Spatial Analysis of Earthquake Vulnerability Based on Geographic Information System (GIS) in Disaster Mitigation Efforts

Alwin [a, *], Ali Sya'ban [a], Agung Adiputra [a]

[a] **Departement of Geography Education. Universitas Muhammadiyah Prof. Dr Hamka**
*alwin07ghifari@uhamka.ac.id

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A B S T R A C T

The earthquake that occurred in the south of Tasikmalaya caused quite severe damage in several areas, one of which was the Pangalengan District in Bandung Regency. The purpose of this research is to identify the impact of damage, specifically buildings due to the earthquake and identify physical and social factors that cause vulnerability in Pangelang District. The research method is descriptive qualitative, secondary data from the literature related to the problem being examined, in the form of regulatory documents, the results of previous studies related to the research location, interpretation and analysis of geological maps, maps of the earth, maps of earthquakes and land use. The results showed that geologically the physical condition of the land in the Pangalengan sub-district was prone to the threat of an earthquake disaster. Based on the assessment of land capability, including unstable land with typology of earthquake-prone type C areas, there are more than 2 mutually damaging factors. Rock types with weak physical properties, close to fault zones, steep slope and high earthquake intensity. In addition to geologically vulnerable land conditions, social factors also contribute to the level of damage, namely the condition of houses that are not earthquake-friendly, settlement patterns are clustered, the level of population density and community knowledge about disasters is still lacking.

Kata Kunci:
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A B S T R A K

Gempa bumi yang terjadi di selatan Tasikmalaya menimbulkan kerusakan cukup parah dibeberapa daerah, salah satunya adalah Kecamatan pangalengan di Kabupaten Bandung. Tujuan penelitian adalah mengidentifikasi dampak kerusakan, khusus bangunan akibat gempa dan mengidentifikasi faktor fisik dan sosial yang menimbulkan kerawanan wilayah Kecamatan Pangelangan. Metode penelitian adalah deskriptif kualitatif, data sekunder dari literatur yang terkait dengan permasalahan yang dikaji, berupa dokumen regulasi, hasil-hasil penelitian sebelumnya yang terkait dengan lokasi penelitian, interpretasi dan analisis peta geologi, peta rupa bumi, peta rawan gempa dan penggunaan lahan. Hasil penelitian menunjukkan bahwa secara geologis kondisi fisik lahan daerah kecamatan Pangalengan rawan terhadap ancaman bencana gempa bumi. Berdasarkan penilaian kemampuan lahan termasuk lahan kurang stabil dengan tipologi kawasan rawan bencana gempa bumi tipe C terdapat lebih dari 2 faktor yang saling melemahkan. Jenis batuan dengan sifat fisik lemah, dekat dengan zona sesar, kemiringan lereng curam dan intensitas gempa tinggi. Selain kondisi lahan rawan secara geologis, faktor sosial turut memberikan andil terhadap tingkat kerusakan, yaitu kondisi rumah tidak ramah gempa, pola pemukiman mengelompok, tingkat kepadatan penduduk dan pengetahuan masyarakat tentang bencana yang masih kurang.

Introduction

A disaster is an event or a series of events that threaten and disrupt people's lives caused by natural and non-natural factors. Disasters can result in human casualties, environmental damage, property losses, and psychological impacts. A disaster is a natural event that cannot be predicted when it occurs. Likewise, earthquake disaster cannot be avoided, but its impact can be reduced through disaster mitigation efforts. Residential areas that are close to the source of the earthquake is a very vulnerable area. Therefore, it is necessary to take strategic steps to reduce or minimize the impact of loss or damage that can be caused by disasters.

An earthquake is an earth-shaking event due to the sudden release of energy in the earth. This usually occurs in collisions between earth plates, active faults in volcanic activity, or rock collapse. The strength of an earthquake due to volcanic activity and rock collapse is relatively small compared to the shock produced by the movement of the earth's plates and active faults.

Tectonic earthquakes are caused by tectonic activity, which is the sudden shift of tectonic plates with strength from very small to very large. These earthquakes cause many damages or natural disasters on earth, and strong earthquake vibrations can spread throughout the earth. The theory of tectonic plates explains that the earth consists of several layers of rock; most of the crust area will be washed away and float on layers like snow. The layers move very slow so that they collide with each other. This has led to a tectonic earthquake.

The development of information technology, both hardware, and software, one of which is GIS (Geographical Information System), can solve various problems concerning space. GIS technology integrates database operations and statistical analysis with unique visualizations and spatial analysis offered through digital maps. This capability distinguishes GIS from other information systems, making GIS more useful in providing information that is close to real-world conditions, predicting results, and strategic planning. Likewise, in concluding the level of earthquake vulnerability, GIS has been utilized to produce thematic maps and final maps in the form of maps of earthquake hazard vulnerability. This earthquake vulnerability information system is an effort to contribute to reducing the impact and loss caused by earthquakes.

Geographical Information System (GIS) is a tool in analyzing the phenomenon of the geosphere. GIS is becoming a rapidly developing scientific discipline during rapid mapping technology. GIS is the basis for decision-makers to make a policy related to spatial planning of an area

The above-mentioned Geographic Information Systems (GIS) can also be used/utilized to: (a) GIS uses both spatial data and attributes in an integrated manner to analyze spatial natural and social disaster mitigation. (b) GIS helps work that is closely related to spatial fields and geoinformation.

Geographically, Indonesia is located in the equatorial region with diverse morphologies from land to high mountains. Morphological diversity is much influenced by geological factors, especially with active tectonic plate movements around Indonesian waters, including the Eurasian plate, Australia, and the Pacific Ocean Baseplate. The movement of these tectonic plates causes earthquake pathways, a series of active volcanoes and faults that can potentially be a source of earthquakes. This subsidy results in andesitic volcanic activity and is followed by carbonate sedimentation in shallow seas (Alzwar, M., Akbar., And Bahcri, 1992).

Several catastrophic earthquake events with large magnitude often occur in several regions of Indonesia, such as the earthquake and tsunami in Aceh on December 26, 2004, Nias Island on March 28, 2005, Yogyakarta on May 27, 2006, Pangandaran July 17, 2006, Tasikmalaya September 2, 2009, and Padang earthquake September 30, 2009.

West Java is one of the regions that have a considerable disaster hazard. This condition is influenced by a complex geological order that is prone to earthquake geological disasters. Based on historical records of destructive earthquakes in Indonesia compiled by the Center for Volcanology and Geological Disaster Mitigation (PVMBG) in the West Java region, there have been at least 29 earthquakes with damaging categories, especially those originating on land since it was recorded in 1883 until now. Some of the areas prone to earthquake geology are in densely populated areas such as Bogor, Cianjur, Ratu-Sukabumi Port, Rajamandala-Padalarang, Ciamis-Kuningan Sumedang-Majalengka, Tasikmalaya, Bandung and almost the entire mountainous region of South West Java. Bandung Basin (Bronto, 2006). Volcanoes almost surround the Bandung Basin; there are volcanic rocks, even in the middle (Silitonga, 1973; Alzwar drr., 1992). Information about why and how the Bandung area came to be dominated by volcanic rocks is needed to find out more.

Earthquake characteristics in West Java are mostly not from subduction zones/subduction zones, but faults / active faults on land. Earthquakes originating from active faults on land can damage even though the magnet is not too large, but the depth is shallow and close to human settlement and activity. The earthquake so far has not been estimated when it happened when, where, and how much. It can occur during the day when we work or at night while sleeping, so that it cannot save itself because it happens so quickly that a building collapsed, a landslide, or swept away by a tsunami.

Efforts to reduce the impact of disasters are by carrying out activities called Disaster Mitigation as stated in Law Number 24 of 2007 concerning Disaster Management to deal with possible future disasters. One form of mitigation to minimize the impact of earthquake victims is by knowing each region's characteristics to determine the level of vulnerability to disasters, as guidelines for spatial planning for earthquake-prone areas as listed in (Law No. 26/2007 on Spatial Planning., 2007).

Community participation in disaster risk reduction efforts can be realized with Disaster Education. People living in disaster-prone areas have knowledge, attitudes, and skills in disaster preparedness and disaster response (Yulaelawati, 2010). Communities living in disaster-prone areas can adapt to disaster education. Understand disaster concepts can make better conditions when, before, and after a disaster occurs. Disaster education can be done through formal and informal education activities. Schools, as formal educational institutions, facilitate the community in reducing disaster risk through learning. Disaster education in schools can be carried out by integrating disaster learning during intra-curricular and extra-curricular activities.

The earthquake on September 2, 2009, which was 7.2 magnitude Richter strength with the epicenter in the south of Tasikmalaya vibrations were felt strongly in several areas in southern West Java such as Tasikmalaya, Garut, Cianjur, Bandung and surrounding areas. One of the areas in Bandung regency that suffered quite severe damage was Pangalengan District, and the impact was seen in several places experiencing building damage ranging from destroyed to mild damage.

Based on the incident, some problems can be examined why Pangalengan District is damaged quite badly compared to other adjacent districts. In advance, it is necessary to know how the physical condition of the land of Pangalengan District and surrounding areas. What is the level and distribution of building damage due to the Tasikmalaya earthquake in Pangalengan District.

This research aims to identify the impact of damage, especially the building due to the earthquake in Tasikmalaya on September 2, 2009, and identify the physical and social factors that cause vulnerability in the Pangalengan District area to the earthquake.

Methods

The method used in this research is descriptive qualitative, interpretation of remote sensing maps, and secondary data analysis from relevant agencies. Primary and secondary data are taken in the field—for example, the physical and social description of the area damaged by the earthquake in Tasikmalaya. Secondary data assessment from the literature related to the problem being examined, in the form of regulatory documents, research results that were previously related to the research location, interpretation, and analysis of geological maps, maps of the earth, maps of earthquakes, and land use.

To analyze an area that is prone to earthquake disasters based on the reference of Law No. 24 of 2007 concerning Disaster Management, Law No. 26 of 2007 concerning Spatial Planning and Minister of Public Works Decree No. 21 / PRT / M / 2007 concerning Spatial Planning Guidelines for Areas Prone to Volcanic Eruptions and Earthquakes. Determination of earthquake-prone areas is based on an assessment of the area indicated as having a potential disaster or a location that is expected to occur.

The assessment to determine whether an area is declared prone to earthquakes requires supporting data on the land's physical condition, such as rock type, geological structure, slope, and soil stability. The community's social conditions, such as population, population structure, settlement patterns, and quality of houses/buildings. These data are complementary in determining an earthquake and tsunami-prone area.

The physical characteristics of earthquake-prone areas are determined based on the earthquake risk level based on geological information and stability assessment. The method of calculation has been simplified in Table 2. Based on this, the earthquake-prone areas can be divided into six types of regions which are described as follows:

Type A, this area is located far from fault areas that are vulnerable to earthquake vibrations. This region is also characterized by a combination of debilitating combinations of dominant factors that can damage. If the earthquake intensity is high (Modified Mercalli Intensity / MMI VIII), the damaging effects are mitigated by compact and strong rocks' physical properties.

Type B, the factor that causes the level of earthquake disaster vulnerability in this type, is not caused by one dominant factor but is caused by more than one factor influencing each other, namely high earthquake intensity (MMI VIII) and physical properties of medium rocks. This area tends to suffer quite severe damage especially for buildings with simple construction.

Type C, There are at least two dominant factors that cause high vulnerability in this region. Existing combinations include high earthquake intensity and weak physical properties of rocks, or the combination of weak rocks' physical properties and being close to fault zones is quite damaging. This area suffered severe damage and damage to buildings with concrete construction, especially those in the path along the fault zone.

Type D, earthquake hazard, is caused by the accumulation of two or three mutually weakening factors. They are areas with a steep slope, high earthquake intensity and located along the destructive fault zone; or are in areas where the physical properties of rocks are weak, earthquake intensity is high, and the tsunami potential is quite destructive. This area tends to suffer severe damage to all buildings, especially those in the path along the fault zone.

Type E, this area is a fault line that is close to the epicenter, which is reflected by high earthquake intensity, and in some places is at the potential of destructive tsunami lanes. The physical properties of rocks and slopes are also in conditions that are vulnerable to earthquake shocks. This area has fatal damage during an earthquake.

Type F, this area is located in a very destructive tsunami-affected area and along the fault zone is very damaging and areas close to the epicenter where earthquake intensity is high.

This condition is exacerbated by soft rocks' physical properties located in steep to very steep morphological areas that are not strong against earthquake shocks. This area has fatal damage during an earthquake. To analyze an earthquake-prone area by scoring, which is the multiplication of "weighting" and "capability value," and from the results of this multiplication, a class range of values is made, which shows the value of land capability in dealing with natural disasters in earthquake areas. From the results of this multiplication, an assessment of land capability levels can be made as follows:

Table 1. Scoring for disaster-prone areas

Stability Classification	Score Range	Area Type
Stable	30 – 40	A B
Not stable enough	41 – 50	C D
Unstable	50 – 60	E F

Source: Minister of Public Works Regulation No. 21 2007

Table 2. Weighting matrices for the stability of the region against earthquake-prone areas

No	Geological Information	Information Class			Capability Value	Weight	Score
1	Geology (physical properties and rock engineering)	Andesite, granite, diorite, volcanic breccias			1	3	3
		Sandstone, coarse tuff, siltstone, arkose, greywacke, limestone			2		6
		Sand, silt, mudstone, marl, fine tuff, flakes			3		9
		organic clay, peat			4		12
2	Slope	Nearly level (0-7%)			1	3	3
		Moderate sloping (7-30%)			2		6
		Steep (30-140%)			3		9
		Very steep (>140%)			4		12
3	Earthquake	MMI		Richter		5	
		I, II,III,IV,V	<0,05g	<5	1		5
		VI, VII	0,05-0,15g	5-6	2		10
		VIII	0,15-0,30g	6-6,5	3		16
		IX, X, XI, XII	>0,30g	>6,5	4		20
4	Geological Structure	Far from fault zone			1	4	4
		Close to fault zone (100-1000m and fault zone)			2		8
		In the fault zone (<100m from the fault zone)			4		16

Source: Minister of Public Works Regulation No. 21 2007

To measure the value of the ability given in this zoning is from numbers 1 to 4. Value 1 is the highest value of an area for its ability to be stable against geological disasters. Value 4 is the value of an area that is unstable to natural geological disasters. The weighting given in this zoning is from numbers 1 to 5. A value of 1 means that geologic information is very high, meaning that the geological information is the information most needed to determine the zonation of natural disasters. Value 5 is the weight of geologic information that is considered very low importance to measure a zoning area of the disaster plan.

Result and discusion

Physical and Climate Conditions

Most of the Pangalengan Subdistrict is a mountainous or hilly area, astronomically located at its coordinates at 07°07′00″S-07°18′00″S and 107°30′00″E-107°38′00″E. They consist of 13 villages or villages, namely Banjarsari, Lamajang, Margaluyu, Margamekar, Margamukti, Margamulya, Pangalengan, Pulosari, Sukaluyu, Sukamanah, Tribaktimulya, Wanasuka, and Warnasari. With a height above sea level varies between 984 m to 1,571 m. Some villages are located on the forest's edge, but there is one village outside the forest area. Pangalengan Subdistrict is also drained by one of the rivers, the Cisangkuy River and Situ Cileunca, where the river and Situ benefit from the agriculture and tourism sectors, as well as hydropower plants. Besides in Pangalengan District, there is a geothermal power plant.

The area of Pangalengan District is 272.95 Km or 27,294.77 Ha. This area is divided into several categories, including 961.86 Ha of paddy farmland, 22,692.48 Ha of non-paddy agricultural land, and 3,640.45 Ha of non-farm land. The climate in Pangalengan Subdistrict located in the highlands or mountains makes the air temperature in this district quite cool, ranging from 16 0 Celsius - 25 0 Celsius. In 2015 rainfall was 1,996 mm/year with an average of 5.47 mm/day. The highest rainfall recorded was 11.61 mm/day occurred in February, the lowest rainfall in July was recorded at 0.34 mm/day and the highest rainy day in February and the lowest rainy day occurred in July. The administrative boundaries of Pangalengan District are 1) Northside: Cimaung District 2) Southside: Talegong District 3) and Bungbulang District 4) Eastside: Kertasari District 4) Westside: Pasir Jambu District.

Figure 1. Administrative map of Pangalengan District

Pangalengan District, in general, is part of the physiography of the South Bandung regional landscape, consisting of hills, mountains, and plateaus. The mountainous region has the most extensive distribution that can be seen from satellite imagery. Morphology of the Pangalengan Subdistrict is a high plateau (1400 m) narrowly surrounded by mountains such as Mount Malabar (2321 m), Mount Tilu (2042 m), Wayang Mountain (2182 m), and Mount Windu (2054 m). The slope of the Pangalengan Subdistrict is based on the interpretation of topographic maps ranging from ramps (> 8% - 15%) to steep (> 25% - 40%). The relatively steep villages are Margaluyu Village, Margamukti Village, and Margamulya Village. The use of the Pangalengan area is a horticultural farming area, tea, and quinine plantations, Situ Cileunca attractions, Cibolang hot springs, and Geothermal Power Plant (Geothermal Power Plant) PLTG) Puppet - Windu.

Figure 2. Regional Geology and Stratigraphic Map

The geological condition of the Pangalengan Subdistrict, based on the analysis of geological maps Pameungpeuk sheets (Alzwar, 1992) also geological maps of the area of South Bandung (Silitonga, 1973) the rocks that feed them are derived from the eruption/pyroclastic deposits of ancient Pangalengan volcanoes (cataclysmic). The geological structure that developed in the Pangalengan District area based on the analysis of the geological map above is seen as the direction of faults that are trending southeast-northwest (Figure 2).

Impact of Building Damage

The impact of damage to buildings due to the Tasikmalaya earthquake on September 2, 2009, in Pangalengan District, covered almost the entire village, consisting of 22,292 family heads (KK) of victims whose houses were damaged from minor damage to destruction (Table 3). Damaged buildings/houses are generally made of permanent / non-reinforced walls with adequate structures. The distribution of houses/buildings that suffered the most damage that is found in Margamukti Village, Pangalengan, Margamulya, Margamekar, and Sukamanah Village. (Figure 3).

Figure 3. Map of Building Damage Zones in Pangalengan District

Table 3. Building Damage Rates in Pangalengan District

NO	DESA	JML KK	KERUSAKAN BANGUNAN		
			HANCUR	BERAT	RINGAN
1	WANASUKA	318	6	40	272
2	BANJARSARI	617	23	180	414
3	MARGALUYU	1813	129	332	1251
4	SUKALUYU	1278	-	431	827
5	WARNASARI	659	12	172	475
6	PULOSARI	552	84	143	325
7	MARGAMEKAR	1.025	121	338	666
8	SUKAMANAH	3.530	270	1.184	2076
9	MARGAMUKTI	3.241	462	1.245	1.534
10	PANGALENGAN	4.957	428	1.664	2865
11	MARGAMULYA	3.514	257	902	2355
12	TRIBAKTIMULYA	442	21	124	290
13	LAMAJANG	346	6	80	260
	JUMLAH	22.292	1.819	6.735	13730

Sumber : Kecamatan Pangalengan 2009

Physical Hazard of Land in Pangalengan District

The factors that influence the Pangalengan District area's vulnerability to the earthquake disaster are caused by more than two factors that weaken each other, namely:

First, the condition of rock types covering it due to Pleistocene volcanic/volcanic sedimentation activity with rock physical properties has not been consolidated (weak), so that if an earthquake occurs the damaging effect cannot be mitigated, so the impact will cause more severe damage.

Second, the geological structure consists of directional trending faults of the northwestern northwest. It is estimated that there is a fault that cuts through the Caldera-Malabar, which results in the shape of the hills being cut into gawir (the Gunung Tilu - Malabar fault). The geological structure is a reflection of how much an area is experiencing "whipping" tectonics. The more complex the geological structure that develops in an area, it shows that the region tends to be an unstable region.

Third, hilly morphology with a slope from slope to steep can be seen from satellite images. The slope can provide an overview of the level of stability against the possibility of landslides or collapse of soil and rocks, especially when earthquake-prone areas occur. The steeper the slope, the greater the soil and rock movement's potential to occur, even though the type of rock that occupies it is sufficient to prevent landslides from occurring.

Fourth, the earthquake's intensity is quite high because it is close to the epicenter of the earthquake in southern West Java. Seismic factors are information that shows the level of earthquake intensity based on the Mercalli scale, gravity anomaly, and Richter scale. The smaller the earthquake factor number listed in an area, the intensity of earthquake-prone areas in the region will be smaller, and the area will be more stable, vice versa.

Based on the results of regional scoring Pangalengan District is in the range> 40-50, meaning that it includes the classification of unstable regions with the typology of earthquake type C disaster vulnerability.

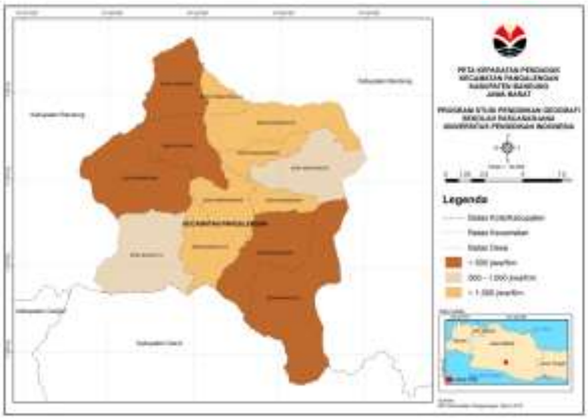

Figure 4. Map of Population Density

Pangalengan Village has the most population compared to other villages in Pangalengan Subdistrict. Likewise, with the overcrowding, Pangalengan Village is a densely populated village, allowing more victims during an earthquake.

Table 4. Scoring of earthquake-prone areas in Kec. Pangalengan

No	Karakaterisik Wilayah	Nilai Kemampuan	Bobot	Skor
01	Batuan Piroklastik (lemah /urai)	3	3	9
02	Dekat Zona Sesar	2	4	8
03	Topografi Landai - Curam	2	3	6
04	Intensitas Gempa Tinggi	4	5	20
	Jumlah			43

Social Vulnerability

Pangalengan Subdistrict is based on the typology of earthquake-prone areas including type C, meaning unstable land conditions prone to earthquake disasters, tend to experience heavy damage especially villages/settlements adjacent to fault zones/lanes, in addition, several things cause Pangalengan District suffered substantial damage.

First, the community ignorance regarding the disaster. The community does not know the right actions to take in an earthquake that causes panic, which can cause more victims.

Second, Most of the people of Pangalengan Village do not know the physical condition of the disaster's unstable and prone location, so there is no anticipation or mitigation done to deal with the earthquake disaster.

Third, the physical condition of the building, which is permanent and not friendly to earthquakes. Most of the building conditions in Pangalengan Village are permanent with inadequate bone structure. Only a few conditions are semi-permanent houses and stilts. Permanent housing conditions will be more easily damaged when affected by an earthquake when compared to houses on stilts.

Fourth, irregular and very dense

settlement patterns. This can be seen from the observations; settlement patterns do not have a good pattern and are not well organized. The distance between buildings is very narrow, so that if a building collapses due to an earthquake does not rule out the possibility of falling on a nearby house.

Fifth, total population and density. Pangalengan Village has the most population compared to other villages in Pangalengan District. Even with the overcrowding, Pangalengan Village is a densely populated village so that there are more victims possible during an earthquake.

Conclusion

The geological condition of Pangalengan Subdistrict consists of volcanic rocks (pyroclastic deposits) which are physically weak, and are traversed by zones. The morphology of the hills with the slope of the slope - steep and near the epicenter of the earthquake in southern West Java with high intensity.

The general condition of the community has never experienced an earthquake with strong shocks (large magnitude). Then the condition of buildings that are not reinforced with adequate concrete bone structure becomes a threat when an earthquake occurs. In addition, the pattern of dense and clustered settlements due to limited land is relatively flat, and the lack of counseling about earthquake disasters from the local government so that there is no preparedness in dealing with disasters.

There are some ideas to mitigate the earthquake disasters in Pangalengan District; socialization needs to be done so that the community knows that the area is prone to earthquake disasters. Most houses/buildings must design to be earthquake-friendly at an affordable cost. Post-disaster area structuring should adjust to the direction of spatial use following spatial planning guidelines for earthquake-prone areas of the Ministry of Public Works No.21 of 2007. And more important is to reduce the impact of the disaster itself by preparing people to 'get used to' living together with disasters, especially for an already built environment, by developing an early warning system and providing guidance on how to prepare for natural disasters, so that people can feel the security and comfort in their lives.

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