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Delineation Of Vulnerable Areas Affected By The Eruption Of Mount Agung, Bali

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ABSTRACT
Vulnerability is a condition of a community or society that causes the inability to face the threat of disaster. Geographic information systems (GIS) have become essential tools in evaluating natural hazards and risks which is an aspect to define vulnerability of the volcano eruption-affected area. Based on activity of volcano, it is necessary to delineate the vulnerability of areas affected by the eruption of Mount Agung by integrating the Mount Agung Area Network Map and Geological Map with physical vulnerability data and social vulnerability. This research using processing methods and spatial analysis of Geographic Information Systems (GIS) and remote sensing methods. Geographic Information System (GIS) is used to create vulnerability maps using scoring, weighting, and overlay methods. The data used for making the vulnerability map include administrative boundaries, DEM (Digital Elevation Model), secondary data from the BPS 2020 Karangasem Regencyt in Figures, geological maps, settlement data and land cover maps. The results based on these data show the number of areas affected by the eruption of Mount Agung, the data states that the data area with low vulnerability has an area of 0.001490 Ha. Medium vulnerability data has an eruption affected area of 47.024493897 Ha. While the high vulnerability has an affected area of 36.878843877 Ha. Differences in the level of vulnerability are influenced by social vulnerability, physical vulnerability, and environmental vulnerability.

INTRODUCTION

Vulnerability is a condition of a community or society that causes the inability to face the threat of disaster (Sauda and Nugraha, 2019). The definition of a vulnerability map is a picture or data representation of an area or place that shows the condition of the area that presents certain vulnerabilities in terms of livelihoods and lives that may result in disaster risk (Wacana, 2011). Geographic information systems (GIS) have become essential tools in evaluating natural hazards and risks which is an aspect to define vulnerability of the volcano eruption-affected area. In the realm of volcanic hazard analysis, GIS has been widely used to create models and maps of the geographical spread of diverse volcanic hazards and evaluate the susceptibility of different vulnerable elements (Alcorn et al., 2013). Many aspects affect the level of vulnerability of an area be it physical, social, economic and environmental. This aspect has been regulated in Perka BNPB number 2 of 2012 concerning General Guidelines for Disaster Risk Assessment (Badan Nasional Penanggulangan Bencana, 2012).

Assessing the risk of an entity facing a hazardous event relies on the fundamental concept of vulnerability, which distinguishes between a solitary physical occurrence and a natural disaster. Vulnerabilities may be subject to alterations and can be influenced by different physical, social, economic, and environmental factors (Reyes-Hardy et al., 2021). Social vulnerability pertains to the possibility of suffering negative consequences due to particular circumstances related to individuals such as their age, gender, education, financial situation, or other conditions that may place them in a precarious state (Hizbaron et al., 2018). Social vulnerability refers to the various factors and characteristics of individuals or groups that affect their capacity to foresee, deal with, withstand, and recuperate from the consequences of a disaster (Fatemi et al., 2017). Social Vulnerability includes the level of Population Density and other social parameters. The population density also affects an area's vulnerability level in the face of disasters. A higher level of population density has a higher level of vulnerability when compared to areas that have a low population density (Tamburaka, 2019). Physical vulnerability is defined as a physical structural property that determines the potential for damage to disasters (type of material and quality of building) (Ebert et al., 2009). Environmental Vulnerability relates to land cover. Land cover is a manifestation of human intervention in the environment. Types of land cover have different responses to volcanic eruption disasters. Forests will tend to have little vulnerability compared to settlements. This is because forests can retain materials from volcanic eruptions, while settlements and rice fields will tend to pass materials from volcanic eruptions. In addition to land cover, rock geology areas also affect the vulnerability of volcanoes (Ardi and Sumunar, 2017).

Indonesia is situated in the Pacific Ring of Fire, which is known for its high levels of seismic and volcanic activity resulting from the convergence of tectonic plates. Consequently, Indonesia has hundreds of active volcanoes, including some of the most difficult and active ones globally. According to the Magma Indonesia application, there are currently 65 active volcanoes being monitored in Indonesia. These volcanoes are categorized into four levels based on their activity level and potential danger. Of the 65 volcanoes monitored, 45 are currently at level 1, which indicates normal or background activity. 15 volcanoes are at level 2, indicating increased potential for eruption; four volcanoes are at level 3, indicating significant turmoil and potential danger; and the volcano is at level 4, indicating ongoing eruptions and major danger impacting the area's surroundings. (Haeriah, et al. 2018). It is essential to note that the level of volcanic activity can change rapidly and unpredictably, and the information provided by Magma Indonesia is intended to help authorities and communities prepare for potential volcanic hazards. If you are in an area affected by volcanic activity, it is crucial to follow official advice and stay informed of the latest developments (Malawani et al., 2020). In addition, there is Mount Agung well known as the highest mountain on the island of Bali with an altitude of 3,142 meters above sea level. This mountain is located in Karangasem Regency, Bali, Indonesia. Mount Agung is a stratovolcano-type volcano. A stratovolcano is a high cone-shaped mountain (volcano) made of hardened lava and volcanic ash; it is often covered in glaciers and tends to erupt violently (Arifiasari, 2018). Although the eruption type of stratovolcanoes can vary, they typically generate explosive eruptions that involve a combination of pyroclastic materials and lava flows. These explosive events can vary in severity, from minor to extremely catastrophic. The volcano emits significant amounts of volcanic ash, rocks, and gases during explosive eruptions, threatening nearby communities due to potential structural damage and health hazards. While stratovolcanoes may also produce effusive eruptions characterized by a gentle lava flow, they can still cause damage to infrastructure and communities in the surrounding area (Kushendratno et al., 2012). (Karátson et al., 2010) conducted research on stratovolcanoes to determine their dominant eruptive style. They utilized a morphometric analysis method and concluded that the shape of a volcanic cone's upper half can indicate the likelihood of specific types of eruptions. Specifically, stratovolcanoes with a concave upper half are more likely to experience gentle, effusive eruptions and less likely to experience explosive eruptions that can cause flanking damage.

Based on this, it is necessary to delineate the vulnerability of areas affected by the eruption of Mount Agung by integrating the Mount Agung Area Network and Geological Map with physical vulnerability data and social vulnerability. The expected result is a vulnerability map that has classified the zones of the affected areas, both low vulnerability, medium vulnerability, and high vulnerability so that it can be a reference for mitigation and spatial planning for sustainable development. Authorities can identify the regions that need to be prioritized for disaster risk reduction and emergency response planning by evaluating the vulnerability of areas affected by the eruption of Mount Agung. This assessment may include creating evacuation plans, setting up early warning systems, and constructing stronger infrastructure. The main objective is to use the information gathered from studying the eruption's impact to determine where to focus resources for preventing future disasters.

There are many research studies about vulnerability disasters, and many methods can be used for that. For example, there are Quantile classification method (Reyes-Hardy et al., 2021), scoring-overlay method (Ardi & Sumunar, 2017; Rani & Khotimah, 2021; Rohmadiani & Subekti, 2020), also scoring and weighting overlay method (Akbar et al., 2020; Dame et al., 2019; Darmawan et al., 2020; Maulana et al., 2017; Ramadhan et al., 2018). The scoring and weighting overlay method is commonly used in many research studies, and each of them has a different way of weighing. According to (Pasaribu et al., 2023), AHP (Analytic Hierarchy Process) can be used for decision-making to determine the criteria and their weighting in assessing the potential for disaster. According to (Darmawan et al., 2020), Composite Mapping Analysis (CMA) can be used in weighting to model the vulnerability map. However, in this research, the authors use scoring and weighting based on the Perka (Head Regulation) BNPB number 12 of 2012, which is the regulation from the government that regulates Disaster Mitigation in Indonesia, same as the research by (Dame et al., 2019). The vulnerability aspects used to determine the level of vulnerability are physical vulnerability, social vulnerability, economic vulnerability and environmental vulnerability.

This research also uses the 3D modelling or 3D analyst method (Rafli, 2021; Riyadi & Harjo, 2016) to visualize the result in a 3D map. Many software and reference data have height information that can be used to transform the 2D data into 3D data. According to (Riyadi & Harjo, 2016), they use GPS data to use Google Sketchup 10.1 and ArcScene 2015 software. However, in this research, the authors only used DEMNAS data as data with high information. DEMNAS data combined with the 2D results to transform it into 3D, and the software used to do the 3D modelling is ArcScene, similar to the research by (Rafli, 2021).

RESEARCH METHODS

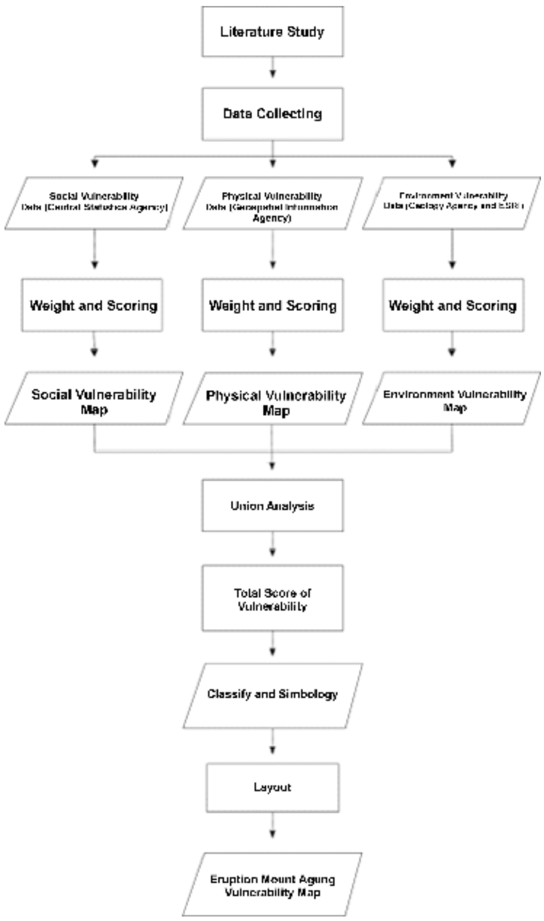

Figure 1. Data Processing Diagram

(Figure 1) is a diagram of the data process in this study. On making this map using processing methods and spatial analysis of GIS and remote sensing methods. GIS is used to create vulnerability maps using scoring, weighting, and overlay methods. Scoring and weighting use a combination of Microsoft Excel and ArcGIS software: ArcMap. 3D map creation was made using ArcGIS software: ArcScene. The data used for making the vulnerability map include primary data on the population density of Karangasem District of 2020 (Central Statistics Agency Karangasem Regency), administrative boundaries (Geospatial Information Agency of Indonesia), DEMNAS (Geospatial Information Agency of Indonesia), the secondary data from the geological maps (Indonesian Geological Agency), settlement data (Geospatial Information Agency of Indonesia) and land cover maps (Environmental Systems Research Institute).

RESULTS AND DISCUSSION

Mount Agung Area Network Map, Karangasem Regency, Bali Province

The data processing for this network map includes DEMNAS (National DEM), RBI Map of Karangasem Regency, and Administrative Map. The data is processed to become a network map. The stages of network map data processing are as follows: starting from DEMNAS data, which is processed by doing a data clipping process that is adjusted to the shape of the boundary of the study area (in this case, Karangasem Regency).

Then, the next processing is inputting RBI Map data Karangasem Regency; the data inputted in this processing is road data and river data, where road and river data is information on road and river networks in the area. In the administrative map data processing, data input is carried out, the input data is the boundary data of Karangasem Regency. Then, after all the resulting data has been processed, the next step is to create a map layout, considering the standard cartographic rules. So that the output of the Mount Agung Area Network Map, Karangasem Regency, Bali Province, can be produced (Figure 2).

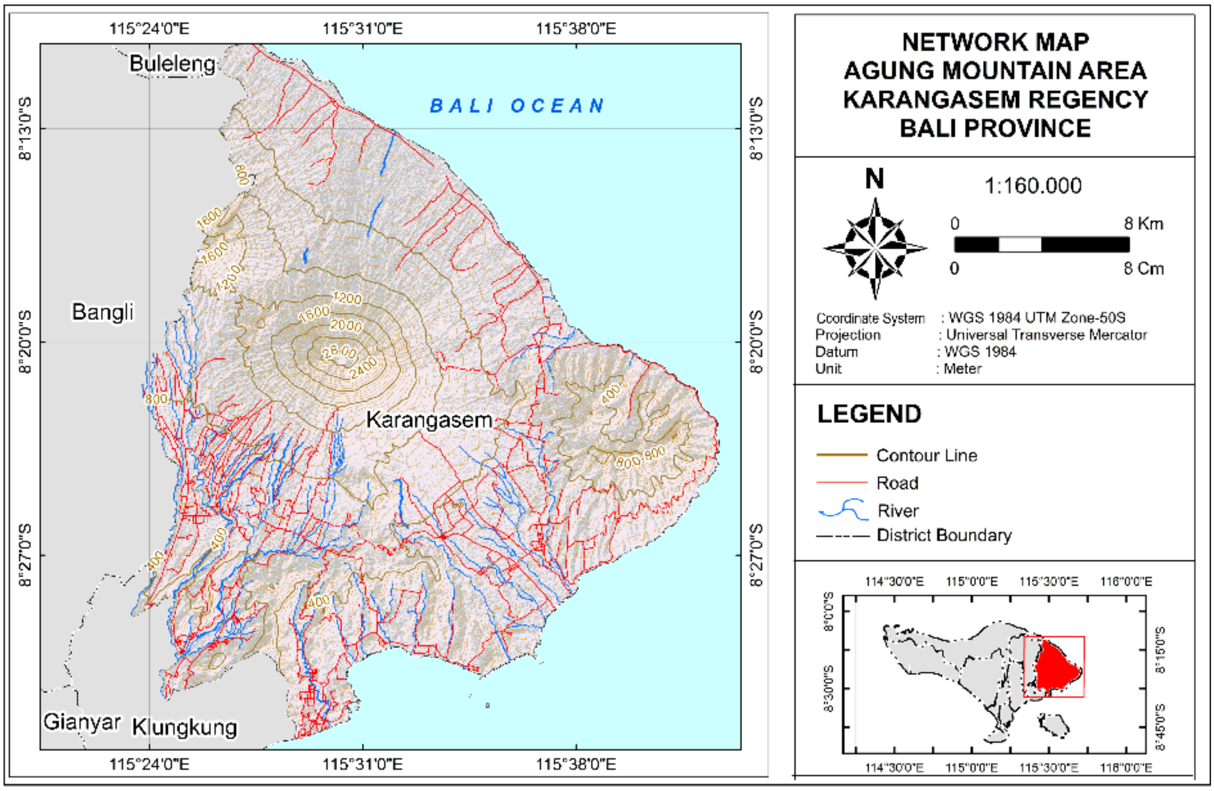

Figure 2. Map of the Mount Agung Area Network

2D Geological Maps

The initial process in manufacturing is to collect the necessary data and then input the data. At the DEMNAS data processing stage, the data goes through a clipping process according to the boundaries of the area under study. After that, a spatial analysis forms a hillshade layer to display surface shadow information.

Then, other data will be inputted, such as the RBI Map data of Karangasem Regency, by entering the road and river shapefile data that has been sorted first. Inputting the Administrative Map by entering the regency boundaries. The next stage is to input existing geological data as a reference in digitizing, which then classifies the geological data that has been digitized again. The next stage is to symbolize both hillshade data, rivers, roads, sub-district boundaries, and also digitized geological data.

Then, the data that has been symbolized and colored is to do scoring and weighting, scoring geological data, by looking at what formations are there and looking at the distance of the geological area to the object of Mount Agung dominated by quaternary-aged rocks. The score of data that tends to be far from the object is scored with a value of "3" which means the vulnerability is low, data that is not too close and not too far from the object is given a value of "2" that means the vulnerability is moderate, and data that tends to be close to the object. The object is assigned a value of “1”, which means the vulnerability is low (Figure 3). The weighted data will later be analyzed for overlay unions to be used as material for environmental vulnerability data. The final stage is layouting by adjusting to standard cartographic rules.

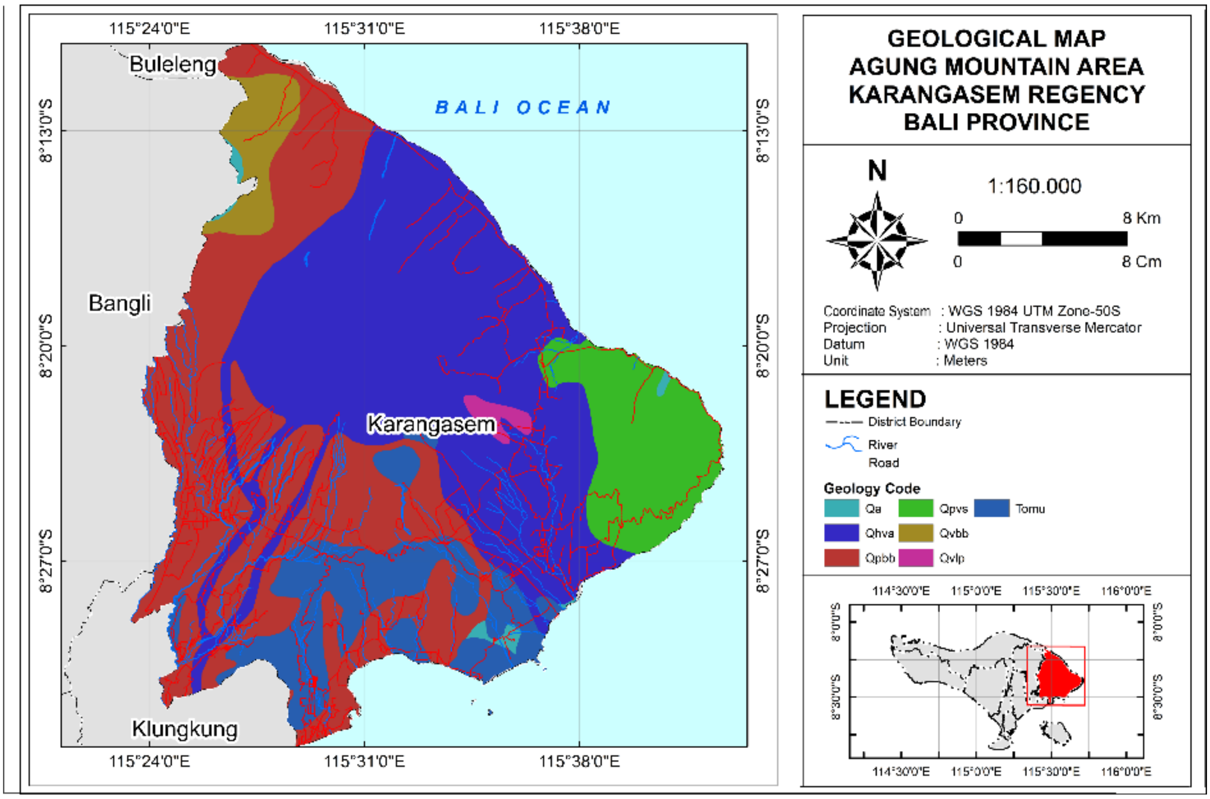

Figure 3. 2D Geological Map of Mount Agung

3D Geological Maps

The data processing stage involves using ArcGIS software products: ArcMap and ArcScene. The first stage is to use ArcMap software; the data used in processing this 3D Geological Map is to use 2D Geological Map output data, which is then the georeferencing process; the goal is that the map can be georeferenced and have spatial data; the spatial data refers to the 1984 WGS datum. The DEMNAS data that has been inputted is then masked according to the face of the map; the aim is that the DEM set-up does not overlap with other sides or parts other than the existing map face.

The next step is to transform the map from 2D to 3D. The map transformation is done through the ArcScene product; with this product software, the 3-dimensional output can be produced. The initial stage in using this device is first to input data, the inputted data is the Geological Map from the layouting and DEM data registered on the 1984 WGS datum. The next step is to set the base high on the two input data. Later, it will produce a 3-dimensional animation from a georeferenced layout map. The function of DEM is to display altitude information in real form. Then, the data export process is carried out to get the output data from the 3D animation. To produce a 3D Geological Map of the Mount Agung Region, Karangasem Regency, Bali Province (Figure 4).

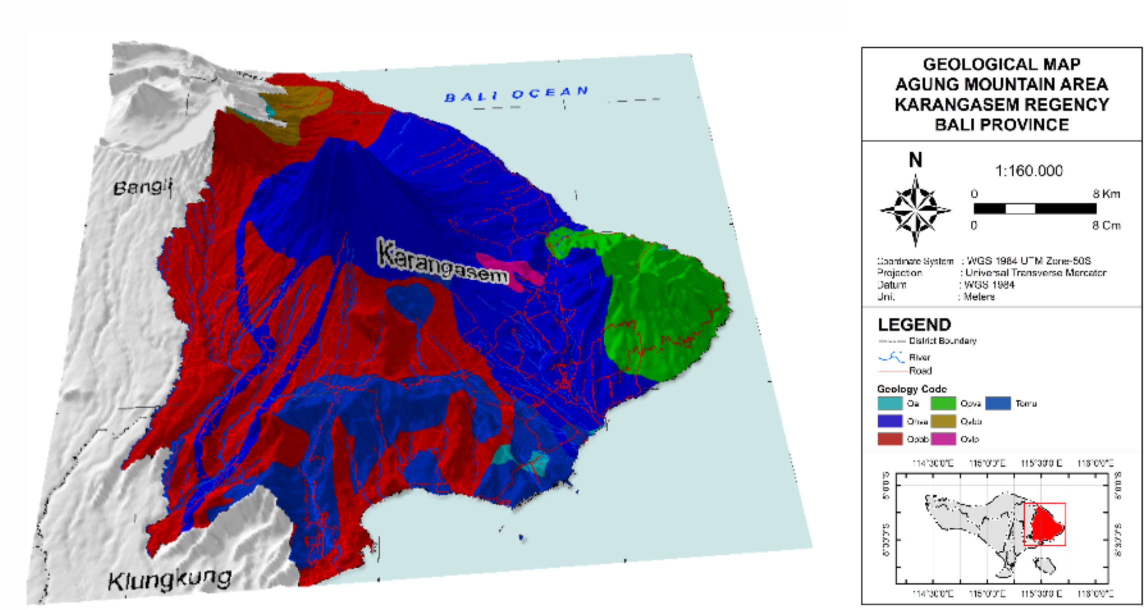

Figure 4. 3D Geological Map of Mount Agung

2D Vulnerability Map of Mount Agung Eruption

Mount Agung is the highest mount in Bali located at Rendang sub-district, Karangasem regency. Mount agung is an active volcano that means it has a potential for an eruption. Based on the data taken, social vulnerability affects the level of vulnerability of an area in facing disasters. Higher population density levels have a higher level of vulnerability when compared to areas with low population density levels. Physical vulnerability is defined as a physical structure property that determines the potential for damage to disaster (type of material and quality of building). Environmental Vulnerability relates to land cover. Land cover is a manifestation of human intervention in the environment. Types of land cover have different responses to volcanic eruption disasters. Forests will tend to have little vulnerability compared to settlements. This is because materials resulting from volcanic eruptions can be retained by forests, while settlements and rice fields will tend to pass materials from volcanic eruptions. In addition to land cover, rock geology also affects the vulnerability of volcanoes.

In the processing of this eruption disaster vulnerability map, it is done by first collecting data, the data used include: social vulnerability data, physical vulnerability data, and environmental vulnerability data. The following are details of the data used:

1. Social Vulnerability: statistical data on population density, statistical data on sex ratios, statistical data on disaster-affected areas.
2. Physical Vulnerability: shapefile data for settlements (RBI Map of Karangasem Regency) and public facilities (including statistical data on the number of schools (Kindergarten-High School) both private and public, statistical data for places of

worship of all religions, and statistical data on the number of restaurants/restaurants). The statistical data is built land data.

3. Environmental Vulnerability: land cover data and re-digitized geological data

Regarding scoring and weighting, here we use a disaster vulnerability assessment processed with the help of Microsoft Excel software. To calculate the score data (from Table 1 to Table 4), it is done by using the if formula in the software. As for the weighting is by using the following formula:

$$Quality\ Value = Score\ x\ 0.6$$ (BNPB, 2012)

Table 1. Population density parameters

No.	Sub-District	Population density (Person/Km^2)	Class	Score	Quality value
1	Rendang	367	Low	1	0.6
2	Sidemen	947	Moderate	2	1.2
3	Manggis	658	Moderate	2	1.2
4	Karangasem	940	Moderate	2	1.2
5	Abang	469	Low	1	0.6
6	Babandem	569	Moderate	2	1.2
7	Selat	496	Low	1	0.6
8	Kubu	253	Low	1	0.6

(Source: Badan Pusat Statistik, 2020)

Table 2. Sex ratio (Badan Nasional Penanggulangan Bencana, 2012)

No.	Sub-District	Population(in thousand)	Class	Score	Quality value
1	Rendang	40.2	Low	1	0.6
2	Sidemen	33.3	Low	1	0.6
3	Manggis	45.9	Low	1	0.6
4	Karangasem	88.6	Moderate	2	1.2
5	Abang	62.9	Moderate	2	1.2
6	Babandem	46.4	Low	1	0.6
7	Selat	39.9	Low	1	0.6
8	Kubu	59.4	Moderate	2	1.2

(Source: Badan Pusat Statistik, 2020)

Table 3. Affected by disaster

No.	Sub-District	Frequency	Class	Score	Quality value
1	Rendang	9	Moderate	3	1.8
2	Sidemen	6	Moderate	3	1.8
3	Manggis	3	Low	1	0.6
4	Karangasem	5	Moderate	3	1.8
5	Abang	11	High	3	1.8
6	Babandem	11	High	3	1.8
7	Selat	11	High	3	1.8
8	Kubu	10	High	3	1.8

(Source: Badan Pusat Statistik, 2020)

Table 4. Social vulnerability

No.	Sub-District	Vulnerability	Rounding	Class
1	Rendang	3	3	Moderate
2	Sidemen	3.6	4	Moderate
3	Manggis	2.4	2	Moderate
4	Karangasem	4.2	4	Moderate
5	Abang	3.6	4	Low
6	Babandem	3.6	4	Low
7	Selat	3	3	Low
8	Kubu	3.6	4	Moderate

Social vulnerability data only uses statistical data obtained from Karangasem Regency in Figures 2020. While physical vulnerability data and environmental vulnerability are combined with data, namely the overlay union analysis process, after the data has gone through the analysis process, the next step is scoring and weighting. , scores and weights that already exist are then carried out by joining tables on the related data. After all the data has gone through the process, the next step is to carry out the overlay union analysis process by combining social vulnerability maps, physical vulnerability maps, and environmental vulnerability maps. After that, the data is calculated for total scoring and vulnerability weights and classed. Where in doing the class using the following equation.

$$I = \frac{value\ difference}{n} = \frac{b-a}{n} = \frac{19-2}{3} = 5.666 \sim 6$$ ...(Badan Nasional Penanggulangan Bencana, 2012)

I = Interval value

b = highest value

a = lowest value

n = number of classes

Based on the calculations above, the range of value intervals in each classification that has been classified into 3 types of vulnerabilities is worth 6. The types of vulnerabilities include low vulnerabilities, medium vulnerabilities, and high vulnerabilities. So that the eruption disaster vulnerability data is classified as follows.

Table 5. Vulnerability classification

No.	Class	Quality value interval
1	Low vulnerability	2-6
2	Moderate vulnerability	7-12
3	High vulnerability	13-19

(Source : Data Analysis, 2023)

The weight interval range is 6 in each class. However, unlike the final class, the residual value interval range is used. Then after the class, the next stage is to do the symbology and coloring which is continued at the layouting stage using standard cartographic rules. Thus, a 2D Vulnerability Map of the Eruption of Mount Agung was produced, Karangasem Regency, Bali Province (Figure 5).

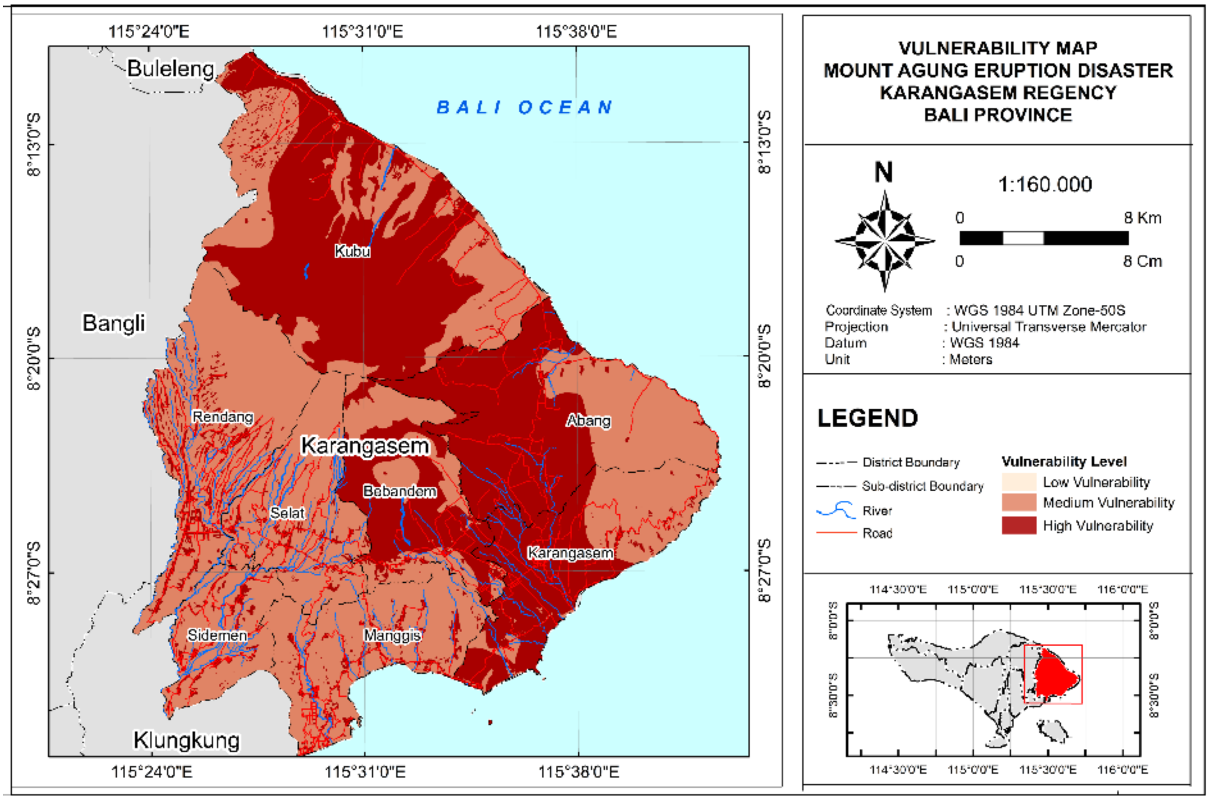

Figure 5. 2D Vulnerability Map of Mount Agung Eruption

3D Vulnerability Map of Mount Agung Eruption

The data processing stage involves utilizing two ArcGIS software products: ArcMap and ArcScene. The initial step involves the utilization of the ArcMap software to process the 3D Geological Map, utilizing 2D Geological Map output data that undergoes a georeferencing process to achieve georeferenced maps with spatial data based on the 1984 WGS datum. The primary aim is to ensure that the maps are accurately georeferenced and have the appropriate spatial data. The input DEMNAS data undergoes a masking process that corresponds to the map face to prevent the set altitude/elevation of the DEM from overlapping with other parts of the map aside from its designated face. The next step is to transform the map from 2D to 3D. The map transformation is done through ArcScene software, with this software, 3-dimensional output can be produced. The initial stage in using this device is to first input data, the data to be input is the Eruption Disaster Vulnerability Map from the layouting and DEM data that has been registered on the 1984 WGS datum. Then, the next step is to set base high on the two inputs data. So that later it will produce a 3-dimensional animation from a georeferenced layout map. The function of DEM is to display altitude information in real form. Then after that, the data export process is carried out to get the output data from the 3D animation. So as to produce a 3D Vulnerability Map of the Mount Agung Eruption Disaster, Karangasem Regency, Bali Province (Figure 6).

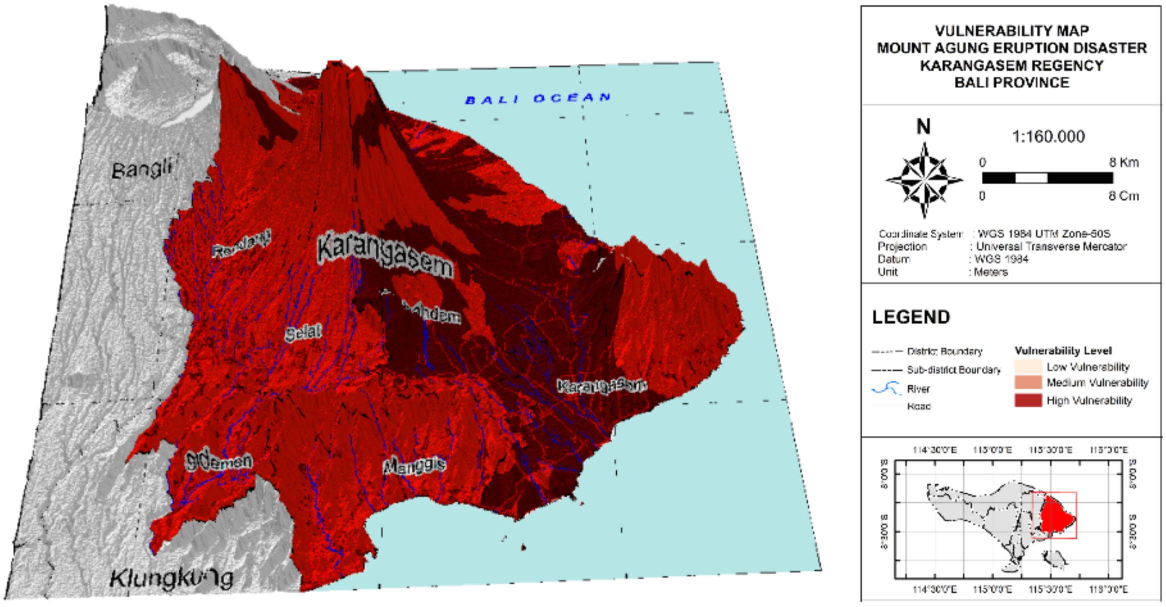

Figure 6. 3D Vulnerability Map of Mount Agung Eruption

Result of Analysis of Area of Eruption Disaster Vulnerability

Based on the analysis of calculate geometry from the classification of vulnerability to the eruption of Mount Agung, the data obtained are area in unit of hectare (ha) also in units of square meters (m^2). The extent of the vulnerability of the eruption of Mount Agung can be seen as follows.

Table 6. Vulnerability classification area

No.	Class	Area (ha)	Area (m^2)
1	Low vulnerability	0.001490	14.90
2	Moderate vulnerability	47024.493897	470244938.97
3	High vulnerability	36878.843877	368788438.77

(Source : Data Analysis, 2023)

The results based on these data show the number of areas affected by the eruption of Mount Agung, the data states that the data area with low vulnerability has an area of 0.001490 ha. Medium vulnerability data has an eruption affected area of 47.024493897 ha. While the high vulnerability has an affected area of 36.878843877 ha. So, we can say that the eruption of Mount Agung in Karangasem regency is dominated by the Moderate vulnerability class which is 56.05% of the total area of Karangasem regency. Meanwhile, the high vulnerability class also has a fairly high percentage, which is 43.95%.

Table 7. Vulnerability sub-district area

Sub-District	Class	Area (ha)	Total Area (ha)	Percentage (%)
Manggis	Low vulnerability	0.00149	0.00149	0.0000018
Abang	Moderate vulnerability	4607.26185	47024.49390	56.05
Bebandem		3444.18431		
Karangasem		3591.96394		
Kubu		8004.86503		
Manggis		7041.30951		
Rendang		9800.91616		
Selat		6716.42227		
Sidemen		3817.57082		
Abang	High vulnerability	8570.00631	36878.84388	43.95
Bebandem		4743.75373		
Karangasem		5617.97298		
Kubu		1511.03984		
Manggis		734.90959		
Rendang		1204.46191		
Selat		467.30590		
Sidemen		430.39361		
Total			83903.33927	100

(Source : Data Analysis, 2023)

The results based on table 5, each sub-district has a different vulnerability class. Manggis has low to high vulnerability divided into 0.00149 ha area that has low vulnerability, 7041.30951 ha area that has moderate vulnerability, and 734.90959 ha area that has high vulnerability. While Abang, Bebandem, Karangasem, Kubu, Rendang, Selat, and Sidemen have moderate to high vulnerability. Abang has 4607.26185 ha area that has moderate vulnerability and 8570.00631 ha area that has high vulnerability. Bebandem has 3444.18431 ha area that has moderate vulnerability, and 4743.75373 ha area that has high vulnerability. Karangasem has 3591.96394 ha area that has moderate vulnerability, and 5617.97298 ha area that has high vulnerability. Kubu has 8004.86503 ha area that has moderate vulnerability, and 15110.03984 ha area that has high vulnerability. Rendang has 9800.91616 ha area that has moderate vulnerability, and 1204.46191 ha area that has high vulnerability. Selat has 6716.42227 ha area that has moderate vulnerability, and 467.30590 ha area that has high vulnerability. Sidemen has 3817.57082 ha area that has moderate vulnerability, and 430.39361 ha area that has high vulnerability.

CONCLUSION

Social vulnerability affects the level of vulnerability because the higher population density levels affect a higher level of vulnerability. Physical vulnerability also affects the level of vulnerability because type of material and quality of building determines the potential for damage to disaster. Furthermore, environmental vulnerability also affects the level of vulnerability because each type of land cover has different responses to volcanic eruption disasters.

The results based on these data show the number of areas affected by the eruption of Mount Agung, the data states that the data area with low vulnerability has an area of 0.001490 ha. Medium vulnerability data has an eruption affected area of 47.024493897 ha. While the high vulnerability has an affected area of 36.878843877 ha. Differences in the level of vulnerability are influenced by social vulnerability, physical vulnerability, and environmental vulnerability.

The vulnerability to the eruption of Mount Agung in Karangasem regency is dominated by the Moderate vulnerability class with percentage area of 56.05% from total area of Karangasem regency. Meanwhile, the high vulnerability class also has a fairly high percentage, which is 43.95%. The authors hope that this research can provide input to the government, especially BNPB and BPBD so that the area that requires more spesific attention can be handled properly and the loss can be reduced.

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