International Journal on Advanced Science Engineering Information Technology

Vol.12 (2022) No. 5
ISSN: 2088-5334

# Spatial Analysis of Social Vulnerability to Earthquake Hazard in Bengkulu City

Della Ayu Lestari [a], Dewi Susiloningtyas [b,*]

[a] *Marine Information System, Universitas Pendidikan Indonesia, Jl. Dr. Setiabudi, 40154, Bandung, Indonesia*
[b] *Geography Department, Universitas Indonesia, Margonda Raya, Depok, 16424, Indonesia*
*Corresponding author: *della.ayu@upi.edu*

***Abstract*— As a province on Sumatera's west coast, Bengkulu is prone to earthquakes. The region lies on the meeting of the Indo-Australian Plate, the Eurasian Plate, and the Sumatra Fault. Additionally, it is affected by the Mentawai Fault. Various attempts were made to reduce the impact of an earthquake, for instance, by identifying the region's vulnerability. Variables used in this study were based on Social Vulnerability Index (SOVI) by Susan L. Cutter, such as the number of people working in the informal sector and the population density to determine exposure. Other variables in the index include the proportions of vulnerable age population, impermanent houses to determine sensitivity, wealthy households, high school graduates and above, and social capital to determine adaptive capacity. This research aimed to map the vulnerability of the region. It followed social indicators connected to the Peak Ground Acceleration of ≥ 5.0 RS earthquake in 2000-2015. The overlay approach and scoring were used to conduct this village-based study. If the regions were farther from the city center, vulnerability levels tended to be lower; the south is an exception. The research also found an interesting pattern of vulnerability levels to earthquakes. The vulnerability level in the high PGA region was high and very high when the magnitude ranged between 5.0 and 5.9 RS. Meanwhile, the region's vulnerability was high and very high in the low PGA region if the magnitude reached 6.0 to 7.9 RS.**

***Keywords*— Earthquake; peak ground acceleration; region vulnerability; social indicator; spatial pattern.**

*Manuscript received 6 May. 2020; revised 24 Feb. 2021; accepted 19 Apr. 2022. Date of publication 31 Oct. 2022.*


## I. INTRODUCTION

Indonesia is located at the intersection of three world's major tectonic plates: Hindia-Australian, Eurasian, and Pacific Plates [1]. Some provinces are affected by this position, for example, Bengkulu Province in the southwest of Sumatera which is affected by the Indo-Australian and Eurasian Plates. This region is also crossed by Sumatera Fault (Semangko Fault) and influenced by the Mentawai Fault [2]. There were two earthquakes in Bengkulu Province from 2000 to 2015 recorded as national disasters. The first was in 2000 with a 7.3 Richter Scale, and a bigger earthquake was documented in 2007 with a 7.9 Richter Scale [2]. Research findings show that its impact on residents was profound because of the magnitude of the disaster. [3] Compared to all regions in the Province of Bengkulu, the biggest loss due to the earthquake hazard was in the most populous region, Bengkulu City [4] In general, existing vulnerabilities of the current population and properties can be associated with the potential risk of seismic activities [5].

Various attempts were made to reduce the impacts or risks of the earthquake, for example, by determining the level of vulnerability [1], [6]. Vulnerability is often associated with an internal risk factor of the subject or system exposed to a danger that reflects its innate predisposition to be harmed or damaged [7]. In particular, this study focused on social vulnerability as a multidimensional construct. This concept enables us to recognize the qualities and experiences of a community or a person allowing them to respond to and recover from the hazard [8], [9]. This study introduce a general framework of a predictive modeling approach to quantifying social vulnerability given intensity during a response or recovery phase [10]. Several generally accepted social vulnerability indicators include population density, age, sex, race, socioeconomic status, educational status, quality of human settlements, and the environment. This indicator is important in understanding regional vulnerability based on social indicators because these characteristics affect the potential for economic loss, injury, and death in a disaster [11]–[13]. The level of vulnerability in this study was examined using three indicators, called levels of exposure, sensitivity, and adaptive capacity. These were made according to social indicators [14]. They were then associated with the Peak Ground Acceleration (PGA) for 16 years in Bengkulu Province. Peak ground acceleration (PGA) is one of the critical factors that affect the determination of earthquake intensity. PGA is generally utilized to describe ground-motion in a particular zone [15].

This research used peak ground acceleration (PGA) for the seismic data to observe bedrock depths deeper than 30 m under the Earth's surface [16]. Research on PGA in Bengkulu City was conducted in 2012 [17], but the data used was restricted to the occurrence of earthquakes in Bengkulu City. Meanwhile, the major damage that occurred in Bengkulu City was caused by earthquakes outside Bengkulu City. Therefore, the data used in this study was collected from earthquake data in Bengkulu Province. Since an earthquake releases wave energy that travels throughout entire directions, Bengkulu City would still be affected by the earthquake even though the epicenter is located outside Bengkulu City [8].

This research aimed to identify and map regional social vulnerability in Bengkulu City and its distribution from earthquake hazards in Bengkulu Province with Peak Ground Acceleration (PGA) analysis. The results of this study are expected to be used as references to mitigation, where disaster anticipation and management will be more effective and efficient [18]. Data with the spatial format was presented in the form of maps and cross tables to facilitate the interpretation of the social vulnerability toward an earthquake.

## II. MATERIAL AND METHOD

### A. *Variables and Data*

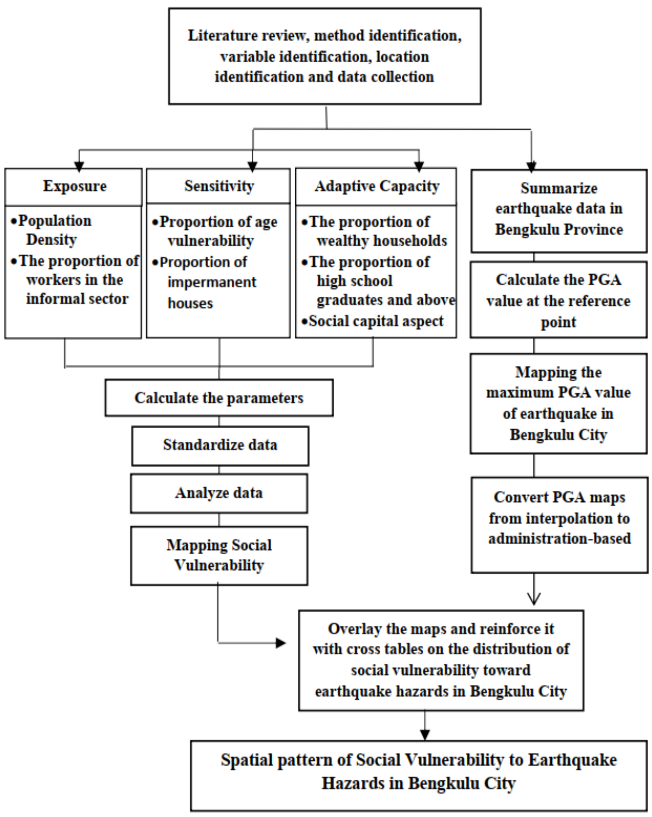


Fig. 1 Flow chart of data processing

Social vulnerability illuminates differences in human capacity to prepare for, respond to, and recover from disasters. It varies over space and time and among social groups, largely due to variations in socioeconomic and demographic features [19]-[20] study used several variables from Social Vulnerability Index (SOVI) [11]–[13], [21], a concept by Susan L. Cutter, to determine the region's vulnerability based on social indicators. This index consists of three variables. The first variable is exposure covering the number of people working in the informal sector and population density. Meanwhile, the second variable is called sensitivity, represented by the ratio of vulnerable age population and non-permanent houses. Finally, variables of adaptive capacity refer to the proportion of wealthy households, individuals who graduated from high school and above, and social capital.

The social vulnerability level is associated with the maximum Peak Ground Acceleration (PGA) value. It provides a general picture of how the earthquake severely affected each village for 16 years to obtain a spatial analysis of social vulnerability to earthquakes in Bengkulu City (Fig. 1). Data on exposure, sensitivity, and adaptive capacity were obtained from the Profile and District Monograph of Bengkulu City. Further, data on earthquakes were obtained from the Meteorological, Climatological, and Geophysical Agency (BMKG) of Bengkulu Province and the United States Geological Survey (USGS). After that, Statistics Indonesia (BPS) Bengkulu City provided the spatial data of village administration. In this study, the vulnerability data was processed by calculating the following parameters (Table 1) and standardizing the data to have the same size with a minimum range of 1 and a maximum range of 2.

TABLE I
CALCULATION OF PARAMETERS OF EACH VARIABLE

| No. | Parameter | Calculation of Parameters |
|---|---|---|
| 1. | Population density | $\frac{\Sigma \text{ population}}{\text{village's area}}$ |
| 2. | The proportion of workers in the informal sector | $\frac{\Sigma \text{ workers in informal sector}}{\Sigma \text{ workers all sectors}}$ |
| 3. | The proportion of the vulnerable age population | $\frac{\Sigma \text{ population aged } 0-4 \text{ years} + \text{population aged} > 60 \text{ years old}}{\Sigma \text{ village's population}}$ |
| 4. | The proportion of impermanent houses | $\frac{\Sigma \text{ impermanent houses}}{\Sigma \text{ permanent houses+semi permanent houses +impermanent houses}}$ |
| 5. | The proportion of wealthy households | $\frac{\Sigma \text{ wealthy household}}{\Sigma \text{ household}}$ |
| 6. | The proportion of high school graduates and above | $\frac{\Sigma \text{ high school graduates and above}}{\Sigma \text{ elementary school} + \text{junior high school} + \text{high school gradite and abobe}}$ |
| 7. | Social capital aspect | $\Sigma$ community organization |

$$X' = a + \frac{(\text{Xi}-\text{Xmin})(b-a)}{\text{Xmax}-\text{Xmin}} \quad (1)$$

Where :
X ' = value of standardized data
Xi = value of data to-i
Xmax = Maximum value of data
Xmin = Minimum value of data
a = Minimum value of range
b = Maximum value of range

Using the equal interval method, every vulnerability indicator in this study was classified into five categories. It is important to note that each variable has been summed up and standardized. This method divided each class with the same interval, as shown in Table II below. All indicators should be incorporated into the vulnerability index to determine the vulnerability level. The social vulnerability level was measured using the following formula [14]:

$$v = \frac{E \times S}{AC} \quad (2)$$

Where :
V = vulnerability
E = exposure
S = Sensitivity
AC = Adaptive Capacity

TABLE II
CLASS INTERVAL OF EACH INDICATOR

| Class | Indicator | | | |
|---|---|---|---|---|
| | **Exposure** | **Sensitivity** | **Adaptive Capacity** | **Vulnerability** |
| Very low | ≤1.20 | ≤1.20 | ≤1.20 | ≤1.20 |
| Low | 1.21-1.40 | 1.21-1.40 | 1.21-1.40 | 1.21-1.40 |
| Moderate | 1.41-1.60 | 1.41-1.60 | 1.41-1.60 | 1.41-1.60 |
| High | 1.61-1.80 | 1.61-1.80 | 1.61-1.80 | 1.61-1.80 |
| Very high | >1.80 | >1.80 | >1.80 | >1.80 |

The Peak Ground Acceleration (PGA) was calculated using Richter's formula. The result was then integrated into the intensity attenuation formula by Ibrahim and Subardjo [22]. It measures earthquakes' magnitude, epicenter distance, and intensity. The present study employed the earthquake epicenter in the Province of Bengkulu. The boundary coordinates were 2°16 '36" South Latitude to 5°26'32" South Latitude and 101°1'24" East Longitude to 103°45'48" East Longitude. There were 284 earthquake's epicenters with a total of 67 references based on weight point in each village in Bengkulu City. To obtain the PGA values of the earthquake, mathematical formulas were then written as the following [22]–[25]. The distance of the epicenter to a specific location X was calculated:

$$\cos\Delta = \cos LE \ \cos LX + \sin LE \ \sin LX \ \cos(\lambda E - \lambda X) \quad (3)$$

Where :
$L_X$ = Latitude of X
$\lambda_X$ = Longitude of X
$L_E$ = Latitude of Epicenter
$\lambda_E$ = Longitude of Epicenter
Δ = Distance between Epicenter and X in degrees

The Δ can be changed from degrees to kilometers by multiplying the value of Δ with 111.11 for every 1°. (This calculation only applies for areas around the equator line). Furthermore, the intensity of the hypocenter can be measured through the Richter Empirical method:

$$Io = 1.5\,(M - 0.5) \quad (4)$$

where:
Io = Source Intensity;
M = Magnitude/body wave (Richter Scale).

Meanwhile, the intensity of location X can be calculated using the constant attenuation formula:

$$I = (Io \times \exp - b\Delta) \quad (5)$$

Where :
I = Surface Intensity;
Io = Source Intensity
Δ = Distance between Epicenter and X
B = Attenuation Constant (0.00217)
exp = Natural Number (2.786).

Richter Empirical formula can be applied to identify the value of PGA in Location X :

$$\log\alpha = \left(\frac{I}{3}\right) - 0.5 \quad (6)$$

Where :
α = PGA in gals (cm/second$^2$);
I = Surface Intensity (MMI);
3 and 0.5 = constant

## B. Analysis

This study divided the PGA value into two groups based on the earthquake's magnitude: magnitude 5.0 – 5.9 RS and magnitude 6.0 – 7.9 RS. The distribution of earthquake's PGA rates was made into one value per village to see the distribution of the region's vulnerability toward earthquakes per village. It was counted by summing up each proportion of region's area in each class multiplied by the median of its PGA Class. Once the value of PGA per village was obtained, it was then divided into five categories, and these categories would have equal intervals, as shown in Table III below.

TABLE III
PEAK GROUND ACCELERATION INTERVAL PER VILLAGE

| Class | PGA (gal) | |
|---|---|---|
| | **Magnitude 5.0 –5.9 RS** | **Magnitude 6.0-7.9 RS** |
| Very low | ≤133.5 | ≤407.5 |
| Low | 133.6-135 | 407.6-427.5 |
| Moderate | 135.1-136.5 | 427.6-447.5 |
| High | 136.6- 138 | 447.6-467.5 |
| Very high | >138 | >467.5 |

The distribution of the region's vulnerability to the earthquake in Bengkulu City was determined by overlaying the vulnerability's map and the PGA distribution's map for each village. The overlaid maps then reported on the cross table analysis with the total villages based on vulnerability's rate and the total villages based on the maximum PGA value per village. This analysis aims to determine whether the region with high vulnerability is located in the region with high PGA or otherwise.

## III. Results and Discussion

### *A. Exposure*

This study divided the exposure level into two variables. The first variable is population density. When population density and the number of workers in the informal sector in certain regions increase, the level of exposure will be higher. Low density was generally dominated in the eastern and southern parts of Bengkulu City and quite far from the city center. Meanwhile, the high and very high population density was concentrated in the northwestern part of Bengkulu, especially in Teluk Segara and Ratu Samban sub-districts. These locations had become the center of city activities since the colonial era.

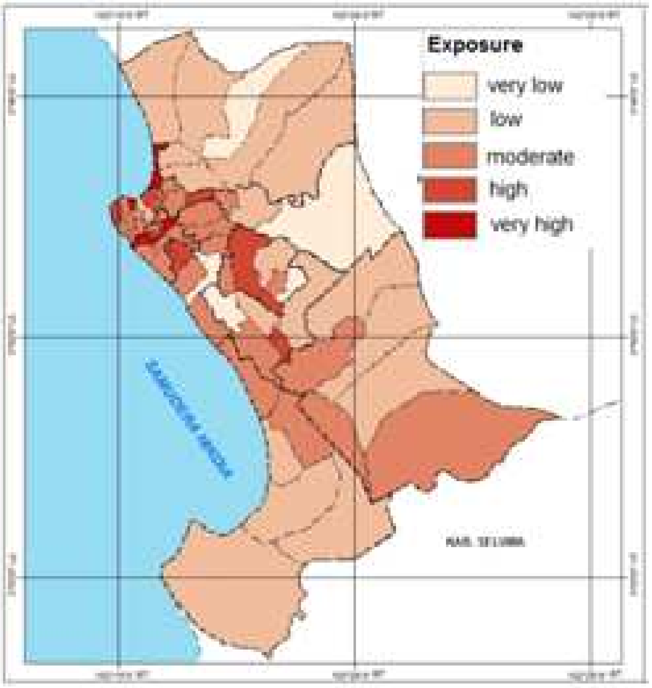


Fig. 2 The level of exposure by villages in Bengkulu city

The second exposure variable is the ratio of people working in the informal sectors. These people will only earn income from work at a certain time [12], [26]. When the disaster strikes, they will be more likely to be exposed to those disasters and more at risk of losing their livelihoods [27]. In the northwestern part of Bengkulu City, the dominant informal occupation sectors were fishermen and traders, while farmers and traders dominated the central and southern parts. The level of exposure was obtained by summing up and standardizing the first and second variables Fig. 2 shows that the moderate level of exposure was dominated by a total of 29 villages or 43.28%, while the very high level of exposure was only located in 4 villages or 5.97% which spreads in the northwestern part of Bengkulu City.

### *B. Sensitivity*

The sensitivity level consisted of the vulnerable age population ratio and the number of impermanent houses. The area is considered more sensitive if the vulnerable age population and the impermanent house ratios are high. The area is usually characterized by informal, unplanned housing with limited access to land. In addition, it is typically overcrowded, low quality, and has a complex set of social, institutional, and economic processes [28]. Then vulnerable ages have problems in their movement if an earthquake happens [9], [29]. This study concentrated on areas with high and very high vulnerable age populations in the west part of Bengkulu City. Furthermore, building quality is related to the resilience of the building as a function of residence. Hence, the number of impermanent houses will affect the opportunities for homelessness [16]. The proportion of areas with high and very high impermanent houses were located in the northwestern part of Bengkulu City or coastal areas with high population density.

By these two variables, sensitivity levels in Bengkulu City can be obtained. This level was obtained by summing up the proportion of the vulnerable age population and the impermanent houses ratio. The variables must be standardized beforehand. Interestingly, it was dominated by a very low level of sensitivity, with a total of 22 villages or 32.84%. Meanwhile, the very high level of sensitivity was only located in 6 villages or 8.95%, which also spread in the northwestern part of Bengkulu City (Fig. 3). These areas had had high proportions of vulnerable age population and unviable houses.

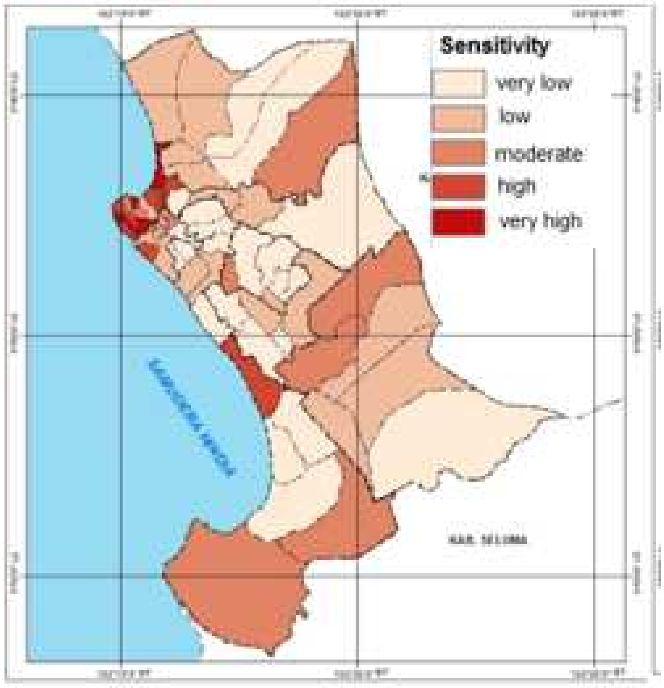


Fig. 3 The level of sensitivity by the village in Bengkulu city

### *C. Adaptive Capacity*

Adaptive capacity can help reduce social vulnerability and make communities more resilient [30]. Variables of adaptive capacity involved the ratio of wealthy families, individuals who graduated from high school and above, and aspects of social capital. The higher level of each variable, the smaller the vulnerability [14]. Wealthy households made it possible to recover quickly from disasters as they could satisfy their basic needs. Hence, they were easily accessible to essential services, such as health and education [12]. This study then found certain areas with moderate to very high wealthy households. These areas were distributed almost all over Bengkulu City. People with a higher level of education (graduates of high school and above) had more ability to understand information and recover from disasters [21]. The proportion of areas with moderate to very high school graduates and above was located in the north and west of Bengkulu City. Then, the social capital aspects of a village were reviewed based on the number of community organizations. The existence of community organizations in a village can contribute to and support to assist the people in dealing with a disaster either before or after the disaster occurs [29]. The western part of Bengkulu City was an area with many community organizations.

The level of adaptive capacity was obtained by summing up and standardizing its variables. Interestingly, Bengkulu City had 21 villages (31.34%) classified as having a high adaptive capacity. Meanwhile, the region with a very low level of adaptive capacity was located in 8 villages or 11.94%. Fig. 4 shows that this region was dominated by moderate to a very high level of adaptive capacity, especially in the center and the northern part of Bengkulu City.

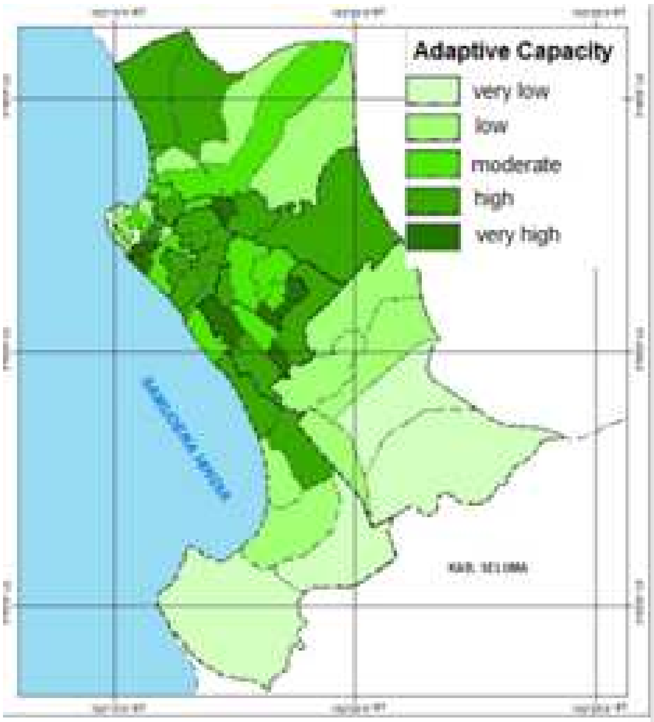


Fig. 4 The level of adaptive capacity of a village in Bengkulu city

*D. Region's Vulnerability Based on Social Indicators*

As argued earlier, region's vulnerability in this study followed social indicators. It was measured using the vulnerability formula [14], which calculates exposure, sensitivity, and adaptive capacity. Fig. 5 illustrates the distribution of the region's vulnerability level in Bengkulu City, which is generally classified as low and very low.

This low level of vulnerability could be caused by several factors, such as a high level of exposure, sensitivity, and adaptive capacity. The study found that 45 out of 67 villages in Bengkulu City fell into moderate to a very high level of adaptive capacity. Further, highly vulnerable regions were found in the northwestern part of Bengkulu City (City Center of Bengkulu City), located in Teluk Segara and Ratu Samban district, especially in the seaside areas.

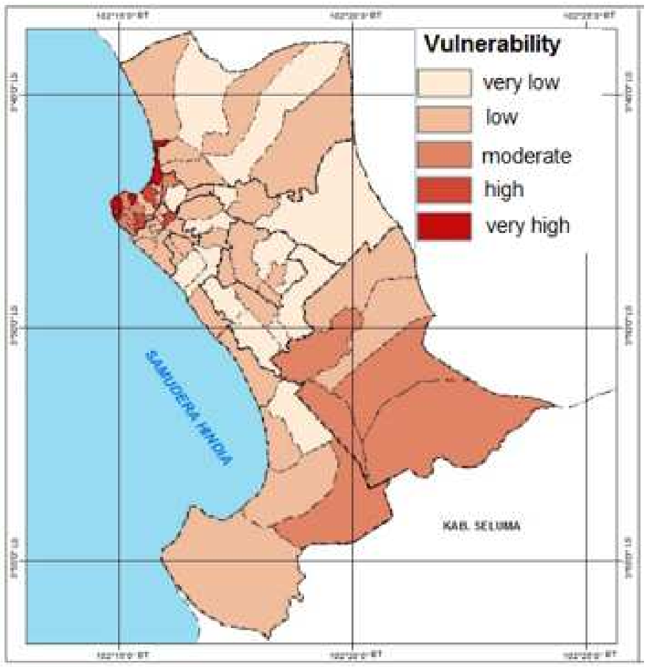


Fig. 5 The level of region'*s vulnerability based on social indicators* by villages in Bengkulu city

*E. The Distribution of Earthquakes in Bengkulu Province*

Earthquakes often occur in Bengkulu province. Between 2000 and 2015, 284 earthquakes were recorded with a strength of 5.0 to 7.9 Richter Scale and a depth of less than 100 km. An earthquake with a magnitude of 5.0 to 5.9 Richter Scale occurred as much as 266 times, while an earthquake with a strength of 6.0 to 7.0 Richter Scale occurred as much as 16 times. Finally, earthquakes with strength above 7.0 Richter Scale occurred two times with magnitudes of 7.3 and 7.9 on the Richter Scale (Fig. 6).

*F. Distribution of PGA's Region by Village in Bengkulu City*

Based on the PGA on magnitude 5.0-5.9 RS, the distribution of PGA's region in Bengkulu City with the lowest value, as shown in Fig. 6, was 130.60 gal. The highest value was 140.33 gal. The highest value of PGA was located in the center of Bengkulu City, and the value decreased as it came closer to the northern and southern. PGA from the earthquake's data on 6$^{th}$ June 2000 with a magnitude of 5.9 RS had a significant impact on every village in Bengkulu City with a range of VIII on the MMI scale (a few damage for well designed and constructed buildings; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken) [29]. PGA of each village on magnitude 5.0-5.9 RS was dominated by a very high level of PGA that was located at the center and southern part of Bengkulu City and spread to 29 villages or 43.28%, while the very low level of PGA was located at three villages or 4.48% (fig. 7).

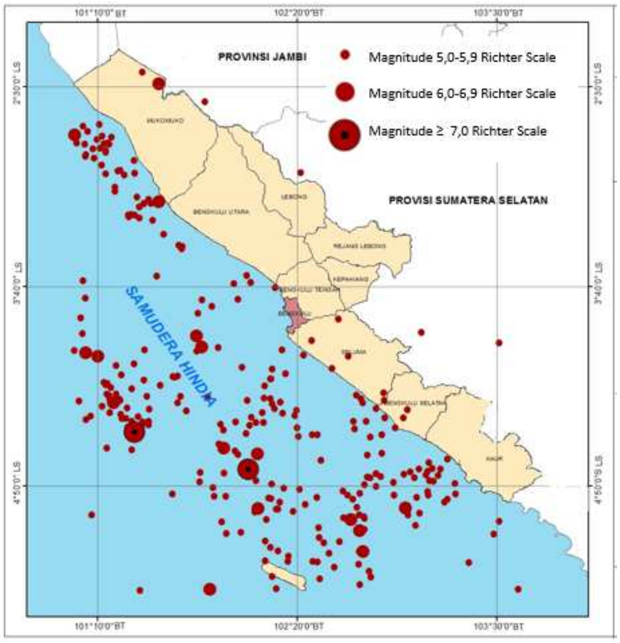


Fig. 6 The distribution of earthquakes in Bengkulu Province

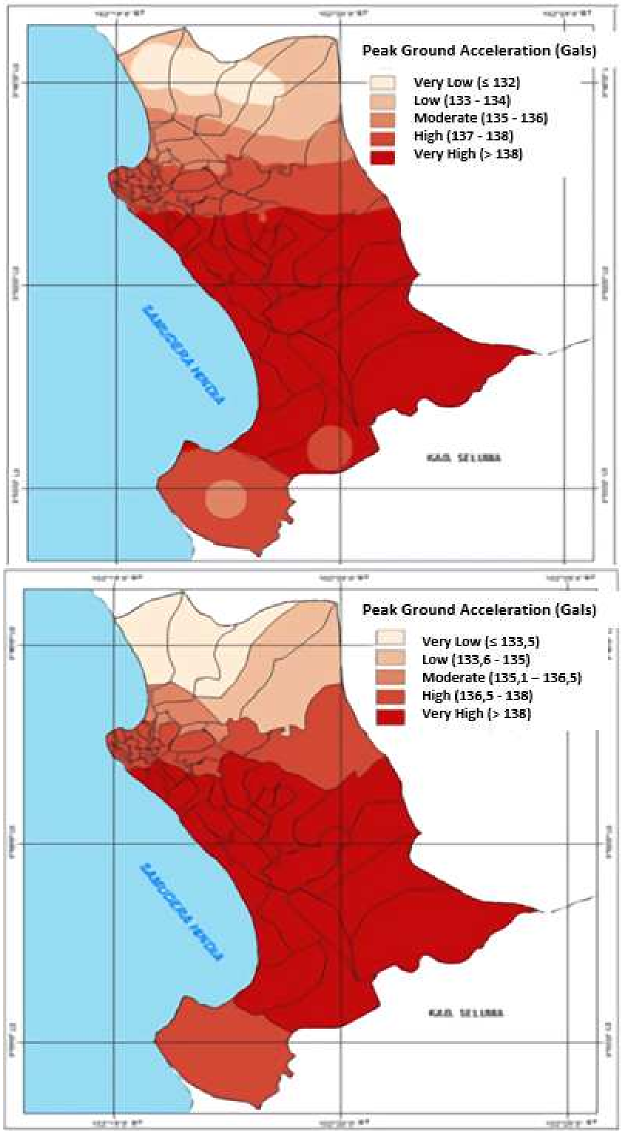


Fig. 7 Distribution of PGA's Interpolation Result (above) and PGA's Distribution by Village (below) at Magnitude 5.0 to 5.9 Richer Scale

TABLE IV.
CROSS TABLE OF REGION'S VULNERABILITY AND PGA DISTRIBUTION BY VILLAGE ON MAGNITUDE 5.0-5.9 RICHTER SCALE

| PGA | vulnerability | | | | |
|---|---|---|---|---|---|
| | **Very Low** | **Low** | **Moderate** | **High** | **Very High** |
| Very Low | 1 | 2 | 0 | 0 | 0 |
| Low | 1 | 1 | 0 | 0 | 0 |
| Moderate | 1 | 3 | 1 | 0 | 1 |
| High | 3 | 12 | 6 | 3 | 3 |
| Very High | 9 | 15 | 5 | 0 | 0 |

On magnitude 6.0-7.9 RS, the lowest PGA value was 376.14 gal. On the other hand, the highest PGA's value was 506.90 gal. The highest value of PGA was located in the southern part of Bengkulu City, and the value decreased as it came up to the northern. The PGA from the earthquake's data on $12^{th}$ September 2007 with magnitude 7.9 RS significantly impacted every village in Bengkulu City with range IX on MMI Scale (Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage is great in substantial buildings, with partial collapse. Buildings shifted off foundations) [12]. PGA in each village with magnitude 6.0-7.9 RS was dominated by a low level of PGA located in 40 villages (59.70%) and spread in the northern part of Bengkulu City. Meanwhile, the very high level of PGA was located in 3 villages (4.48%), spreading in the southern part of Bengkulu City (fig. 8). The distribution of region's vulnerability to the earthquake in Bengkulu City was determined by overlaying the vulnerability's map and the PGA distribution's mapping for each village, as reported in the analysis of cross-table (See Table 4).

On magnitude 5.0-5.9 RS (Table IV), high and very high level of vulnerability was directly proportional to the high level of PGA, which spread in the city center of Bengkulu City. With "high-risk level one" [26] or level VIII on MMI scale, Bajak Village, Pasar Melintang Village, Belakang Pondok Village, Pasar Bengkulu Village, Malabero Village, Pondok Besi Village, and Sumur Meleleh Village became the most affected and disadvantaged region and the hardest to recover from the earthquake of all villages.

TABLE V
CROSS TABLE OF REGION'S VULNERABILITY AND PGA DISTRIBUTION BY VILLAGE ON MAGNITUDE 6.0-7.9 RICHTER SCALE

| PGA | vulnerability | | | | |
|---|---|---|---|---|---|
| | **Very Low** | **Low** | **Moderate** | **High** | **Very High** |
| Very Low | 2 | 5 | 1 | 0 | 1 |
| Low | 8 | 20 | 6 | 3 | 3 |
| Moderate | 4 | 5 | 2 | 0 | 0 |
| High | 1 | 1 | 2 | 0 | 0 |
| Very High | 0 | 2 | 1 | 0 | 0 |

Then, on magnitude 6.0-7.9 RS (Table V), the value of the vulnerability shifts from high and very high to low and very low. However, the magnitude of the earthquake had a greater risk as a whole, which included "very high-risk level one" [26] or level XI on the MMI scale. Although the high and very high levels of vulnerability spread to low and very low PGA's region, with high disaster risk, still the region with a high level of vulnerability was the most potential area to get the biggest impact and the hardest to recover from disaster.

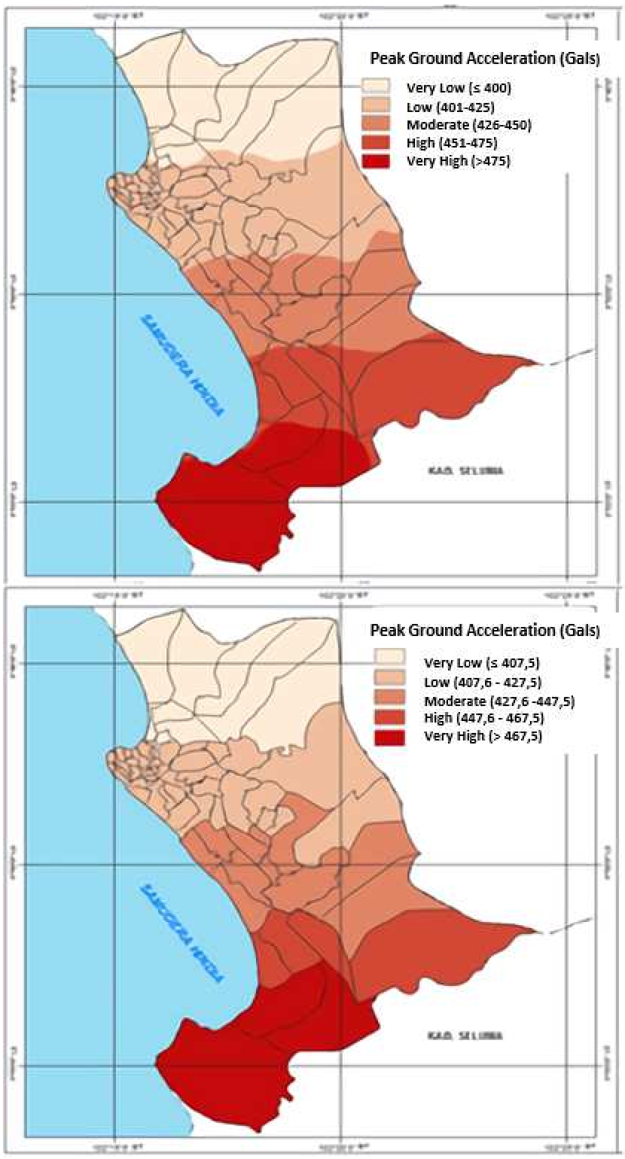


Fig. 8 Distribution of PGA's Interpolation Result (above) and PGA's Distribution by Village (below) at Magnitude 6.0 to 7.9 Richer Scale

## IV. Conclusion

The spatial pattern of region's vulnerability indicated that the vulnerability value would get lower when the distance is farther away from the city center. The exception was for the south, as the region generally had a moderate vulnerability. About 70% of villages in Bengkulu City were classified as having a moderate to very low level of vulnerability and generally spread away from the city center, and seven villages were classified as high and very high and spread in the city center. The pattern of the region's vulnerability based on social indicators towards earthquakes of magnitude 5.0-5.9 RS with the high and very high level of region's vulnerability was also located on the high level of PGA's region. A different pattern occurred to patterns of region's vulnerability based on social indicators on magnitude 6.0-7.9 RS as that high and very high level of region's vulnerability was located on the low level of PGA's region.

## References

[1] D. A. Lestari and B. Sakti, “Social vulnerability to earthquake hazard at Pringsewu District, Lampung Province,” *IOP Conf Ser Earth Environ Sci*, vol. 561, no. 1, p. 012046, Aug. 2020, doi: 10.1088/1755-1315/561/1/012046.

[2] Z. Zheng, S. Jin, and L. Fan, “Co-seismic deformation following the 2007 Bengkulu earthquake constrained by GRACE and GPS observations,” *Physics of the Earth and Planetary Interiors*, vol. 280, pp. 20–31, Jul. 2018, doi: 10.1016/j.pepi.2018.04.009.

[3] M. A. Thiri, “Uprooted by tsunami: A social vulnerability framework on long-term reconstruction after the Great East Japan earthquake,” *International Journal of Disaster Risk Reduction*, vol. 69, p. 102725, Feb. 2022, doi: 10.1016/j.ijdrr.2021.102725.

[4] National Agency for Disaster Management, “National Disaster Management Plan/2010-2014,” 2010.

[5] N. S. Sauti, M. E. Daud, M. Kaamin, and S. Sahat, “GIS spatial modelling for seismic risk assessment based on exposure, resilience, and capacity indicators to seismic hazard: a case study of Pahang, Malaysia,” *Geomatics, Natural Hazards and Risk*, vol. 12, no. 1, pp. 1948–1972, Jan. 2021, doi: 10.1080/19475705.2021.1947903.

[6] C. C. Anderson, M. Hagenlocher, F. G. Renaud, Z. Sebesvari, S. L. Cutter, and C. T. Emrich, “Comparing index-based vulnerability assessments in the Mississippi Delta: Implications of contrasting theories, indicators, and aggregation methodologies,” *International Journal of Disaster Risk Reduction*, vol. 39, p. 101128, Oct. 2019, doi: 10.1016/j.ijdrr.2019.101128.

[7] R. M. da S. P. Vieira *et al.*, “Characterizing spatio-temporal patterns of social vulnerability to droughts, degradation and desertification in the Brazilian northeast,” *Environmental and Sustainability Indicators*, vol. 5, p. 100016, Feb. 2020, doi: 10.1016/j.indic.2019.100016.

[8] D. S. K. Thomas, S. Jang, and J. Scandlyn, “The CHASMS conceptual model of cascading disasters and social vulnerability: The COVID-19 case example,” *International Journal of Disaster Risk Reduction*, vol. 51, p. 101828, Dec. 2020, doi: 10.1016/j.ijdrr.2020.101828.

[9] B. K. Badmos *et al.*, “Micro-level social vulnerability assessment towards climate change adaptation in semi-arid Ghana, West Africa,” *Environ Dev Sustain*, vol. 20, no. 5, pp. 2261–2279, Oct. 2018, doi: 10.1007/s10668-017-9988-7.

[10] Y. (Victor) Wang, P. Gardoni, C. Murphy, and S. Guerrier, “Empirical Predictive Modeling Approach to Quantifying Social Vulnerability to Natural Hazards,” *Ann Am Assoc Geogr*, vol. 111, no. 5, pp. 1559–1583, Jul. 2021, doi: 10.1080/24694452.2020.1823807.

[11] S. L. Cutter and S. Derakhshan, “Implementing Disaster Policy: Exploring Scale and Measurement Schemes for Disaster Resilience,” *J Homel Secur Emerg Manag*, vol. 16, no. 3, Sep. 2019, doi: 10.1515/jhsem-2018-0029.

[12] S. L. Cutter, B. J. Boruff, and W. L. Shirley, “Social Vulnerability to Environmental Hazards *,” *Soc Sci Q*, vol. 84, no. 2, pp. 242–261, Jun. 2003, doi: 10.1111/1540-6237.8402002.

[13] S. L. Cutter, “The Perilous Nature of Food Supplies: Natural Hazards, Social Vulnerability, and Disaster Resilience,” *Environment: Science and Policy for Sustainable Development*, vol. 59, no. 1, pp. 4–15, Jan. 2017, doi: 10.1080/00139157.2017.1252603.

[14] B. L. Turner *et al.*, “A framework for vulnerability analysis in sustainability science,” *Proceedings of the national academy of sciences*, vol. 100, no. 14, pp. 8074–8079, 2003.

[15] M. M. Hason, A. N. Hanoon, and A. A. Abdulhameed, “Particle swarm optimization technique based prediction of peak ground acceleration of Iraq’s tectonic regions,” *Journal of King Saud University - Engineering Sciences*, Jun. 2021, doi: 10.1016/j.jksues.2021.06.004.

[16] M. Munirwansyah, M. A. Fulazzaky, H. Yunita, R. P. Munirwan, J. Jonbi, and K. Sumeru, “A new empirical equation of shear wave velocity to predict the different peak surface accelerations for Jakarta city,” *Geod Geodyn*, vol. 11, no. 6, pp. 455–467, Nov. 2020, doi: 10.1016/j.geog.2020.05.003.

[17] A. I. Hadi, M. Farid, and Y. Fauzi, “Pemetaan percepatan getaran tanah maksimum dan kerentanan seismik akibat gempa bumi untuk mendukung Rencana Tata Ruang dan Wilayah (RTRW) Kota Bengkulu,” *Jurnal Ilmu Fisika Indonesia*, vol. 1, no. 2, pp. 81–86, 2012.

[18] D. A. Lestari, N. S. Fitriasari, T. E. Ahmad, D. R. Azhari, and A. Rais, “Distribution of peak ground acceleration in Pandeglang Regency,

Banten," *IOP Conf Ser Earth Environ Sci*, vol. 846, no. 1, p. 012007, Sep. 2021, doi: 10.1088/1755-1315/846/1/012007.

[19] T. Fraser, "Japanese social capital and social vulnerability indices: Measuring drivers of community resilience 2000–2017," *International Journal of Disaster Risk Reduction*, vol. 52, p. 101965, Jan. 2021, doi: 10.1016/j.ijdrr.2020.101965.

[20] X. Fu and W. Zhai, "Examining the spatial and temporal relationship between social vulnerability and stay-at-home behaviors in New York City during the COVID-19 pandemic," *Sustain Cities Soc*, vol. 67, p. 102757, Apr. 2021, doi: 10.1016/j.scs.2021.102757.

[21] S. L. Cutter, "Risk," in *Companion to Environmental Studies*, N. Castree, M. Hulme, and J. D. Proctor, Eds. Routledge, 2018.

[22] G. Ibrahim and Subardjo, *Pengetahuan Seismologi*. Badan Meteorologi dan Geofisika. Jakarta, 2005.

[23] D. A. Lestari, D. Susiloningtyas, M. Hartanto, T. E. Ahmad, D. R. Azhari, and A. Rais, "Spatial Patterns of Peak Ground Acceleration (PGA) Earthquake on Final Disposal Sites Plan in Samosir Regency," in *IOP Conference Series: Materials Science and Engineering*, 2021, vol. 1062, no. 1, p. 12010.

[24] N. V. Silacheva, U. K. Kulbayeva, and N. A. Kravchenko, "On the realization of seismic microzonation of Almaty (Kazakhstan) in ground accelerations based on the 'continual' approach," *Geod Geodyn*, vol. 11, no. 1, pp. 56–63, Jan. 2020, doi: 10.1016/j.geog.2019.07.006.

[25] N. V. Silacheva, U. K. Kulbayeva, and N. A. Kravchenko, "Probabilistic seismic hazard assessment of Kazakhstan and Almaty city in peak ground accelerations," *Geod Geodyn*, vol. 9, no. 2, pp. 131–141, Mar. 2018, doi: 10.1016/j.geog.2017.11.002.

[26] H. Gu *et al.*, "A hierarchical pattern of urban social vulnerability in Shanghai, China and its implications for risk management," *Sustain Cities Soc*, vol. 41, pp. 170–179, Aug. 2018, doi: 10.1016/j.scs.2018.05.047.

[27] N. G. Pricope, J. N. Halls, L. M. Rosul, and C. Hidalgo, "Residential flood vulnerability along the developed North Carolina, USA coast: High resolution social and physical data for decision support," *Data Brief*, vol. 24, p. 103975, 2019, doi: https://doi.org/10.1016/j.dib.2019.103975.

[28] N. M. Waly, H. M. Ayad, and D. M. Saadallah, "Assessment of spatiotemporal patterns of social vulnerability: A tool to resilient urban development Alexandria, Egypt," *Ain Shams Engineering Journal*, vol. 12, no. 1, pp. 1059–1072, Mar. 2021, doi: 10.1016/j.asej.2020.07.025.

[29] Fauzi et al, "Geographic Information System for Natural Disaster Map in Indonesia." 2000.

[30] R. Patrick Bixler and J. Jones, "Indicators for Community Resilience: Social Vulnerability, Adaptive Capacity, and Multi-Hazard Exposure in Austin, Texas," 2022, pp. 11–25. doi: 10.1007/978-3-031-06940-6_2.