usgs.gov/ (accessed April 2021)

Badan Informasi Geospasial 2021 Peta Rupa Bumi Indonesia p1 https://tanahair.indonesia.go.id/portal-web/download/perwilayah (accessed January 2021).

Rosidi H M, Gafoer S, and Tjokrosapoetra S 1996 Peta Geologi Lembar Kupang – Atambua, Timor 1:250.000 p1

Food and Agriculture Organization of the United Nations 2019 Digital soil map of the world – ESRI shapefile format https://data.apps.fao.org/map/catalog/srv/eng/catalog.search?id=14116 #/metadata/446ed430-8383-11db-b9b2-000d939bc5d8 (accessed April 2021)

Fernandes L F S, Cardoso L V R Q, Pacheco F A L, Leitão S, and Moura J P 2014 DRASTIC and GOD vulnerability maps of the Cabril River Basin, Portugal Revista Escola de Minas 67 133–142

Duran Z, Doğru A G, and Toz G 2004 Web-based mul- timedia GIS for historical sites XXth ISPRS Congress Technical Commision V vol 35 434–437

Adji T N, Haryono E, and Woro S 1999 Kawasan Karst Dan Prospek Pengembangannya INARxiv

Acknowledgments
The authors sincerely acknowledge the Department of Geological and Environmental Engineering at Gadjah Mada University, which has provided the opportunity to do research and also to the Ministry of Public Works and Public Housing for their generous support in presenting data.