# Earthquake Social Vulnerability Assessment Using Entropy Method

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**Abstract.** Earthquake is the most devastating event in the current time. Given the probability of highly dangerous future events, risk estimation should be given focus through probabilistic models that can use the limited and freely available information to predict future vulnerable scenarios of an area that observe the involved uncertainty in the analysis. However, vulnerability assessments should be prospective and based on expected scientifically acceptable events. Therefore, we applied a valuable weight calculation approach called entropy to produce a social vulnerability map for a particular city. We used the population data, including educated and non-educated people and household information, to develop the earthquake social vulnerability map. We used entropy to evaluate the actual weight and produce a good quality map because of some difficulty in the fuzzy synthetic evaluation method for factor weight calculation and relationship ignorance among layers. Results showed that approximately 6% of the population is under very high vulnerability and around 14% are under high vulnerability areas in Banda Aceh City. The developed model is accurate by considering the inventory earthquake vulnerability map. The applied method was favorable, and the process provided good evaluation results, which was reasonable for earthquake hazard, vulnerability, and risk assessment.

***Keywords:*** Earthquake; Social vulnerability; Entropy; GIS; Mapping

## 1. Introduction

Natural disasters, such as earthquakes, often result in serious damage or loss of lives and properties. Reducing the disaster risks and enhancing society's resilience, emergency capability and response are the present major challenges that cannot be ignored. The rapid societal growth accelerates geo-environmental changes; consequently, natural disasters cause the potential extent of the damage. Therefore, earthquake social vulnerability has been gaining attention from researchers. Earthquake social vulnerability is defined as society's susceptibility to the destructive effects of an earthquake [1]. Several researchers have highlighted earthquake social vulnerability as an important object of study in human vulnerability. Numerous countries worldwide have actively integrated disaster research in the last decade of the 20th century in the "International Decade for Natural Disaster Reduction" (1990), thereby resulting in a new age of disaster analysis. However, scientists and researchers have mainly concentrated on examining the characteristics of natural disasters, such as earthquakes [2, 3]. Disaster studies have been narrowly undertaken from the view of other prospects, particularly earthquake social vulnerability to disasters. The authors in [4] conducted the most exciting research on social vulnerability. They discussed the concept of natural disasters' vulnerability and then projected the methodology and social vulnerability applications to natural hazards. They also described the social vulnerability importance of natural disaster reduction and concluded that evaluation of social vulnerability should be performed in future analysis. According to the socio-economic and population data of the USA, the authors in [8] applied 42 indicators and conducted a factor analysis approach in calculating the social vulnerability index to generate a social vulnerability map. The authors in [4] and [5] selected 10 indicators from the extended literature review, applied principal component analysis, performed the analysis and assessed the social vulnerability to natural hazards of 11 cities in Shaanxi Province. Ref [10, 11] conducted objective reality research to estimate the social vulnerability to disasters. Their research was on the concept of natural hazards and vulnerability estimation. Finally, they proposed the methodological assessment of how social vulnerability could contribute to natural hazards. They pinpointed the utmost importance of social vulnerability for natural hazards monitoring and mitigation planning. They also mentioned in their research that the evaluation of social vulnerability should be conducted in future research. [12] developed an index of social vulnerability up to four levels such as; economy, structure, population, disaster. The whole study was conducted using ArcMap software and other GIS-based spatial analysis software.

After the 2004 earthquake and tsunami, geological disasters appeared frequently in the tsunami-affected areas of Aceh Province, thereby growing major concerns on the social effects of natural hazards. In this study, we combined previous works on risk estimation and conducted a social vulnerability assessment of earthquake hazard areas in Aceh Province after the 2004 earthquake, which is vital and may lead to disaster prevention planning and human life and property protection.

## 2. Materials and methods

### *2.1. Study area*

Indonesia is an archipelagic country located between $60^0$ 8′ north and $11^0$15′ south latitude and between $94^0$45′ west and $141^0$ 05′ east longitude (BPS, 2010b). It lies between the Asian and Australian continents. Indonesia is bounded by the South China Sea in the north, the Pacific Ocean in the north and east and the Indian Ocean in the south and west. Banda Aceh, the capital city of Aceh Province, is specifically located on a fault population, including the Seulimeum and Aceh Faults [9]. Urban growth, nonstandard and poor building construction and rapid growth of population density make the city extremely vulnerable to earthquakes. The recurrence of earthquakes in Banda Aceh is 150 years, which was also the period when the last large earthquake was experienced in the city [9]. Thus, a large earthquake is imminent in Aceh Province. Site effects in Banda Aceh City vary significantly because of its unique geological setting. However, Banda Aceh lies in a basin, which is structure-controlled in Krueng Valley. The city is surrounded by two major tectonic faults on either side, which are seismically active. The Aceh Fault can be found in the southwest, whereas the Seulimum Fault is located in the northeast and covered by vegetation. Therefore, Banda Aceh plains tremble strongly when any seismic activity occurs around the city.

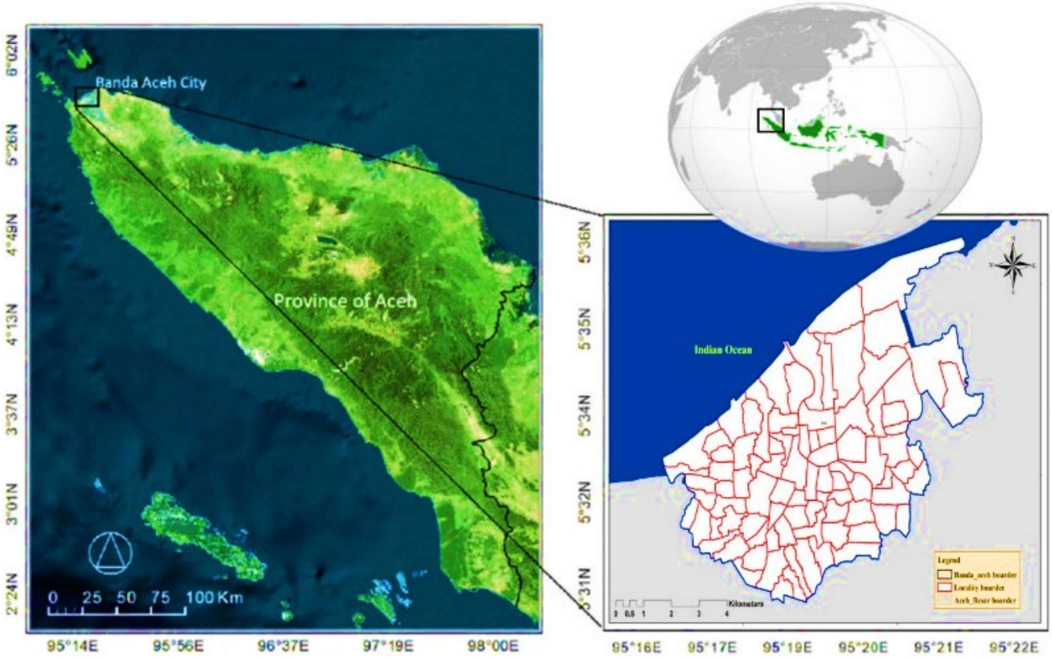


Figure 1. Study area location map, Banda Aceh.

*2.2 Materials*

In the set of the first indicator, several variables were selected for the analysis on the basis of the recent literature review on earthquake vulnerability assessment [4, 8, 9]. Some specific and potential indicators, such as medical services and 'special needs' populations, were not considered in this study because of the limited availability of data at the city scale. A multicollinearity test was performed, and 10 variables were retained to calculate a social vulnerability index and produce a map. These variables are listed in Table 1. Data were collected from the 2010 Survei Sosial Ekonomi Nasional (SSN) and the 2010 Sensus Penduduk (SP) provided by BPS-Statistics Indonesia. SSN is the data source that provides annual socioeconomic surveys and information on education, housing condition, welfare, income/expenditure, and sociocultural activities. SP provides the data of population census; they collect population characteristics, such as gender, age, marital status, educational attainment, migration, occupation, and religion. Population census data are obtained every 10 years, the most recent of which is from 2010, which was used in this study.

Table 1. Data used in this study.

| Indicators | Scale | Type |
|---|---|---|
| • Population density<br>• Educated people characteristics<br>• Village chiefs<br>• Household density | 1:30000 | Raster type |

*1.3. Methodology.*

The entropy method is an objective evaluation technique that is comprehensive in nature. Theoretically, entropy is the uncertainty measure for any specific problem. However, an information entropy index is evaluated as small, where the coefficient difference is large, which results in a large index weight. Therefore, a lot of information was provided by the indicators. Therefore, a comprehensive entropy method required for an application that involves several aspects. Ref. [13] Applied the entropy method to estimate the entropy weight of vulnerability for towns in association with combined fuzzy logic theory to estimate the total vulnerability. However, the human social system could be considered as entropy. The complex dissimilarities lead to differences associated with their entropy, respectively. Further, the use of the entropy principle to evaluate social vulnerability is highly feasible. In the current research, GIS was integrated with the entropy value method to analyze the social vulnerability objectively and intuitively for earthquakes in Banda Aceh city in Indonesia.

Ref. [14] described the steps required in the entropy processes for comprehensive evaluation are described below.

Step 1: Original data standardization processing

Different characteristics among the magnitudes, dimensions, and the changes in factors are obtained. They are perceived to influence the results. The data should be unified to remove the effect of dimensional processing, which is called a standardized deviation. Standard deviation should be selected as needed [1].

Step 2: Standardized data normalization

Here, data standardization is achieved in huge differences among the indices. The index should be normalized to remove these differences.

Step 3: Information entropy processing

Each index is quantified with the degree of social vulnerability. The weight *pij* of scheme *i* under index *j* is calculated as follows [2]:

$$\frac{Xij}{\sum_{i=1}^{n} Xij}. , \quad (1)$$

Step 4: Difference coefficient calculation

$$gj = 1 - ej, \quad (2)$$

Where, *gj* is the difference coefficient, and *ej* is the entropy.

Step 5: Index weight calculation

The weight of index *j* can be calculated as

$$\frac{gj}{\sum_{j=1}^{n} gj}, \quad (3)$$

Where, *aj* denotes the weight, and *ej* represents the entropy.

Step 6: Score calculation

The score of the sample in preparation for comprehensive analysis is complicated and must be calculated as follows [1, 2]:

$$\boldsymbol{Zi = a1xi1 + a2xi2 + a3xi3 \ldots, akxij + \cdots, apxpp}, \quad (4)$$

Step 7: Using ArcGIS software platform for data processing and classification

The social vulnerability map can be created using the weights of layers calculated from the entropy method via the ArcGIS platform. We used the weighted overlay technique and a natural breakpoint method for mapping and classifying the vulnerability map. We comprehensively analyzed the social vulnerability of the city using the score of the entropy method (Figure 2).

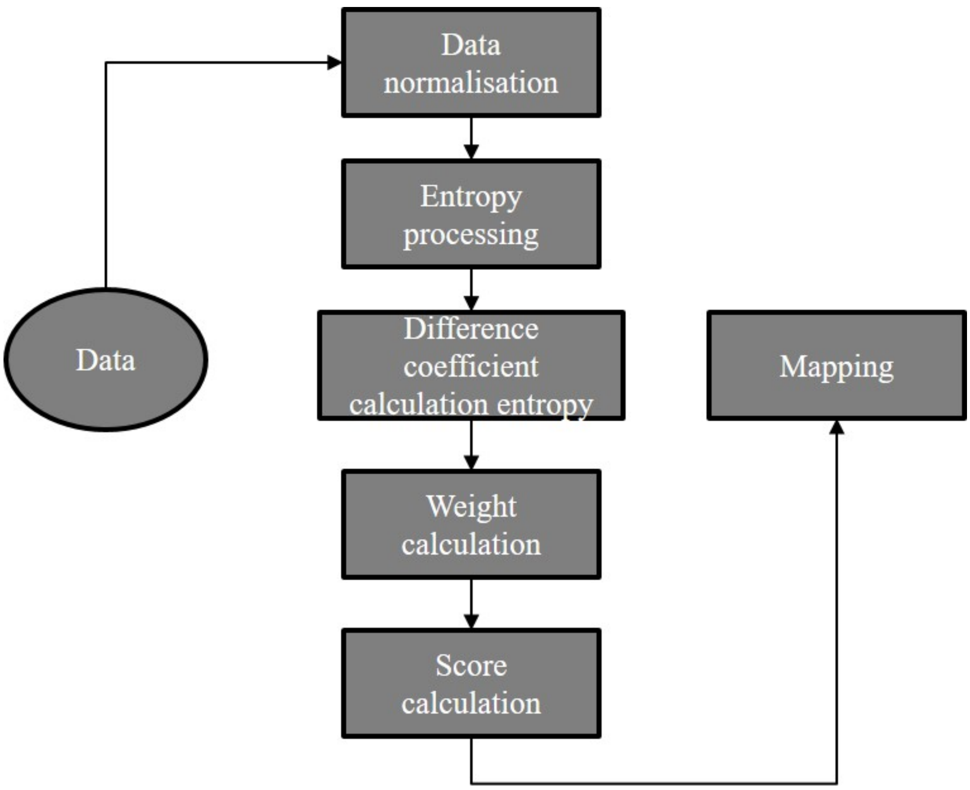


Figure 2. Methodological flowchart.

**3. Results and Discussion**

The spatial distribution of social vulnerability is shown in Figure 3. The distribution of social vulnerability in the city center of Banda Aceh projects the strong influence of vulnerability in the urban development of an area. For instance, the most vulnerable area can be found in the city center, whereas the surrounding areas show less vulnerability. Observations on the city structure indicate that the city center is highly developed along with some old buildings with the maximum population. The housing density is also relatively higher in the city center compared with the surrounding areas. Meanwhile, with a higher educational level, the younger generations are commonly found in the city center. The social vulnerability was calculated considering several factors of people's characteristics.

Urban expansion in the city increases the number of buildings with a growing population. Therefore, the city needs a well-planned infrastructure that considers other areas of the state. Specific interesting situations were not considered in determining social vulnerability. The constructed social vulnerability map shows that vulnerability is classified into five, namely, very high, high, moderate, low and very low.

Figure 3 shows the percentages of social vulnerability through a map of Banda Aceh City. Interesting observations can be made with regard to urban expansion patterns on socioeconomic characteristics for vulnerability assessment [6, 7]. Old buildings in the city increase the percentage of vulnerability if managed by less educated people. Therefore, the recent replacement of old masonry to be managed by highly educated people is needed in the city to reduce social vulnerability. Thus, a lower social vulnerability score is somehow associated with a higher percentage of RC buildings, whereas it increases with the presence of masonry structures. This apparent trend is still far from being standardized; however, it could certainly be a matter worth further investigation.

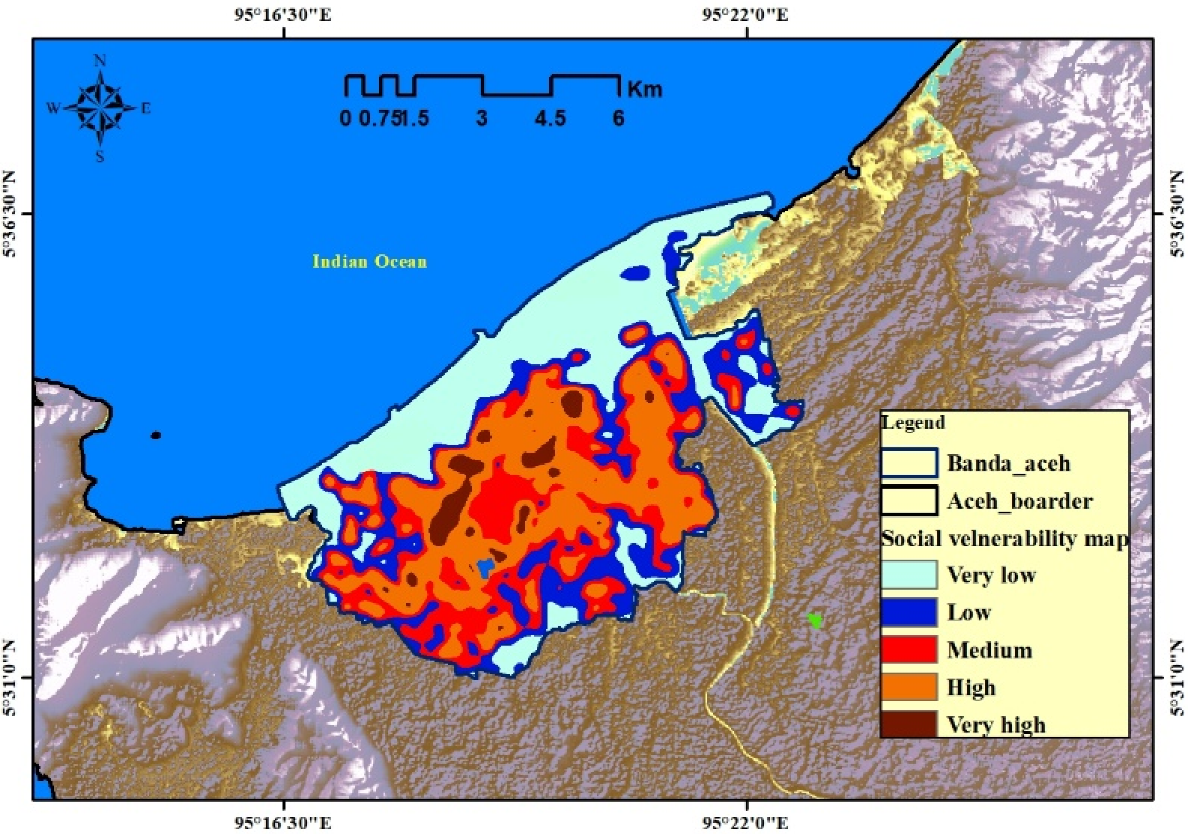


Figure 3. Social vulnerability map created using the entropy method.

As the Banda Aceh city is the home to 223,446 population however**,** earthquakes and tsunami could cause massive losses and it's expected. Because of the building coverage, high population density, distance from the road, road density, educated people it is highly vulnerable to earthquakes. However, the vulnerability could be lower if high-quality medical services, personnel support, and social welfare were provided. Support of social forces could help in quick response time that could reduce expected losses that might result from earthquakes. Therefore, the social vulnerability index could help in mapping the future risk to a certain level. Emergency response in Banda Aceh could reach a higher level of earthquakes occurs. Relatively, the self-recovery ability becomes weaker with respect to the high social vulnerability area. Proper emergency support needed in Banda Aceh with a corresponding area.

The achievements of the estimation of social vulnerability to earthquake hazards in Banda Aceh City are based on the successful analysis by previous researchers associated with the current knowledge framework. The data collection involved is at different difficulty levels. The collected data are complete and highly accurate, thereby making the vulnerability evaluation perfect and acceptable. Nevertheless, some improvements are necessary to execute analysis with improved accuracy for the prevention of earthquake hazard in future research.

## 4. Conclusion

This study can be considered an initial effort for disaster management, mitigation, preparedness and vulnerability prevention and reduction at a city scale in Indonesia. The social vulnerability approach is applied in quantifying the earthquake social vulnerability in Banda Aceh City to analyze its driving factors. The results show that earthquake social vulnerability varies potentially among different city sections in Banda Aceh City. The three main driving factors that affect social vulnerability are socioeconomic status and infrastructure, population growth and family structure. This analysis applies only five specific variables to assess the earthquake's social vulnerability due to constraints in data availability. The driving factors to social vulnerability can be understood well by considering and modifying some important variables. Finally, the method used in this study, namely, entropy approach at the city level, should be given focus. Using this approach to assess the social vulnerability of Indonesian districts and sub-districts can also be analyzed in the future.

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## References

[1] HR. Pourghasemi, M. Mohammady, B. Pradhan. “Landslide susceptibility mapping using index of entropy and conditional probability models in GIS: Safarood Basin, Iran,” Catena, Vol.1, pp. 71-84, Oct 2012.
[2] KC. Devkota, AD. Regmi, HR. Pourghasemi, K. Yoshida, B. Pradhan, IC. Ryu, MR. Dhital, OF. Althuwaynee. “Landslide susceptibility mapping using certainty factor, index of entropy and logistic regression models in GIS and their comparison at Mugling–Narayanghat road section in Nepal Himalaya,” Natural hazards, Vol.1, pp.135-65, Jan 2013.
[3] AM. Youssef, B. Pradhan, AF. Gaber, MF. Buchroithner. “Geomorphological hazard analysis along the Egyptian Red Sea coast between Safaga and Quseir,” Natural Hazards & Earth System Sciences, Vol.1 pp. 9, May 2009
[4] B. Pradhan, AA. Moneir, R. Jena. “Sand dune risk assessment in Sabha region, Libya using Landsat 8, MODIS, and Google Earth Engine images,” Geomatics, Natural Hazards and Risk, Vol. 1, pp. 1280-305, 2018 Jan
[5] B. Pradhan, R. Jena. “Spatial relationship between earthquakes, hot-springs and faults in Odisha, India”. In IOP Conference Series: Earth and Environmental Science 2016 Jun (Vol. 37, No. 1, p. 012070). IOP Publishing.
[6] AM. Youssef, B. Pradhan, AF. Gaber, MF. Buchroithner. “Geomorphological hazard analysis along the Egyptian Red Sea coast between Safaga and Quseir,” Natural Hazards & Earth System Sciences, Vol.9, 9(3), May 2009.
[7] R. Jena, B. Pradhan. “A novel model for comparing Peak Ground Acceleration derived from three attenuation laws using an integrated GIS technique in Sabah area, Malaysia,” IJSRP, Vol. 11, pp. 1-10, Sep 2018.

[8] SL. Cutter, BJ. Boruff, WL. Shirley. "Social vulnerability to environmental hazards," Social science quarterly, Vol. 84, pp.242-61, Jun 2003.

[9] M. Delescluse, N. Chamot-Rooke, R. Cattin, L. Fleitout, O. Trubienko, C. Vigny. "April 2012 intra-oceanic seismicity off Sumatra boosted by the Banda-Aceh megathrust," Nature, Vol. 490, pp. 7419, Oct. 2012.

[10] J.S. Yang, P.T. Robinson, C.F. Jiang, Z.Q. Xu. "Ophiolites of the Kunlun Mountains, China and their tectonic implications". *Tectonophysics*, Vol. *258*, pp.215-231, 1996.

[11] C.L. Jiang, L.H., Xu. Diversity of aquatic actinomycetes in lakes of the middle plateau, yunnan, china. *Appl. Environ. Microbiology*, Vol. *62*, pp.249-253, 1996.

[12] L. Tang, Y.J. Liu. Index evaluation system and spatial pattern of social vulnerability to natural disasters. J UESTC (Soc Sci Ed), Vol. 14, pp. 49–53, 59 (In Chinese), 2012.

[13] Y. Jiang. An integrated entropy weight variable fuzzy sets evaluation approach for small town disaster Vulnerability Problem. Geogr Geo-Inf Sci, Vol. 25, pp. 88–91 (In Chinese), 2012.

[14] W.Q. Zhao. The evaluation systematic index of social vulnerability to natural hazards—a case study of Chongqing City. Chongqing Normal University, Chongqing (In Chinese), 2008.