Earthquake Vulnerability Mapping Using Spatial and SWOT Analysis: A Case Study at Cisarua, Indonesia

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Abstract
Cisarua District is a sub-district in West Bandung Regency that is prone to earthquake disasters. The Lembang Fault is the source of the main earthquake close to Cisarua District. This earthquake can cause negative impacts, such as the 28 August 2011 earthquake which caused damage to buildings in Jambudipa District. Mapping the level of vulnerability to earthquakes needs to be carried out to find out which areas are vulnerable physically, economically, socially and environmentally. Mapping the level of vulnerability to earthquakes uses spatial analysis in the form of an overlay that combines all indicators of vulnerability to earthquake disasters. Apart from that, this research also uses SWOT analysis to determine strategies that can be implemented to reduce the level of vulnerability to earthquake disasters. From the results of this research, it is known that of the 8 villages in Cisarua District, only 2 villages have high vulnerability to earthquake disasters, namely Jambudipa Village and Kertawangi Village. The area with high vulnerability in Jambudipa Village is 177,1754 Ha. Meanwhile, the village with the lowest threat level is Sadangmekar Village with a very low to low threat class. Based on the SWOT analysis, a suitable strategy to use in reducing vulnerability to earthquake disasters in Cisarua District is an aggressive and competitive strategy that prioritizes strengthening building construction, spatial planning based on disaster vulnerability, and preparing aid and access during disaster emergency response.

Keywords: Cisarua, Earthquake, SWOT, Vulnerability

1. Introduction

Indonesia is a country with the highest frequency of geological disasters in the world, including earthquakes which can occur every year throughout Indonesia. Indonesia's geological conditions are certainly one of the causes of earthquake disasters. Geologically, Indonesia is located at the meeting point of several major and minor plates [1]. The major plates surrounding Indonesia are the Eurasian Plate, the Indo-Australian Plate, the Philippine Plate, and the Pacific Plate. This third plate is what triggers earthquakes throughout the year in Indonesia [2]. From western to eastern Indonesia, an active subduction zone has been identified and several small earthquakes resulting from the collision of various plates are the source of earthquakes in Indonesia. Apart from that, Indonesia has 16 subduction-zone segments and 269 active faults identified throughout its territory. An active subduction zone is a zone that can produce strong earthquake energy that can cause other disasters, such as tsunamis. The danger of earthquakes is very threatening to life on the earth's surface, especially in fault areas on land [3].

West Java is a province with the highest population in Indonesia. This province has a fault with a tragic history dating back thousands of years, this fault is the Lembang Fault. The Lembang Fault is located in the northern part of Bandung City which extends from west to east for 29 km. The appearance of this fault can be seen in the topography as a cliff [4][5][6] and [7]. There are six sections included in the Lembang Fault, these sections are Cimeta, Cipogor, Cihideung, Gunung Batu, Cikapundung, and Batu Lonceng. The movement mechanism of the Lembang Fault itself is a left-hand shear movement, this is influenced by the pressure on the Indo-

Australian Plate in the NNE direction [8]. Meanwhile, in general, the movement of the Lembang Fault is normal with variations in shear (strike slip) in the Cimeta, Cikapundung, and Batu Lonceng segments [9]. As for the results of geological slip rate measurements carried out by Daryono in 2016, it was found that there was movement of 2-6 mm/year on the Lembang Fault and had the potential to release an earthquake with a magnitude of 6.5 -7 Richter scale [10].

Historically, there were large earthquakes in the Lembang Fault area in 1699, 1834 and 1900 [11] and [12]. Apart from that, there were three earthquakes that occurred in the 15th century, 2300-60 BC, and 18,000 BC [13]. The earthquake that occurred in the 15th century had a magnitude of 7. Meanwhile, many people think that the Lembang Fault is no longer active because the Meteorology and Geophysics Agency (BMKG) said that tectonic activity on this fault has not been detected since 1600. However, this public opinion was shattered by an earthquake on the Lembang Fault, with a magnitude of 3.4 and a depth of 6 km, on July 22 2011. This is a sign that the Lembang Fault is still active, which was strengthened by the earthquake on August 28 2011, of 3.4 magnitude with a shallower depth of 1.45 Km [14]. From 2011 to 2012, BMKG detected 14 earthquakes around the Lembang Fault with magnitudes of 1 to 3.3. One of the impacts resulting from this phenomenon is damage to Jambudipa Village.

The earthquake that occurred on August 28 2011 had various negative impacts on the Cisarua sub-district around the Lembang fault. The impact of this incident was the destruction of 268 houses in Jambudipa Village, with 89 houses slightly damaged, 72 moderately damaged, and 107 with no information. Not only Jambudipa Village, this incident also resulted in 10 houses being damaged in Pasirhalang Village. The strong shaking of the earthquake at that time caused house roof tiles to fall, walls were destroyed, and furniture fell. The damage that occurred in Cisarua District could not be separated from the earthquake epicenter which was close to residential areas. Apart from that, the magnitude of the shock is consistent with the research results, which stated that the North Bandung area (including Cisarua District) had the highest peak ground acceleration along the Lembang Fault route [9]. Cisarua District area, which has a radius closer to the Lembang Fault, has a moderate to high level of vulnerability; this is attributable to the low level of community preparedness in facing earthquake disasters [15].

Mapping the level of vulnerability to earthquake disasters is very important for minimizing the impacts when an earthquake occurs. Apart from that, an analysis is also needed that can identify the strengths, weaknesses, opportunities and threats that exist in Cisarua District in facing earthquake disasters. This research aims to mapping areas that are vulnerable to earthquakes in Cisarua District and identify existing advantages and disadvantages using SWOT analysis to provide consideration in earthquake disaster mitigation as well as consideration in drafting regulations related to spatial planning.

2. Study Area

Cisarua District is one of the sub-districts located in West Bandung Regency, Indonesia, with an astronomical position at 6° 3.73′ - 7° 1.031′ South Latitude and 107° 1.10′ - 107° 4.40′ East Longitude as illustrated in Figure 1. Cisarua District has an area of 5511 Ha and is divided into 8 villages: Cipada Village, Jambudipa Village, Kertawangi Village, Padaasih Village, Pasirhalang Village, Pasirlangu Village, Sadangmekar Village, and Tugumukti Village. The population in Cisarua District is 81,744, accounting for 4.4% of the total population of West Bandung Regency, with a population density of 14.7 people/ha [16]. Based on lithology, structure, and geomorphological characteristics, Cisarua District is included in the Bandung Physiographic Zone and is traversed by the Lembang Fault with a west-east orientation [17].

3. Methods

3.1 Earthquake Vulnerability Analysis

This research uses a scoring method on spatial data and SWOT analysis of four types of earthquake vulnerability. The four types of earthquake vulnerability used in this research are physical vulnerability, social vulnerability, economic vulnerability and environmental vulnerability. In terms of physical vulnerability, the aspects assessed include the length of the road network, distance from faults, and length of the road network. In social vulnerability, the aspects assessed are population density, the number of the under-five population, the number of the elderly population, the number of the female population, and the number of people with disabilities. The parameters used to measure economic vulnerability include the number of poor people and GRDP.

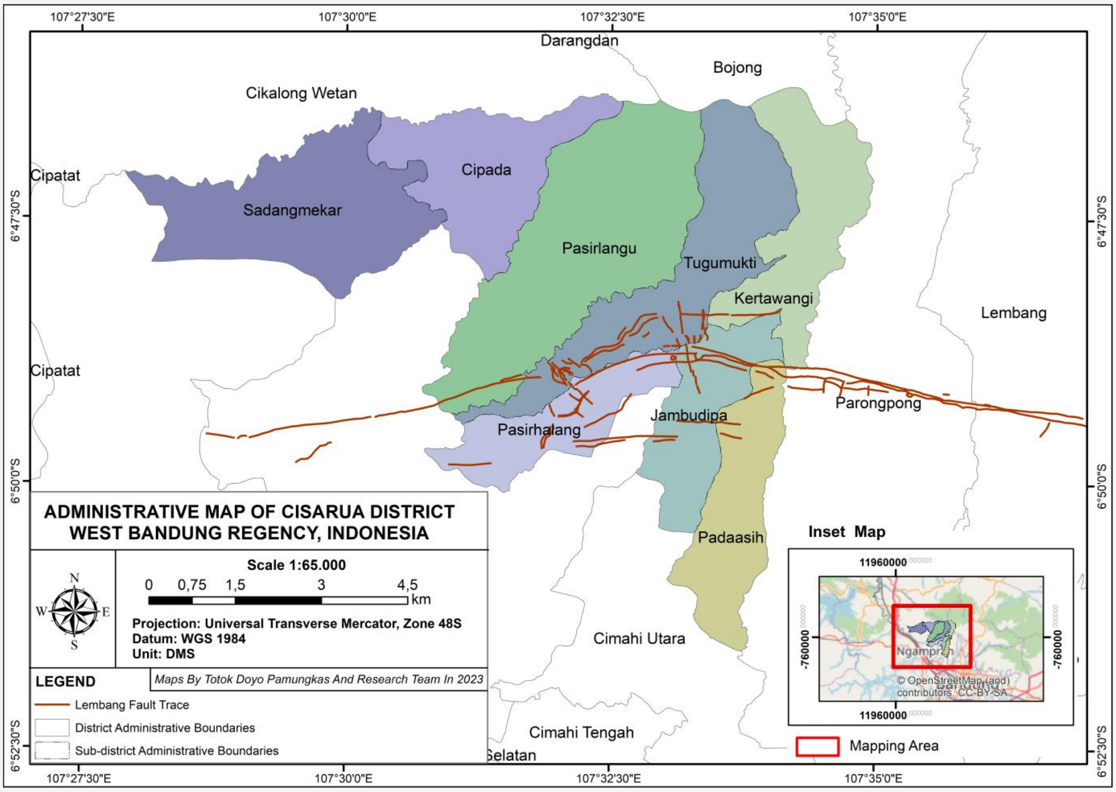

Figure 1: Administrative map of Cisarua district

Meanwhile, the parameters assessed to measure environmental vulnerability include slope, land use, and rock type. Analyzing all vulnerability indicators was carried out using the ArcGIS 10.8 application, which was used in each village. All data used are in vector type with a spatial resolution of 8 m × 8 m.

The data analysis technique used to analyze the various types of vulnerabilities is to assign a score to each parameter. Scoring and weighting of each parameter is based on Minister of Public Works Regulation Number 21 of 2007, which regulates spatial planning in areas prone to earthquake disasters, as well as Regulation of the Head of BNPB Number 2 of 2012, which regulates scoring criteria and weighting in mapping vulnerability to earthquakes. The assessment results are displayed for each village and then entered into the attribute table in ArcGIS software. The data will be filtered for each village individually so it can be shown in the district administration chart. However, as shown in Table 1, the classification of each parameter is based on a scoring system comprising beta and critical points.

The formula that can be used to calculate the final results of the earthquake disaster vulnerability index is defined in Equation 1:

$$EqV = SV + EV + PV + EnV$$

Equation 1

Where:

EqV = Earthquake Vulnerability
SV = Social Vulnerability
EV = Economic Vulnerability
PV = Physical Vulnerability
EnV = Environmental Vulnerability

From the results of the final earthquake vulnerability score, the classification of the earthquake vulnerability index in Cisarua District can then be determined using Equation 2:

$$C = \frac{X_n - X_i}{k}$$

Equation 2

Where:

c = Class intervals
X_n = Highest value
X_1 = Lowest value
k = Number of classes

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Table 1: Scoring and weighting criteria of the level of vulnerability to earthquakes

Variable	Parameter	Score	Weight (%)
Environment Vulnerability			
Slope [18]	0° – 8°	1	10
	8° – 15°	2	
	15° – 25°	3	
	25° – 45°	4	
	> 45	5	
Landuse [18]	Forests, Shrubs, Gardens, Moors, Rivers and Lakes	1	10
	Domestic Tourism Area	2	
	Rice Fields and Ponds	3	
	Housing and Public Facilities	4	
	Cultural Heritage, Industry, Foreign Exchange Tourism Areas, and Roads	5	
Lithology [18]	Andesite, Granite, Metamorphic, and Volcanic Breccia	1	5
	Agglomerate, Sedimentary Breccia, and Conglomerate.	2	
	Sandstone, Limestone, Coarse Tuff, and Siltstone	3	
	Sand, Silt, Fine Tuff, and Shale	4	
	Clay, Peat, Mud	5	
Physical Vulnerability			
Distance From Fault [19]	> 250 Meter	1	10
	200 - 250 Meter	2	
	150 – 200 Meter	3	
	100 – 150 Meter	4	
	< 100	5	
Length of Road Network [19]	< 8 Km	1	5
	8 – 16 Km	2	
	16 – 24 Km	3	
	24 – 32 Km	4	
	32 – 40 Km	5	
Building Density [20]	< 10 Building/Ha	1	10
	10 – 30 Building/Ha	2	
	30 – 50 Building/Ha	3	
	50 – 80 Building/Ha	4	
	> 80 Building/Ha	5	
Social Vulnerability			
Population Density [19]	< 10 People/Ha	1	24
	10 – 15 People/Ha	2	
	15 – 20 People/Ha	3	
	20 – 25 People/Ha	4	
	> 25 People/Ha	5	
Population Under Five Years Old [19]	< 500 People	1	4
	500 – 1000 People	2	
	1000 – 1500 People	3	
	1500 – 2000 People	4	
	> 2000 People	5	

Table 1: Scoring and weighting criteria of the level of vulnerability to earthquakes (con't)

Variable	Parameter	Score	Weight (%)
Number of Vulnerable Old Age Population [19]	< 500 People	1	4
	500 – 1000 People	2	
	1000 – 1500 People	3	
	1500 – 2000 People	4	
	> 2000 People	5	
Number of Female Population [19]	< 4300 People	1	4
	4301-5400 People	2	
	5401-6500 People	3	
	6501-7600 People	4	
	> 7600 People	5	
Number of People with Disabilities [19]	< 9 People	1	4
	9 – 18 People	2	
	18 – 27 People	3	
	27 – 36 People	4	
	36 – 45 People	5	
Economic Vulnerability			
Number of Poor People [19]	1300 - 1800 People	1	6
	1801 - 2300 People	2	
	2301 - 2800 People	3	
	2800 - 3300 People	4	
	> 3300 People	5	
GRDP (Gross Regional Domestic Product) [21]	< 50 Million Rupiah	1	4
	50 - 100 Million Rupiah	2	
	100 - 150 Million Rupiah	3	
	150 - 200 Million Rupiah	4	
	> 200 Million Rupiah	5	

Table 2: SWOT matrix

Perspective		External Factors	
		Opportunities (O)	**Threats (T)**
Internal Factors	**Strengths (S)**	Aggressive strategies (SO)	Conservative strategies (ST)
	Weakness (W)	Competitive strategies (WO)	Defensive strategies (WT)

3.2 SWOT Analysis

SWOT analysis is used to find out the right strategy to minimize the level of vulnerability to earthquake disasters in Cisarua District. Apart from that, SWOT analysis can also be used to evaluate failures in mitigation due to the 2011 earthquake disaster in Cisarua District. The SWOT matrix in Table 2 is used to develop four types of strategies to reduce earthquake vulnerability. The four strategies were obtained from the results of matching the four SWOT parameters, namely the SO strategy (strengths - opportunities), the WO strategy (weaknesses - opportunities), the ST strategy (strengths - threats), and the WT strategy (weaknesses-threats) [22]. An internal factor evaluation matrix (IFE) and an external factor evaluation matrix (EFE) are used in a SWOT analysis of vulnerability to earthquake disasters [23] and [24], as presented in Figure 2. Even though the IFE and EFE matrices are not used, recognizing external and internal factors in SWOT analysis is essential. Usually, SWOT analysis uses a 2x2 table and produces 4 strategy groups.

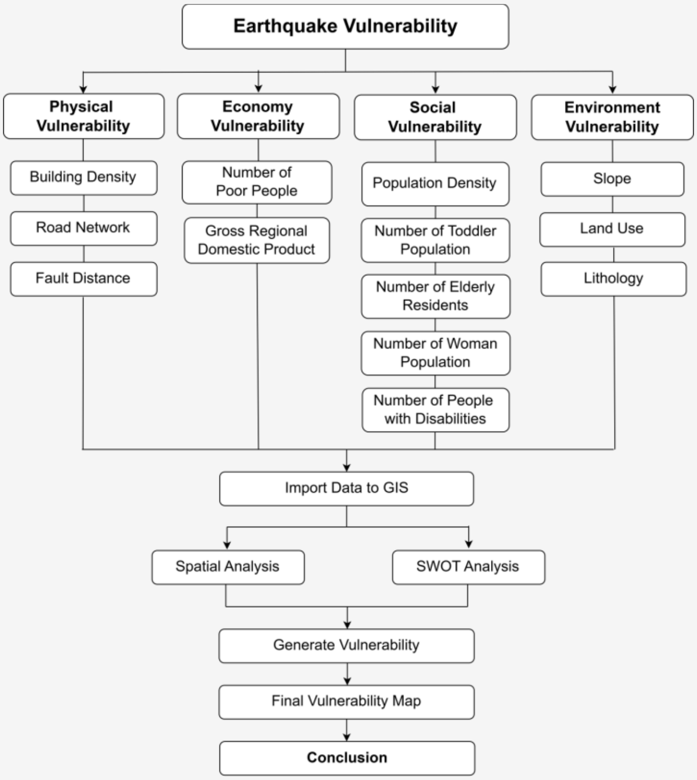

Figure 2: Earthquake vulnerability analysis study workflow

Table 3: Extent of physical vulnerability levels in each village in Cisarua district

Village	Area Size Based on Level of Vulnerability (Ha)					Total Area/Village
	Very Low	Low	Moderate	High	Very High	
Cipada	-	572.32	1.355	33.62	-	607.29
Jambudipa	-	218.10	156.09	32.27	21.95	428.41
Kertawangi	-	485.85	30.11	61.93	7.93	585.82
Padaasih	345.70	37.51	102.60	6.72	3.19	495.71
Pasirhalang	140.64	130.06	96.88	23.95	-	391.53
Pasirlangu	2.35	1081.0	114.19	23.07	1.45	1222.07
Sadangmekar	-	849.87	30.26	-	-	880.13
Tugumukti	-	591.82	189.36	13.39	19.00	813.57

4. Results and Discussion

4.1 Earthquake Vulnerability Analysis

4.1.1 Physical vulnerability

The results of physical vulnerability analysis through data overlay with a weight of 25% of the total summation results data, which includes building density (10%), length of road network (5%), and distance from faults (10%) show that Cisarua District has a very low to very high classification variation, which is divided into five classes (Figure 3). Each physical vulnerability parameter determines the range of values in the vulnerability area classification, with a 23.2 interval, a maximum of 125, and a minimum of 9. The following table shows physical vulnerability areas and visualizes the analysis data. Based on Table 3, villages with very high physical vulnerability include Jambudipa, Kertawangi, Padaasih, Pasirlangu, and Tugumukti. This condition is caused by high physical parameters in this area. This is also directly proportional to areas with a non-very-low physical vulnerability classification. This result is due to a more intensive distribution of vulnerability levels at higher levels. The greater the number of buildings and the longer the road network, as well as the wider coverage of the area within a radius of 50-250 meters, the stronger the influence on physical vulnerability.

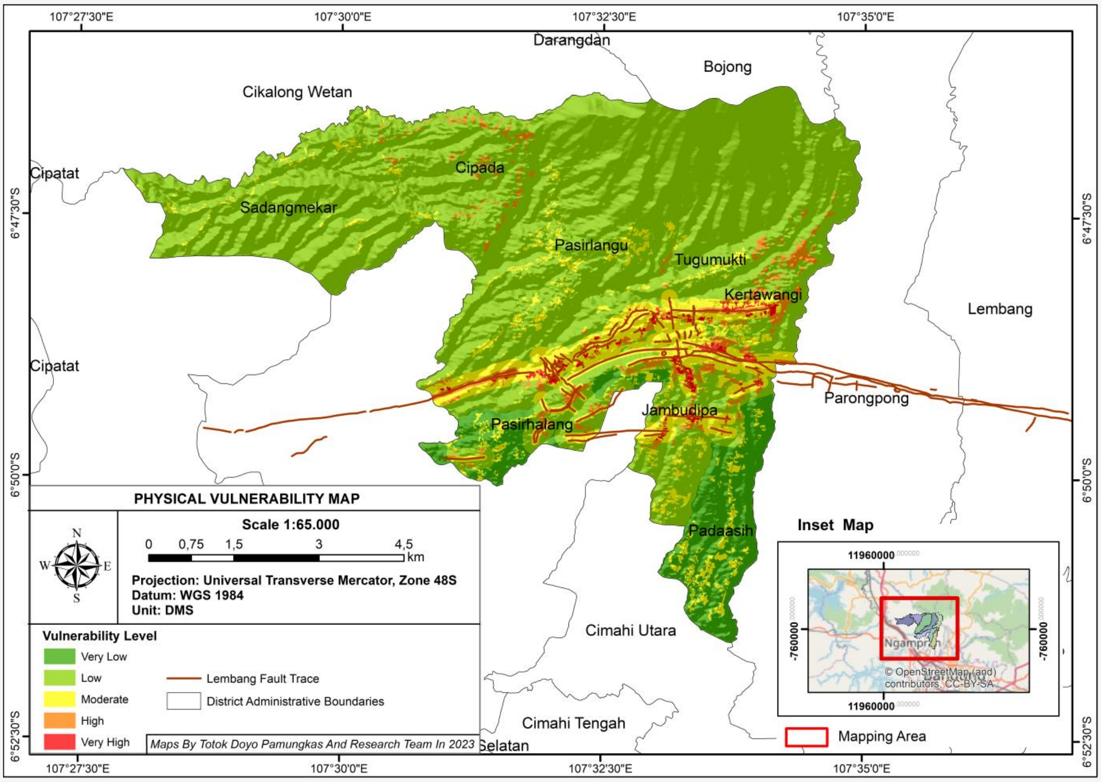

Figure 3: Physical vulnerability map in Cisarua district

Table 4: Classification of economic vulnerability levels in Cisarua district

Village	GRDP (million rupiah)	Number of Poor People	Total Score	Vulnerability Level
Cipada	155.8814356	3818	46	Very High
Jambudipa	109.9629	3625	42	Very High
Kertawangi	150.378473	2865	40	High
Padaasih	127.2390031	2908	36	Moderate
Pasirhalang	100.5001268	3255	36	Moderate
Pasirlangu	313.0879159	1952	32	Low
Sadangmekar	225.9035987	3412	46	Very High
Tugumukti	208.8392139	1337	26	Very Low

4.1.2 Economic vulnerability

Economic vulnerability (Figure 4) is a condition of the threshold level of an individual's or community's ability to face threats from economic aspects. The aspect in question consists of two parameters, namely Gross Regional Income (GRDP) and the number of poor people. The two parameters each represent the income capacity of a study area, measured in rupiah. The poor population represents the average monthly per capita expenditure below the poverty line. The higher the GRDP value and the number of poor people, the higher the resulting score. Table 4 visualizes the economic vulnerability data. Based on the table, it is known that economic vulnerability in Cisarua District consists of very low to very high classifications. There are more villages classified as very high economic vulnerability than other classes. These villages include Cipada, Jambudipa, and Sadangmekar villages. This classification is determined by the number of poor people, villages with poor people tend to have a high vulnerability value. Another meaning of this data is that areas with high vulnerability tend to have a low economic capacity threshold.

4.1.3 Social vulnerability

Social vulnerability is the threshold for how easily danger occurs within social aspects of an area (Figure 5). The parameters used in scoring, weighting, and overlay analysis include population density, number of female residents, number of children under 5, number of elderly people, and number of people with disabilities or handicaps.

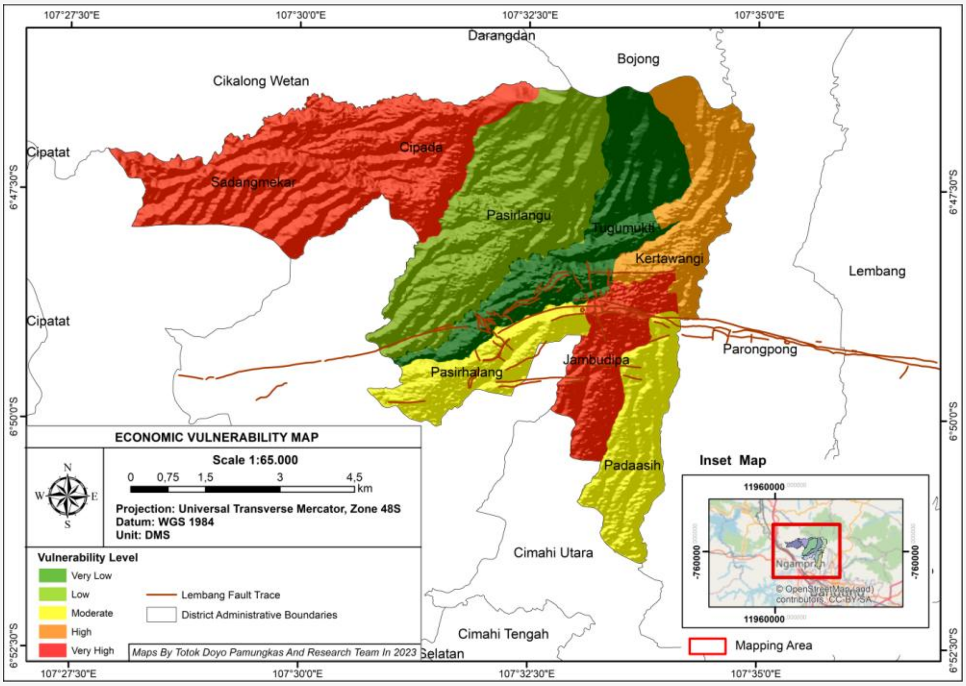

Figure 4: Economic vulnerability map in Cisarua district

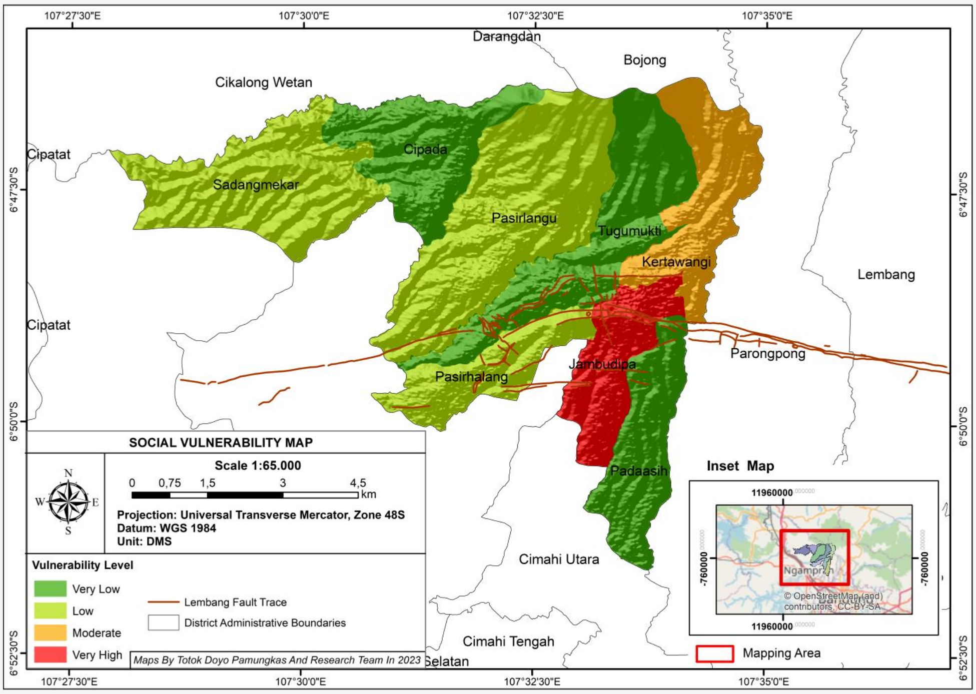

Figure 5: Social vulnerability map in Cisarua district

The following table presents the results of the social vulnerability analysis in Cisarua District. Based on Table 5, social vulnerability in Cisarua District ranges from very low to very high. The higher the score obtained for each parameter, the higher the level of vulnerability. Jambudipa Village is the only village classified as having very high social vulnerability. This condition is caused by each parameter being higher than in other villages. Apart from that, this village is the center of population growth and sub-district government.

Table 5: Classification of social vulnerability levels in Cisarua district

Village	Population Density (Person /Ha)	Number of Female Population	Number of Toddler Population	Number of Elderly Population	Number of People with Disabilities	Total Score	Vulnerability Level
Cipada	13.34	3988	986	537	0	72	Very Low
Jambudipa	38.94	8616	1038	1568	1	172	Very Hgh
Kertawangi	23.38	6634	1256	905	3	136	Moderate
Padaasih	14.8	3228	188	291	27	72	Very Low
Pasirhalang	17.5	3378	613	247	0	92	Low
Pasirlangu	9.97	5988	1066	387	0	56	Low
Sadangmekar	7.9	3399	557	253	35	56	Low
Tugumukti	8.84	3593	678	350	0	44	Very Low

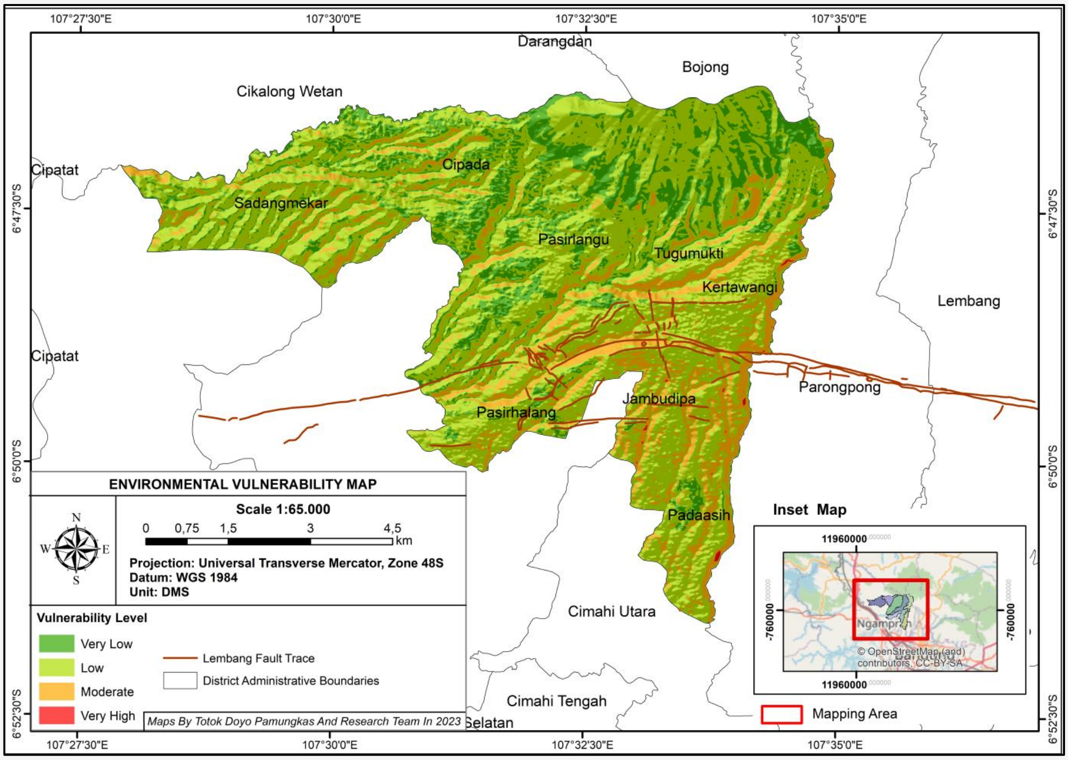

Figure 6: Environmental vulnerability map in Cisarua district

4.1.4 Environmental vulnerability

Environmental vulnerability is one of the factors that contribute to greater environmental risks (Figure 6). This aspect consists of three parameters, namely slope, land use, and rock type, which have undergone scoring and weighting, culminating in an overlay analysis. The classification of environmental vulnerability ranges from very low to very high, with a maximum score of 125 and a minimum of 25. The following are the results of the vulnerability level analysis in Cisarua District. Based on Table 6, villages with a high environmental vulnerability classification include Jambudipa, Kertawangi, Padaasih, Pasirhalang, and Tugumukti Villages.

The parameters that most influence this vulnerability are slope, slope, and land use, especially at slopes > 45° with residential land use. Meanwhile, the geological aspects in Cisarua District are predominantly composed of compact igneous rocks and sediments, so geological parameters only provide a limited indication of environmental vulnerability.

4.1.5 Earthquake Vulnerability

After the four vulnerabilities, which include physical vulnerability, economic vulnerability, social vulnerability, and environmental vulnerability, are known, a spatial overlay analysis is carried out to determine the level of vulnerability to earthquake disasters in Cisarua District as a whole. Then, the results of the overlay analysis are classified by level of vulnerability, as shown in Figure 7. According to the results in Table 7, only two villages have high vulnerability in their areas: Jambudipa Village and Kertawangi Village. Jambudipa Village is the most populous village in Cisarua District and is directly crossed by a fault line, making it highly vulnerable.

Table 6: Extent of environmental vulnerability levels in each village in Cisarua district

Village	Area Size Based on Level of Vulnerablity (Ha)			
	Very Low	Low	Moderate	High
Cipada	211.350	342.461	52.314	-
Jambudipa	2.836	310.352	113.954	0.614
Kertawangi	118.070	370.587	94.6859	0.843
Padaasih	21.313	305.117	164.819	2.160
Pasirhalang	30.245	265.359	93.9182	0.031
Pasirlangu	327.307	816.755	75.877	-
Sadangmekar	133.647	639.995	102.471	-
Tugumukti	134.358	523.534	156.063	0.054

Table 7: Extent of earthquake vulnerability levels in each village in Cisarua district

Village	Area Size Based on Level of Vulnerability (Ha)			
	Very Low	Low	Moderate	High
Cipada	0.108	605.327	0.690	-
Jambudipa	-	1.427	250.567	177.175
Kertawangi	-	36.040	534.922	13.223
Padaasih	21.086	463.622	8.701	-
Pasirlangu	291.377	928.412	0.150	-
Pasirhalang	0.584	342.894	46.074	-
Sadangmekar	120.240	755.873	-	-
Tugumukti	555.030	258.293	0.686	-

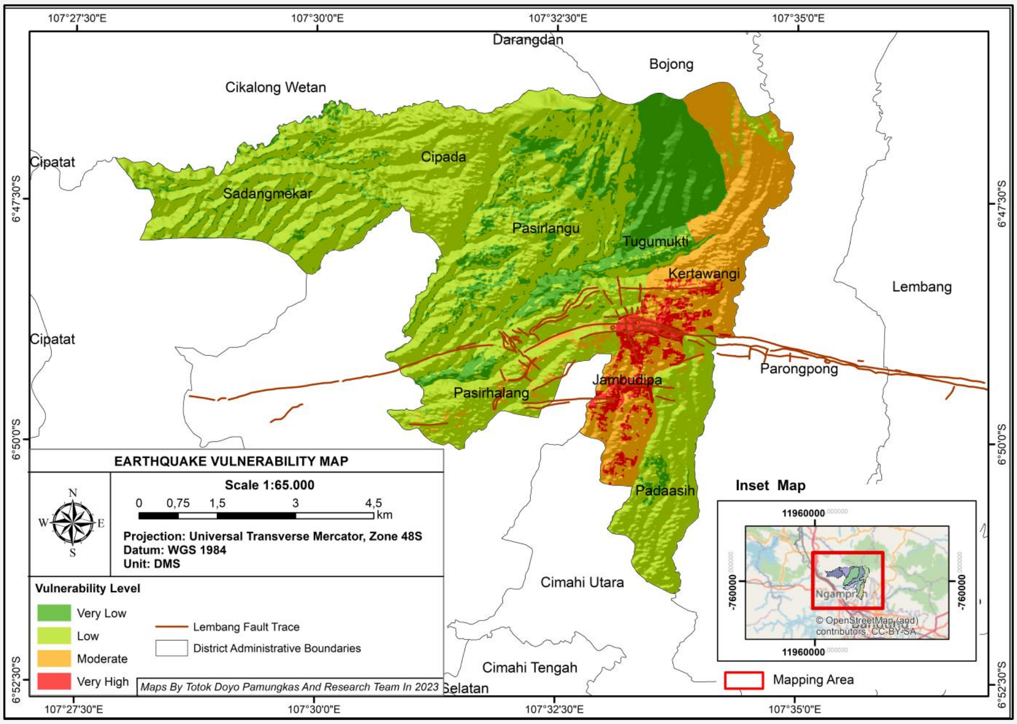

Figure 7: Earthquake vulnerability map in cisarua district

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4.2 Strategies to Reduce Earthquake Vulnerability

4.2.1 External factors

External factors help identify and evaluate factors that influence the level of earthquake vulnerability from the outside. This factor will evaluate how well the opportunities and challenges are in reducing the level of vulnerability to earthquake disasters in Cisarua District. These opportunities and challenges include environmental, physical, social, and economic factors. Based on Table 8, opportunities to reduce vulnerability to earthquake disasters in Cisarua District include environmental and social factors. The three environmental parameters, which include land use, rock slope, and rock type, show good opportunities in reducing the impact of earthquake disasters. This is in line with the results of environmental vulnerability mapping in Cisarua District, which is dominated by low- to medium-vulnerability classes. Meanwhile, the social parameter included in the opportunity to reduce the impact of the earthquake disaster is population age, which is dominated by young people. Young people are considered stronger and better able to evacuate and survive earthquakes.

4.2.2 Internal factors

Internal factors help in identifying and evaluating various internal factors that influence the level of vulnerability to earthquake disasters in Cisarua District. This analysis will help identify strengths and weaknesses in dealing with earthquake disasters that originate from within. The analysis results show that the internal factors influencing vulnerability to earthquake disasters stem from physical, social, and economic factors. Based on Table 9, the main strength of Cisarua District in facing vulnerability to earthquake disasters is its economic factors, specifically its high GRDP. GRDP can be the basis for financial capability in building both pre-disaster, in the form of buildings with strong construction, and post-disaster, in the form of recovery, rehabilitation, and reconstruction. Meanwhile, the weaknesses of Cisarua District in facing vulnerability to earthquake disasters include physical factors such as high building density, as well as social factors such as high population density and a high number of female residents. High building density will affect the number of buildings that could collapse and strike people, especially in densely populated areas, such as Jambudipa Village. Meanwhile, the female population is vulnerable to earthquakes because they are considered less capable of evacuating and surviving during such disasters.

4.2.3 SWOT Matrix analysis

After all external and internal factors are identified, an analysis of each parameter within each factor is conducted to develop a suitable strategy to reduce vulnerability to earthquake disasters in Cisarua District, Indonesia. This research identifies 4 general strategies, which are combinations of Strengths - Opportunities (SO), Strengths - Threats (ST), Weaknesses - Opportunities (WO), and Weaknesses - Threats (WT), as shown in Table 10. The strategy focuses more on strengthening building construction, spatial planning that accounts for disaster risks, and providing aid facilities and access for disaster emergency response. This cannot be separated from the location of the activities of the people of Cisarua District, which appear close to the Lembang Fault route. So, based on aggressive and competitive strategies, building construction is better suited to field conditions.

Table 8: External factors that influence to earthquake vulnerability

Strength	Factor	Description
Opportunities	Environment	- Land use is dominated by agricultural areas
		- The slope slope is predominantly < 15º
		- Bedrock is compact
	Social	- Total population
Challenge	Physicalness	- Close to the fault line
		- Complex road network
	Economy	- High number of poor people

Table 9: Internal factors that influence to earthquake vulnerability

Strength	Economy	High GRDP level
Weakness	Physicalness	- High building density
	Social	- High population density
		- The number of female residents is high

Table 10: SWOT matrix analysis of earthquake vulnerability

Perspective		External Factors	
		Opportunities (O) 1) Land use is dominated by agricultural areas 2) The slope slope is predominantly < 15o 3) Bedrock is compact 4) The number of young people is high	**Threats (T)** 1) Close to the fault line 2) Complex road network 3) High number of poor people
Internal Factors	**Strengths (S)** 1) High GDP level	**SO** 1) Spatial planning that considers disaster risks 2) Development in the plains 3) Youth empowerment in increasing disaster awareness	**ST** 1) Increase assistance facilities around faults 2) Strengthen building construction 3) Prepare effective and efficient evacuation routes 4) Providing assistance to poor people
	Weakness (W) 1) Density Building tall 2) High population density 3) The number of female residents is high	**WO** 1) Revitalization of risky land uses 2) Design of open spaces as gathering points 3) Optimal consideration of natural phenomena	**WT** 1) Reorganize population density and building density around high-risk areas 2) Prevent the development of development in high risk areas 3) Effective and efficient road network reform

Extreme measures can be taken by implementing defense strategies that minimize human activity in areas highly vulnerable to earthquakes. This will definitely address the challenges in both policy and the very large budget required.

5. Conclusion

Overall, the level of vulnerability to earthquake disasters in Cisarua District is in the low to medium class. There are only 2 villages with areas of high vulnerability: Jambudipa Village and Kertawangi Village. This cannot be separated from the position of the two villages, which are close to the Lembang Fault route, high population and building density, as well as other social and economic factors. Meanwhile, the village with the lowest vulnerability score is Sadangmekar Village, which is only categorized in the very low and low classes, so the village is relatively not vulnerable to earthquake disasters caused by the Lembang Fault.

Based on the results of the SWOT matrix analysis of the level of vulnerability to earthquake disasters in Cisarua District, four general groups of strategies can be implemented. From the results of this analysis, it can be seen that strategies that can be used to reduce the level of vulnerability to earthquake disasters in Cisarua District include strengthening building construction, spatial planning based on disaster vulnerability, and preparing aid and access facilities during disaster emergency response that are in accordance with real conditions in Cisarua District. Meanwhile, defensive strategies require more time and larger amounts of funding.

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References

[1] Bird, P., (2003). An Updated Digital Model of Plate Boundaries. *Geochemistry, Geophysics, Geosystems,* Vol. 4(3), 1027. https://doi.org/10.1029/2001GC000252.

[2] Wekke, I. S., (2021). *Mitigasi Bencana*. Indramayu: Adab. 1-135.

[3] Pusat Studi Gempa Nasional., (2017). *Peta Sumber dan Bahaya Gempa Indonesia Tahun 2017*. [Map of Indonesian Earthquake Sources and Hazards in 2017]. Jakarta: Puslitbang Perumahan dan Pemukiman, Kementerian PUPR, 1-375.

[4] Tjia, H. D., (1968). The Lembang Fault, West Java. *Geologie En Mijnbouw,* Vol. 47(2), 126 – 130.

[5] Setyadji, B., Murata, I., Kahar, J., Suparka, S. and Tanaka, T., (1997). Analysis of GPS Measurement in West Java, Indonesia. *Annual Disaster Prevention Research Institute, Kyoto University*, Vol. 40(1): 27 – 33. https://www.

dpri.kyoto-u.ac.jp/nenpo/no40/40s0/a40s0p05.pdf.

[6] Nossin, J. J., (2005). *Volcanic Hazards in Southeast Asia*. Oxford: Oxford University Press.

[7] Supartoyo, E. T., Putranto and Djaja., (2005). *Active Faults and Destructive Earthquake Epicenter Distribution Map of Indonesia*. Bandung: PVMBG.

[8] Afnimar, Yulianto, E. and Rasmid, (2015). Geological and Tectonic Implications Obtained from First Seismic Activity Investigation Around Lembang Fault. *Geoscience Letters,* Vol. 2(4). https://doi.org/10.1186/s40562-015-0020-5.

[9] Pamungkas, T. D. and Ningrum, E., (2022). Analysis of Lembang Fault Characteristics Based on Literatures of Geological Structure, Rock Formation and Peak Ground Acceleration Probabilistic Earthquake Analysis. *Jurnal Geografi Gea,* Vol. 22(2), 117-124. https://doi.org/10.17509/gea.v22i2.45233.

[10] Daryono, M. R., (2016). *Paleoseismology of Tropical Indonesia: Case Study on Sumatran Fault, Palukoro-Matano Fault, and Lembang Fault*. Doctoral Program Dissertation. Bandung: Institut Teknologi Bandung.

[11] Visser, S. W., (1922). *Inland and Submarine Epicentra of Sumatra and Java Earthquakes*. Javasche boekhandel en drukkerij.

[12] Wichmann, A., (1918). *Die Erdbeben des indischen Archipels bis zum Jahre 1857*,[The earthquakes of the Indian archipelago up to the year 1857]. Vol. 20(4). Amsterdam: Müller.

[13] Daryono, M. R., Natawidjaja, D. H., Sapiie, B. and Cummins, P., (2019). Earthquake Geology of the Lembang Fault, West Java, Indonesia. *Tectonophysics*, Vol. 751, 180-191. https://doi.org/10.1016/j.tecto.2018.12.014.

[14] Sulaeman, C. and Hidayati, S., (2011). Gempa Bumi Bandung 22 Juli 2011. [Bandung Earthquake, July 22, 2011]. *Jurnal Lingkungan dan Bencana Geologi,* Vol. 2(3), 185-190. http://dx.doi.org/10.34126/jlbg.v2i3. 30.

[15] Pamungkas, T. D., Aliyan, S. A., Nurfalah, I., Ningrum, E. and Maryani, E., (2023). Preparedness of the Community in Facing Disasters Like Earthquakes (Case: Cisarua, Indonesia). *Jàmbá-Journal of Disaster Risk Studies,* Vol. 15(1), 1-9. https://doi.org/10.4102/jamba.v15i1.1438.

[16] Badan Pusat Statistik., (2022). *Kabupaten Bandung Barat Dalam Angka 2022*. [West Bandung Regency in Figures 2022]. Bandung Barat: Badan Pusat Statistik.

[17] Bemmelen Van, R.W., (1949). *The Geology of Indonesia*. Netherland: The Haque.

[18] Kementerian Pekerjaan Umum., (2007). *Minister of Public Works Regulation Number 21/PRT/M/2007*. Jakarta: Kementerian Pekerjaan Umum.

[19] Desmonda, N. I. and Pamungkas, A., (2014). Penentuan Zona Kerentanan Bencana Gempa Bumi Tektonik Di Kabupaten Malang Wilayah Selatan. [Determination of Tectonic Earthquake Disaster Vulnerability Zones in the Southern Region of Malang Regency] *Jurnal Teknik ITS*, Vol. 3(2), C107-C112. https://doi.org/10.12962/j23373539.v3i 2.7232

[20] Kementerian Pekerjaan Umum., (1987). *Minister of Public Works Regulation Number 378/KPTS/1987*. Jakarta: Kementerian Pekerjaan Umum.

[21] Badan Nasional Penanggulangan Bencana., (2012). *Regulation of the Head of the National Disaster Management Agency Number 2 of 2012 about General Guidelines for Disaster Risk Assessment*. Jakarta: Badan Nasional Penanggulangan Bencana.

[22] David, F. R., (2006). *Manajemen Strategi. 10th Edition*. Jakarta : Salemba Empat.

[23] Alizadeh, M., Zabihi, H., Rezaie, F., Asadzadeh, A., Wolf, I. D., Langat, P. K., Khosravi, I., Beiranvand Pour, A., Mohammad Nataj, M. and Pradhan, B. (2021). Earthquake Vulnerability Assessment for Urban Areas Using an ANN and Hybrid SWOT-QSPM Model. *Remote Sensing,* Vol. 13(22). https://doi.org/10.3390/rs13224519.

[24] Arrasyid, R., Ihsan, H. M., Ruhimat, M. and Pratama, A. R., (2023). Suitability Evaluation of Land Use/Land Cover (LULC) Towards Landslide Prone Areas in Structural and Volcano Landform. *International Journal of Geoinformatics*, 19(6), 61-75. https://doi.org/10.52939/ijg.v19i6.2697.