Vol. 5, No. 1, January 2023: 42-50

Jambura Geoscience Review

p-ISSN 2623-0682 | e-ISSN 2656-0380
Department of Earth Science and Technology, Universitas Negeri Gorontalo

Earthquake Hazard Analysis in Ciletuh Pelabuhan Ratu Geopark Area, West Java

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ARTICLE INFO

Article history:
Received: 7 June 2022
Accepted: 9 January 2023
Published: 25 January 2023

Keywords:
Earthquakes; Geographic Information Systems; Hazard Level; Lineament

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ABSTRACT

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Indonesia is situated between Asia and Australia, as well as the Indian and Pacific Oceans. This circumstance places Indonesia in a geologically complicated pattern, which increases the intensity of earthquakes, tsunamis, volcanoes, and landslides. UNESCO has classified Pelabuhanratu Ciletuh Geopark as a world heritage area. This has resulted in an explosion in tourist and development activity. Even though this tourism destination has the potential for high seismicity, there has been no analysis of the seismic hazard in this region. This study aims to map the earthquake hazard in the Ciletuh Pelabuhan Ratu Geopark Area. This will be important for determining vital assets' placement and development planning. This study employs remote sensing studies and geographic information systems to examine and classify earthquake-prone locations. We evaluated data from DEM, RBI, and soil-type maps. This method evaluates each earthquake hazard metric using the Analytical Hierarchy Process (AHP). The large research area has a slope between $0-30^{0}$. Few locations have steep slopes. In the Districts of Cisolok, Cikakak, and portions of Pelabuhan Ratu, the characteristics of the huge hard rock are derived from the Quaternary volcanic deposits of Mount Endut. As a result, this region possesses a solid rock structure that can absorb an earthquake propagation wave. This dynamic process of geomorphological creation can also demonstrate that the region surrounding the lineage will feel the effects of a future earthquake. The results show that Ciemas, Simpenan, parts of Cisolok, and Pelabuhanratu districts are included in the moderate to high category of earthquake threats.

How to cite: Ar-rouf, F. B., & Masitoh, F. (2023). Earthquake Hazard Analysis in Ciletuh Pelabuhan Ratu Geopark Area, West Java. *Jambura Geoscience Review, 5*(1), 42-50. doi:https://doi.org/10.34312/jgeosrev.v5i1.14698

1. INTRODUCTION

Indonesia is an archipelagic country geographically located between two continents, Asia and Australia, and two oceans, the Indian and Pacific Oceans. Geotechnically, Indonesia is a meeting place for active plates in the world. This condition results in patterns of geological structures that can have impacts such as earthquakes, tsunamis, volcanic eruptions, ground motions, and other destructive geology (Hendrasto et al., 2014). Therefore disaster mitigation efforts, especially earthquakes, need to be done because, statistically, earthquakes are disasters that often occur. The latest is the incident in Cianjur on November 21, 2022, with records of victim reports from BNPB dated 12/12/2022 totaling 335 people and also the latest information from the Cianjur Regent, which stated that victims reached 600 more people who were obtained by the recording system by name, by address, issued from the death certificate of the village government (Detik, 2022). As reported by the BNPB Report as of December 7, 2022, damaged buildings included 12,956 heavily damaged houses, 15,196 moderately damaged houses, 25,256 lightly damaged houses, 540 schools, 272 places of worship, and 18 health facilities. By looking at the earthquake incident in Cianjur, which resulted in hundreds of casualties and material and immaterial losses, it is necessary to create an earthquake hazard map in areas prone to earthquake hazards, so that hazard reduction can be carried out as early as possible.

Earthquakes are vibrations or shocks that occur on the earth's surface due to the sudden release of energy from within, which creates seismic waves. In preparing for the mitigation, several steps have been prepared. From collecting data on geological conditions, geophysics, history, and seismic activity preparing disaster vulnerabilities, compiling earthquake hazard maps, and structural and non-structural mitigation measures (Agung et al., 2021). Examples of structural mitigation are physical efforts to reduce the impact of disaster events, such as infrastructure development and the use of technology. While non-structural actions are actions related to policy, and knowledge development, including increasing community capacity against disasters (Rahman, 2015)

The earthquake caused damage to infrastructure buildings and casualties. Efforts in earthquake prediction have progressed, especially regarding long-term hazard analysis of an area to support emergency management and hazard preparedness. Earthquake vulnerability is related to several factors, such as lithology, typology of building structures, population, and earthquake intensity (D'Urso et al., 2018)

Ciletuh Geopark area in the BMKG report (Meteorology, Climatology and Geophysics Agency) often experiences earthquakes. There have been reports from the BMKG website (https://www.bmkg.go.id/tag/?tag=gempabumi&lang=ID) regarding the Isoseismal map several times that earthquake vibrations were felt in the Ciletuh Pelabuhan Ratu Geopark area from 2017-2022. From the earthquake's depth intensity and the magnitude scale's size, it can be identified as ranging from 3.3 to 6.9 Mw (BMKG, 2022), indicating that it has a relatively large scale. In addition, shallow earthquake source epicenters will be able to have a large impact on buildings. Therefore, this study aims to map the earthquake hazard in the Ciletuh Pelabuhan Ratu Geopark Area. This is so that the development of tourism destinations will not be misdesigned and losses and casualties can be reduced to a minimum when an earthquake occurs.

2. METHOD

2.1. Research Location

The research area is located in the Ciletuh Pelabuhan Ratu Geopark area, which UNESCO has designated as a world heritage (Tempo.co, 2018). This area includes the Districts of Cisolok, Cikakak, Pelabuhan Ratu, Simpenan, Ciemas, Waluran, Ciracap, and Surade (Figure 1a).

2.2. Data Sources and Tools

The data used in this study include 1) Digital Elevation Model (DEM) data from DEMNAS Ina-Geoportal (2022) (https://tanahair.indonesia.go.id/demnas/#/); 2) Base Map of Indonesian Rupa Bumi Sukabumi Regency sourced from BIG (2022), other data used are rock and fault types with shp format data (Badan Geologi ESDM https://geologi.esdm.go.id/geomap/index.php/); 3) Soil Type Map sourced from Food and Agriculture Organization (FAO, 2022). The software used in this study uses the ArcGIS Desktop 10.8 application.

2.3. Data Processing

Data processing in this study is shown in Figure 1b. The initial stage of data management in Geographic Information System software is determining the boundaries of research locations (Figure 1a). Three data sources are used: DEM (Digital Elevation Model) data in raster data, Indonesian Topographical Maps (RBI), and Soil Type Maps in the vector data category. Analysis of DEM data into slope data is processed with ArcGIS software. This method describes the surface topography in three dimensions to show the natural landscape. DEM can be a source of photogrammetric mapping analysis and contour digitization. DEM data is divided into three types: Grid, TIN, and contour (Bi et al., 2006). The application of slope-making analysis can be seen in Figure 2a.

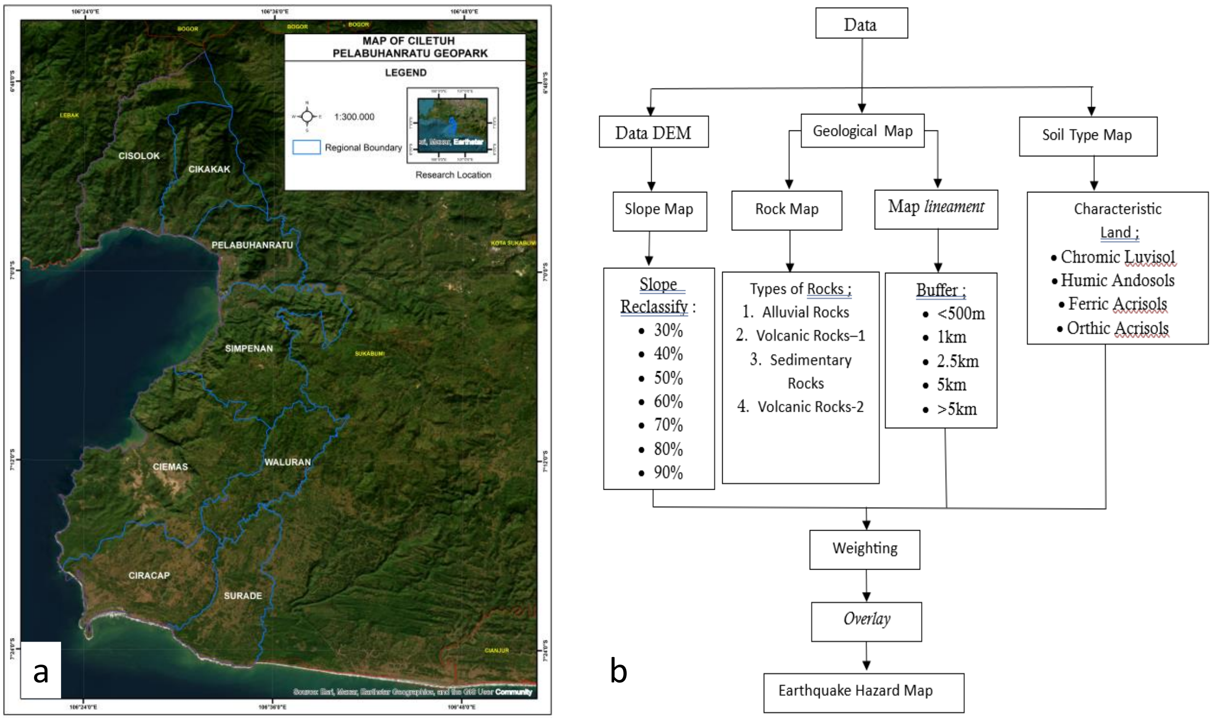

Figure 1. a) Research location map; b) Data processing flow chart.

After the DEM data becomes slope data, Reclassify is performed. This method is used to classify slopes with a degree of slope. The empirical method for analyzing slope stability starts with an angle of 30^0. This is to determine the connection between slope height and slope angle, whether stable or not (Parra et al., 2018). Vector data from geological maps are used for rock characterization and buffering on lineaments, and soil-type maps are carried out for characteristics. Source data from geological data, DEM, and soil types that have been processed are given a weighting characteristic based on Table 1. Vector data in each map has its weight to determine dangerous areas for earthquakes, so the weighted overlay method (WOM) is used in Arc GIS Desktop Spatial Analyst tools (Shit et al., 2016). By processing this stage, earthquake hazard map data is obtained.

3. RESULT AND DISCUSSION

Processing map data for creating an earthquake hazard map for the Ciletuh Geopark area consists of four types of map data. Both raster data in the form of DEM, vector data from RBI, and soil type maps. In data processing, all maps use the same resolution. This is because all the initial data comes from satellite imagery with a spatial resolution of 1:100.000 (Arifin dan Hidayat, 2014).

3.1. Slope Map

The slope angle owned by a slope will affect the stability of the hill. The slope angle $<30^0$ will be more stable, whereas $>70^0$ will tend to be unstable if the slope height is less than 200 m (Agustawijaya, 2019). Therefore, making slopes starts from a slope angle of 30^0-90^0. The results of data processing can be seen in Figure 2a. The large study area has a slope of 0^0-30^0. Only some places have high slopes, especially in the Cisolok, Cikakak, Pelabuhan Ratu, Simpenan, and parts of the Ciemas area. Attribute data from Figure 2a shows that the slope size of 0^0-30^0 is 937 km^2, 30^0-40^0 is 112 km^2, 40^0-50^0 is 73 km^2, 50^0-60^0 is 44 km^2, 60^0-70^0 is 24 km^2, 70^0-80^0 is 12 km^2, 80^0-90^0 with an area of 10 km^2.

3.2. Rock Characteristic Map

Information about rocks is needed for foundation soil, adjustment of building models, basic materials for industry, and others. Information on rock characteristics with massive hard rock types shows low susceptibility. Because the rock groups are relatively compact, they are more

Table 1. Earthquake hazard assessment parameters

Map type	Characteristics	Weight
Soil	Solid Sand	2
Source: FAO	Cohesive Sand	3
	Loose Sand	4
	Solid Clay	4
	Soft Clay	5
Rock	Massive Hard Rock	2
Source: Geological Map	Discontinuous Hard Rock	3
	Massive Soft Rock	3
	Crushed Hard Rock	4
	Discontinuous Soft Rock	4
	Dense Granular Soft Rock	4
	Loose Granular Soft Rock	5
Distance from Fault	> 5km	1
Source: Geological Map	2.5km – 5km	2
	1km – 2.5km	3
	500m - 1km	4
	< 500m	5
Slope	30%	1
Source: DEM	40%	2
	50%	3
	60%	4
	70%	5
	80%	6
	90%	7

Source: Agustawijaya (2019)

Table 2. Rock types classification

No	Rock Type	Score
1	Alluvial Rocks (Qav, Qa, a)	1
2	Volcanic Rock-1 (Qvsl, Qvu, Qvep, Qvpo, Qvk, Qvba)	2
3	Sedimentary Rock-1 (Tmn, Tmj)	3
4	Volcanic Material-2 (Qvsb, Qpv, Qvst, Qvb, Qvt, Qvl) and Sediment-2 Material (Tmb, Tmbl, Tmtb)	4

Source: Departemen Pertanian (2006)

stable against a slope that allows landslides to occur due to earthquakes (Desmonda & Adjie, 2014). This study's spatial classification of rocks can be seen in Figure 2b. The classification of rock types with scoring based on Departemen Pertanian (2006) can be seen in Table 2.

Attribute data information in Figure 2b shows a description of the rock coverage of the Ciletuh Geopark area covering 273 km^2 of massive hard rock, 75 km^2 of discontinuous hard rock/massive soft rock, 637 km^2 of crushed hard rock/discontinuous hard rock/solid granular soft rock, and 231 km^2 of loose granular soft rock. In the districts of Cisolok, Cikakak, and parts of Pelabuhan Ratu, massive hard rock characters originate from the volcanic deposits of Mount Endut during the Quaternary age. The impact is that this area has a strong rock structure that can dampen if an earthquake propagation wave hits it. In contrast, the Ciemas area is classified as a loose granular rock due to Alluvium deposits in the Quaternary era. These deposits are the same as the earthquake that occurred in Cianjur, in which if at any time it is hit by the propagation of earthquake waves, the effect of the damage to buildings is bigger.

3.3. Lineament Map

One of the dangers of earthquakes can be described in terms of the probability of an event occurring within a certain period. Earthquake-prone areas can be assessed and predicted through

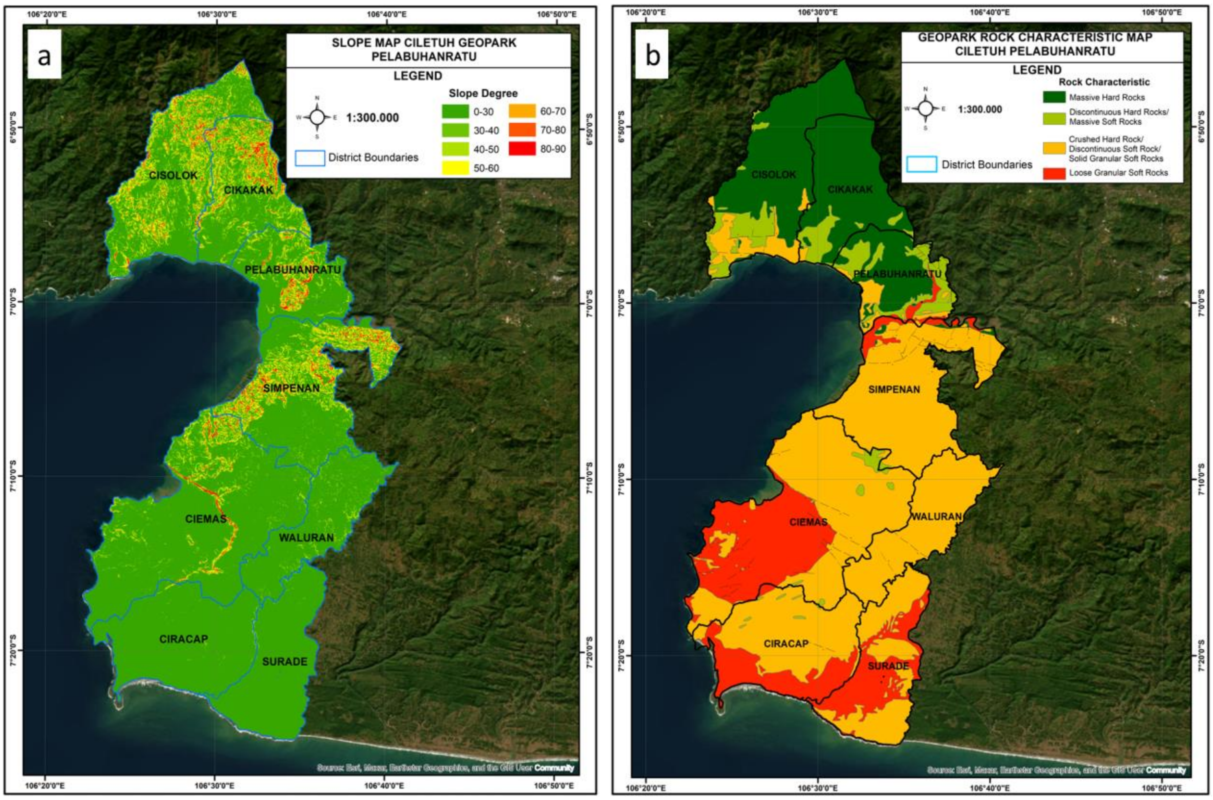

Figure 2. a) Slope map; b) Map of rock characteristics, Ciletuh Pelabuhan Ratu Geopark Area.

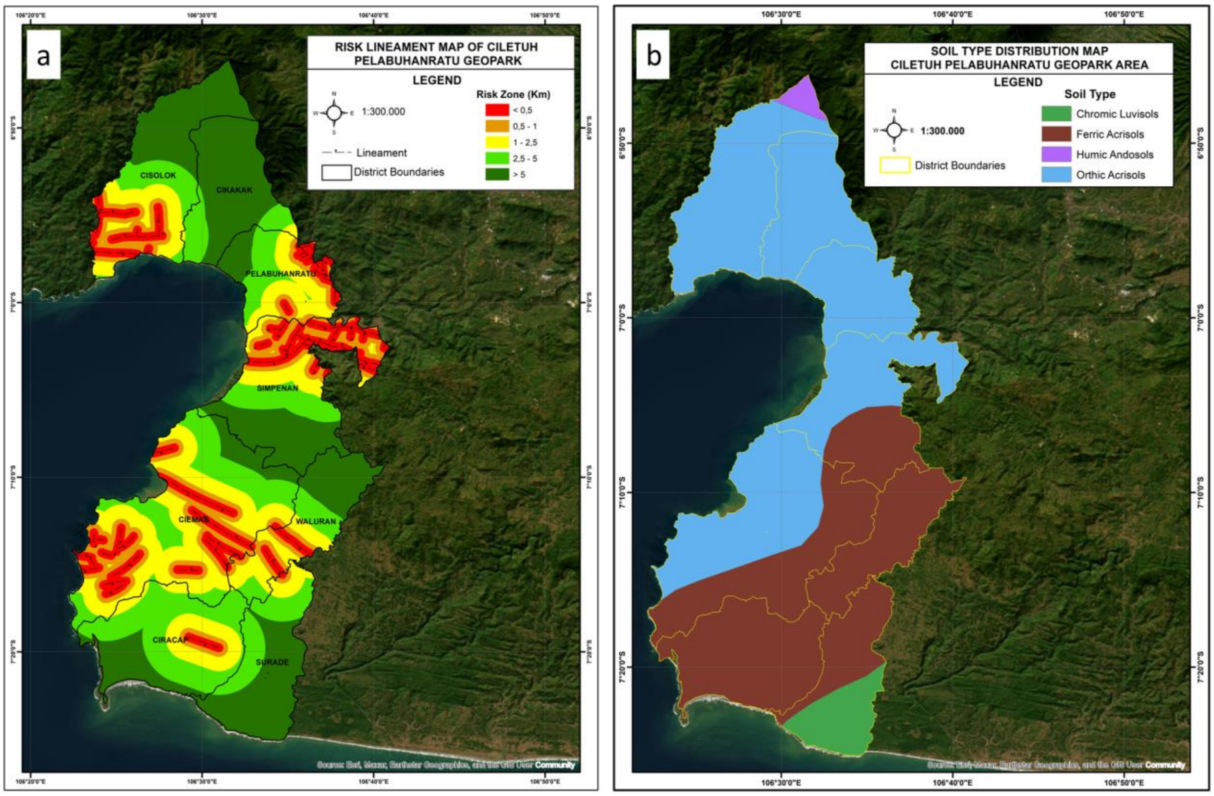

Figure 3. a) Fault hazard zone map; b) Map of the distribution of soil types.

scientific analysis of earthquake hazard maps to reduce damage. To achieve this goal, remote sensing and Geographic Information Systems are used to determine existing fault activity because earthquakes can propagate and cause this activity. Earthquake hazard to fault activity is divided into five earthquake hazard zones as follows;

1. The very high danger zone with a distance of less than 500 m from the fault
2. High hazard zone, for areas with a distance of 500 m – 1 km from the fault
3. Moderate danger zone, for an area of 1 km – 2.5 km from the fault
4. Medium-low hazard zone for areas with a distance of 2.5 km – 5 km from the fault and,
5. Low hazard zone for areas above 5 km from the fault (Sharifikia, 2010).

Based on the distribution of earthquake hazard zones to faults, processing uses the buffer method, which can be described spatially in the study area in Figure 3a. Processing the buffer in the lineament shows that the Ciletuh Pelabuhan Ratu Geopark area is active in developing tectonic geomorphology caused by endogenous forces. This can be shown by the number of rock fractures formed in the Districts of Ciemas, Simpenan, Pelabuhan Ratu, and Cisolok. The active process of forming this geomorphology can also indicate that if an earthquake hits at any time, the area around the lineament will feel the impact. The Ciletuh Pelabuhan Ratu Geopark area has an active fault, namely the Cimandiri Fault, which extends from Pelabuhan Ratu Bay to Padalarang District, West Bandung Regency. These faults are often active and cause damage and casualties (Indriyanti., 2019)

3.4. Soil Type Characteristics Map

Soil results from weathering consisting of rock fragments, mineral grains, organic matter, and water. According to their occurrence, there are two main types of soil: residual soil and transported soil. Both can cover bedrock, either thin or thick. Residual soils are formed from the weathering of local bedrock and have not been moved far enough. Meanwhile, transported land is land from being moved from another place using water, wind, ice, or gravity media such as sedimentary rock, flood deposits, and lava deposits (Agustawijaya, 2019). From the data presented by FAO on land distribution, the Ciletuh Pelabuhan Ratu Geopark area has four types of soil which can be seen in Figure 3b.

The data provided by FAO can provide information about the type of soil in the study area. This way, the known soil types can be classified and described in Table 1. For example, andosol soils are characterized by having a cross-section that is growing, thick, loose, and rich in organic matter, physical properties sensitive to erosion, and rocks of origin from andesite tuff and dacite.

Table 3. Weight calculation of earthquake hazards

Map type	Characteristic	Weight
Slope	0^0-30^0	1
	30^0-40^0	2
	40^0-50^0	3
	50^0-60^0	4
	60^0-70^0	5
	70^0-80^0	6
	80^0-90^0	7
Rock	Massive Hard Rock	1
	Massive Discontinuous/Soft Rocks	2
	Crushed Hard Rock/Discontinuous Soft Rock/Dense Granular Soft Rock	3
	Loose Granular Soft Rock	4
Distance from fault	Low	1
	Medium Low	2
	Currently	3
	Tall	4
	Very high	5
Soil type map	Humic Andosols	2
	Chromic Luvisols	3
	Ferric Acrisols	5
	Orthic Acrisols	5

After describing the physical properties, it can be categorized as what type of soil weighs the threat of an earthquake.

3.5. Earthquake Hazard

An earthquake is a vibration felt on the surface due to the collision of tectonic plates or volcanic eruptions. Tectonically, Indonesia is an unstable country due to three tectonic plates colliding with each other. The magnitude of the earthquake potential in the earthquake hazard analysis consists of elements of soil, rock, faults, and geomorphology. In this study, the map parameters must be weighted first based on Table 1 using the overlay method to make an earthquake hazard map. The characteristic weighting table can be seen in Table 3.

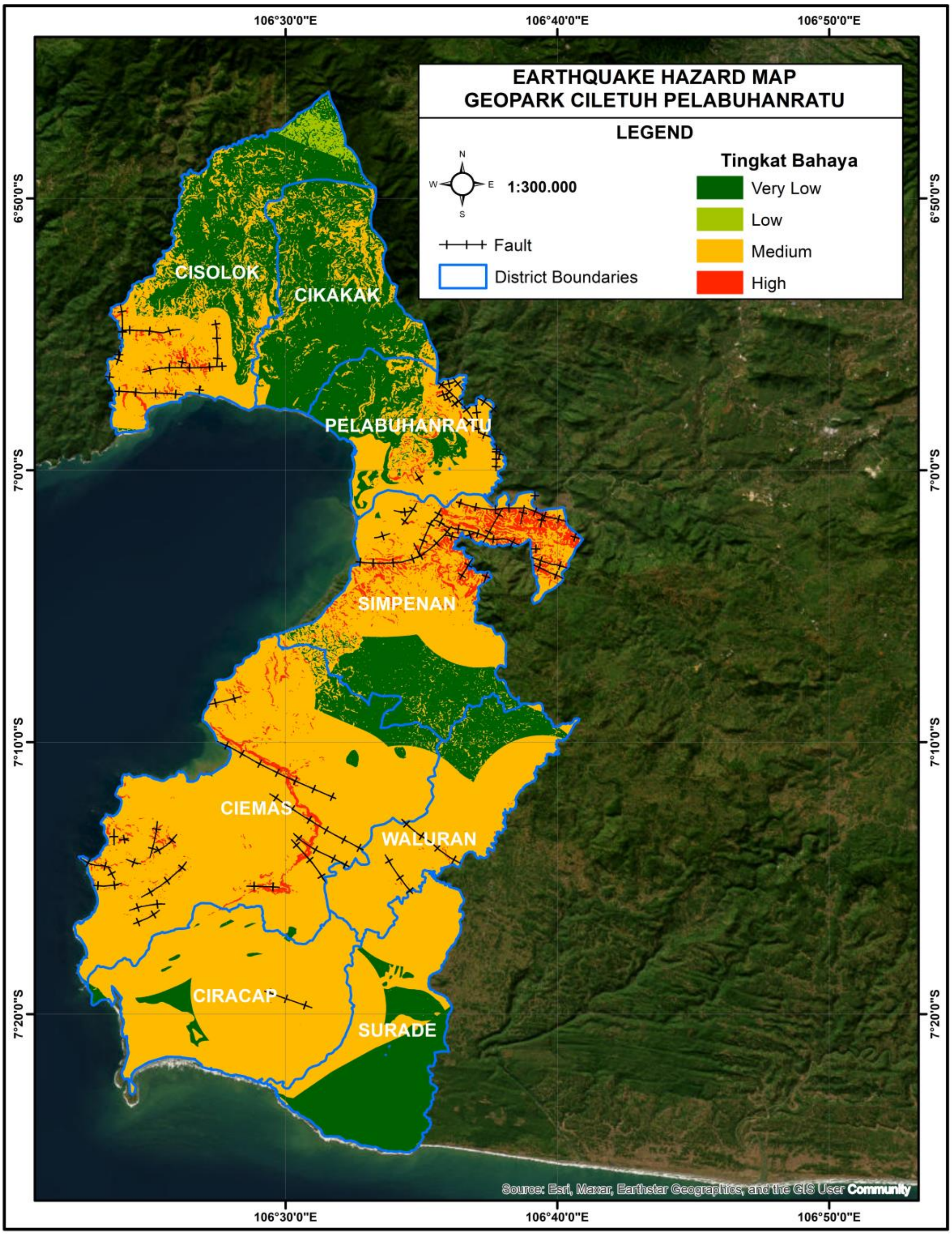

Figure 4. Earthquake Hazard Map of Ciletuh Pelabuhan Ratu Geopark Area

The weighting is based on Table 3 in the ArcGIS software with the help of the intersect tool to help determine the possibility of areas that are prone to earthquake hazards. Earthquake hazard analysis in the Ciletuh Pelabuhan Ratu Geopark area based on four influencing aspects can be seen in Figure 4. Based on the processing of earthquake hazard analysis shows the distribution of which areas are included in earthquake hazards. The analysis results show that the earthquake hazard level is high in Ciemas, Simpenan, and parts of the Cisolok and Pelabuhan Ratu areas. This area has a high earthquake hazard because it has a large slope of 70-90 degrees, soft relief, and easily detached soil types.

In areas that are included in the category of earthquake hazard, disaster mitigation can be carried out by adjusting the parameters of the hazard level. Figure 4 provides information on the high earthquake hazard level dominated and associated with fault structures. So the Districts of Cisolok, Simpenan, and Ciemas must be a priority in mitigating the danger of future earthquakes. Data from earthquake hazards can be forwarded into new research to estimate vulnerability to the number of people affected based on the hazard class. To support this data, new data on population and buildings are needed (Nyimbili et al., 2018).

4. CONCLUSION

The results of the Earthquake hazard analysis in the Ciletuh Pelabuhan Ratu Geopark area show that Simpenan, Ciemas, and parts of the Cisolok area have a moderate to high hazard of the threat of an earthquake. The impact is that if at any time an earthquake occurs, this area can potentially experience damage. So in the future, it is necessary to carry out programs to reduce the danger of earthquakes, such as designing earthquake-resistant buildings, conducting socialization of disaster mitigation to the community, etc.

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