Earthquake vulnerability mapping in the at-risk Opak Fault, Sengon Village, Central Java, Indonesia

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Abstract. This study aims to perform vulnerability assessment in a detailed scale at villages adjacent to Opak fault, Central Java. The study took place in Sengon Village, Prambanan District, Klaten Regency. Sengon is located near Opak fault zone and experienced tremendous disaster in 2006. The method for vulnerability assessment in earthquake hazard used in this study involves three criteria, i.e. physical, social, and economic with various indicators within. The mapping unit are hamlet units, which more detailed than village unit. The result of physical vulnerability assessment in Sengon village was dominated by a medium level of vulnerability. Sengon village has clustered settlement characteristics and this is a type of rural village in Indonesia. The advantage of clustered settlements is that there is a large evacuation site in this case paddy fields. The socio-economic vulnerability indicates that the majority of Sengon village are informal workers. This will have a big impact if an earthquake occurs because there will be many people lose their income. The total vulnerability assessment shows that all levels of vulnerability are distributed similarly. The advantage of this study is helpful to determine the action for reducing vulnerability especially in the at-risk of earthquake hazard.

1 Introduction

Vulnerability mapping is one of the important variables in disaster risk reduction (DRR) planning, besides hazard and capacity mapping. The DRR evolves from a national and regional scale into a more detailed scale such as villages, therefore the vulnerability, capacity, and hazard analysis follow. However, the disaster risk mapping guide in Indonesia only available on a scale of 1:25,000. Many researchers have developed methods for enhancing vulnerability approach and variable on a detailed scale because vulnerability mapping is most modifiable than others. This is made many criteria and indicators published for measuring vulnerability. It is important to note that criteria and indicators in vulnerability mapping are customs depend on their objective, but they must be measurable [1].

Indonesia has faced many types of hazards, one of them is an earthquake which often threatens. Earthquake DRR in Indonesia lead by collaboration between BNPB (national board for disaster management) and BMKG (Meteorology, Climatology, and Geophysical Agency), also supported by Geological Agency and Ministry of Public Work. The DRR has been concern in national-wide, but not up to in detailed scale such as villages scale. The shifting paradigm of DRR that start from a detailed scale drives many researchers to develop an analysis method in a detailed scale. Most boarders methods used for developing vulnerability assessment are AHP (analytic hierarchy process) and SMCE (spatial multi-criteria evaluation), although they are not a new method [2]–[4]. Other development in vulnerability assessment also performed using Bayesian Network resulting in four criteria such as building damage, evacuation, resistant capacity, and loss of life [5]. Generally, criteria and indicator of vulnerability in regional scale are measurable for detailed scale, but it might not suitable in some indicator due to different scale of data and challenging to apply for the wider region [1], [4], [5]. Method for vulnerability assessment actually has been developed for a block of residence (same as Kampung) by only concern in physical and social criteria [6]. This method is powerful if developed for household-scale because in physical criteria is included single building characteristics. There is a good example of developed vulnerability assessment in Indonesia with the village as a mapping unit [1].This development method is included geotechnical criteria, which actually used for hazard analysis. Based on various methods from previous researches indicate that the vulnerability assessment from the Indonesian Disaster Risk Mapping Guide is possible to be developed.

This paper aims to perform vulnerability assessment in a detailed scale at villages adjacent to Opak fault, Central Java. This location was experienced massive damage in the 2006 earthquake and leaving a sense of trauma for some residents. In addition, there were only a few changed in terms of building plan and structure after reconstruction (Figure1). Using hazard scenarios the same as 2006, risk potential in this location may

be bigger. Vulnerability assessment in this location is useful for management input regarding to vulnerability reduction since they have no proper mitigation plan except initiative evacuation infrastructure [7]. We use hamlet as a mapping unit and some data also presented in a household unit. The criteria and indicators used in this paper are also developed especially at the level of the mapping unit. In order to reduce the damage caused by an earthquake, an earthquake vulnerability map can be used by village government for planning purpose [8].

Fig. 1. (A) Reconstructed buildings and road in Sengon Village after destroyed during earthquake 2006; **(B)** Photographs collection of 2006 earthquake event, restored at Pijar Monument, Sengon Village.

2 Methods

Many researchers have developed methods for earthquake vulnerability assessment with various criteria and indicators. Some of them using pairwise comparison and AHP (Analytic Hierarchy Process) [6], Rough AHP [2], the combination of AHP and VIKOR (VIseKriterijumska Optimizacija I Kompromisno Resenje) [1], complex vulnerability index using SMCE (Spatial Multi-Criteria Evaluation) [9], and development of vulnerability indicators using catastrophe progression assessment [4]. However, the spatial resolution of also different, most of them in the urban-district scale, but one of them has a detailed scale in the village unit [1]. Another development method for vulnerability assessment in a detailed mapping unit on villages scale is performed in lahar hazard using SMCE [3]. The various criteria and indicators developed by previous researches listed in Table 1. This list is useful for the selection of vulnerability assessments in this paper.

Table 1. Various criteria and indicators for the vulnerability assessment due to earthquake hazard

Criteria	Indicator	Reference
Physical	Width of street, building material, pop. density, number of floor, distance to: open site, medical centre, fire station	[6]
Socio-economic	Annual income and capital asset, Educational level, Employment	[2]
	Village chief, Popular place, visiting place, park and other	[1]
	Poor people and unemployment, education and housing	[4]
	Elderly population, ratio of children, Female population, widows,	[9]

Criteria	Indicator	Reference
	housing density, average number of persons per household, average number of wage earners per household, minimum level of education, women with many children	
	Unemployed, ratio incomes, degree of occupancy per room, room area per person, average area of rooms, private residences, population density per residence	
	Age, gender, tourism, cultural building, migrant, residence factor, security feeling	[6]
Population and household	Age and family structure	[1]
	Disadvantaged population	
Building vulnerability	Average height and age of building	[2]
	Density of built environment	
	Average age, building density, building layer	[4]
	Residence building density, age and average height of buildings, type of buildings (structure and building materials)	[9]
Structural and Infrastructure	Major office, transport node	[1]
	Educational institution, service centre, stadium, museum, historical places	
	Total health institution, sickbed and physician per 1000 pop	[4]
Geotechnical	Slope, curvature, lithology, distance to fault	[1]
Demographic	Population density, age structure, family structure, gender	[4]
Capacity	Distance to hospitals, distance to fire stations, distance to police stations, accessibility, literacy rate	[11]

Vulnerability assessment in this paper will be set on villages scale with hamlet as mapping unit, thus criteria and indicator presented in Table 1 should be selected which is fits at that mapping unit. First is selecting the criteria. Based on the guide for risk mapping from Indonesian national broad for disaster management (BNPB), there four criteria for vulnerability assessment, namely physical, social, economic, and environment. These guides only fit for the District scale (sub-district mapping unit), therefore need and enhancement for the indicator within. Some enhancement has been done for vulnerability assessment on a detailed scale but in a hazard type of lahar [3]. In that study, the environmental criteria are ignored, but some indicators in physical and social are enriched for the substitution.

It is important to note in the BNPB mapping guide that not all types of hazards should analyze the environment's criteria. In this paper, the vulnerability assessment using three criteria, namely physical, social, and economic (Table 2).

Table 2. Criteria and indicators for the vulnerability assessment in this study

Criteria	Indicator	Assumption
Physical	Number of building	Higher number of building, higher vulnerability
	Building density	Higher building density, higher vulnerability
	Evacuation route	If there an evacuation route, lower vulnerability
	Critical facility (health, market, mosque, etc.)	Higher number of critical facility, higher vulnerability
Social	Population	Higher population, higher vulnerability
	Population density	Higher population density, higher vulnerability
	Disabled population	Higher disabled population, higher vulnerability
	Elderly population	Higher elderly population, higher vulnerability
	Toddler population	Higher toddler population, higher vulnerability
Economic	Poor / unemployment population	Higher poor/unemployment population, higher vulnerability
	Micro industry	Higher number of micro industry, higher vulnerability
	Informal worker	Higher informal worker population, higher vulnerability

3 Result and Discussion

The indicators for vulnerability assessment are custom depends on the mapping scale. The more detailed scale needs more indicators and data input. This is significant to the disaster reduction on a detailed scale that required an applicable action plan. In this study, earthquake vulnerability assessment involves three criteria, i.e. physical, social, and economic with various indicators within. In earthquake vulnerability assessment, building distribution and its density is important to take into account, especially in physical vulnerability. The denser building distribution leads to the more vulnerable. Building distribution is easy to obtain using aerial photo or satellite image, because image with high spatial resolution is adequate and up-to date data for disaster management [10]. The previous study showed that the number of building and building density is influenced to physical vulnerability. For the technical purpose, a constructional characteristic also necessary [11].

However, in this study, the constructional characteristic of a building are ignored. In the study area, building distribution has a nucleated type, but some of them are also dispersed along the road (Figure 2). In Sengon village, there was much open space functioned as an agricultural field that surrounds the settlement area. This type of building distribution is common in a rural area in Indonesia. The highest building number is in Cabakan hamlet, consist of 251 buildings. In general, building density in Sengon is not dense as in urban, but some hamlets have high density of over 10 building/ha, i.e. Sengon, Sumberejo, Belan, and Cabakan.
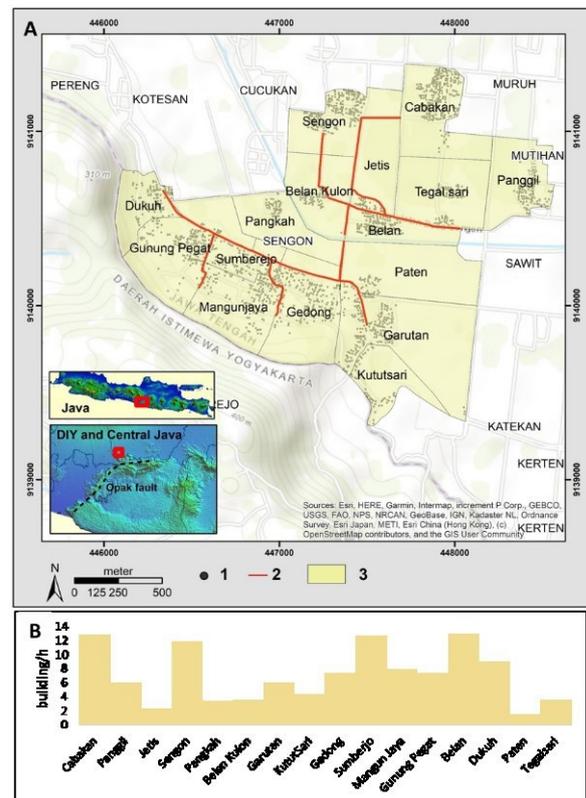

Fig. 2. **(**A) Building distribution in Sengon village (3) shows in black dot (1). In the study area was already installed evacuation route (2). (B) Graph of building density in Sengon Village shows that Paten hamlet is the lowest, and dominating by four hamlet with a building density over 10/ha.

Besides building, the evacuation route became one of the indicators for physical vulnerability assessment. The evacuation route is important in disaster preparedness for reducing chaotic events during a crisis. In this study, the assumption built for the evacuation route is where the settlement located near from evacuation route, the more prepared for evacuation and lower vulnerable. The evacuation route was installed in Sengon village according to the accessibility of the main assembly point, type, and condition of route [7]. There is two main evacuation direction, the northern parts of the village are directed to the Village Office of Sengon, and the southern parts are directed to the Dukuh football field.

The result of physical vulnerability assessment in Sengon village was dominated by a medium level of vulnerability (Figure 3). A half from total hamlets in Sengon village are classified into a medium level.

Therefore, three hamlets are at a low level, and five others are at a high level. Three hamlets which classified into a lower level which have a lower building number compared to others. This is indicated that physical vulnerability in Sengon village mostly controlled by building distribution (number and density). Landuse in Sengon village are dominated by agricultural fields (>60 %). This kind of land use is useful in case of emergency as a first escape place for avoiding building damage.
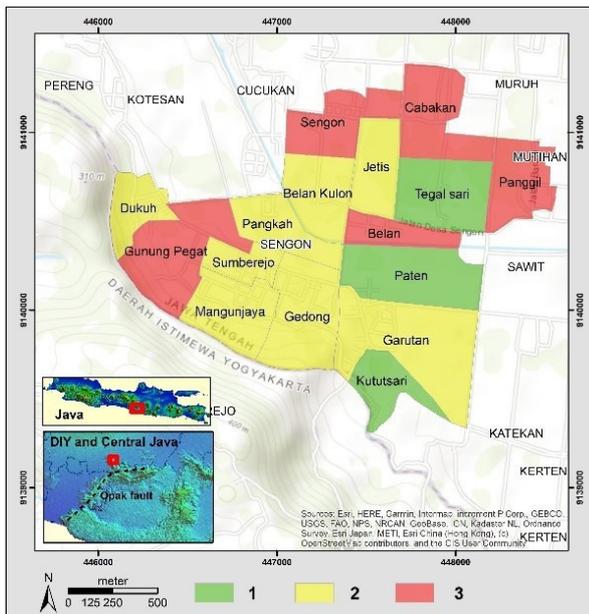

Fig.3. Physical vulnerability of earthquake hazard in Sengon village, there hamlets at low level (1), a half of total hamlets are classified in medium level (2), and five other are in high level (3).

Social and economic vulnerability are performed together due to interdependency indicators. The combination of social and economic assessment resulting in socio-economic vulnerability which poor people as the most influenced indicator. This is mostly similar to the vulnerability assessment performed by Ref. [4]. In the same research, health infrastructures are also important for vulnerability assessment. In Sengon villages, there is only one health infrastructure located in Cabakan hamlet. Nevertheless, this health infrastructure is accessible for all residents in Senogn village. Socio-economic vulnerability in Sengon village was consist of four hamlets at a high level (Figure 4). Medium and low level is the same, distributed in six hamlets. It is important to note that >90% of residents in Sengon are informal workers, who tend to be as vulnerable people when a disaster occurs. Another indicator that influenced socio-economic vulnerability is the population number. Hamlets with a higher population number tend to a higher level of vulnerability such as in Gedong and Cabakan.
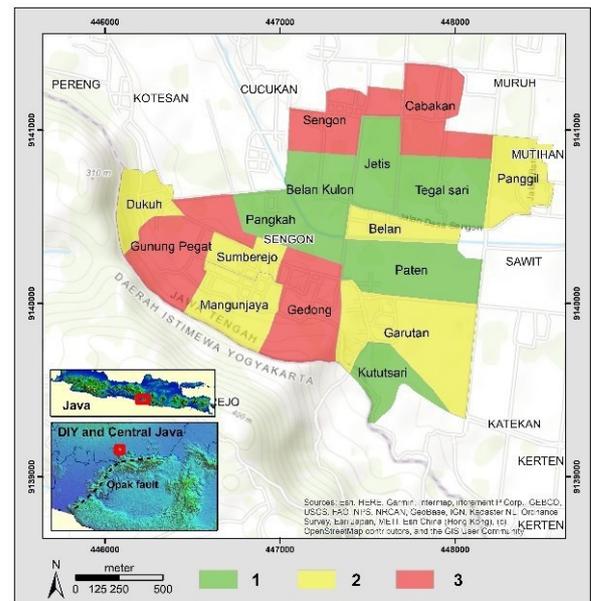

Fig. 4. Socio-economic vulnerability in Sengon village. The medium (2) and low (3) level are the sume, consist of six hamlets, while high level (3) distributes in four hamlets.

The combination of three different types of vulnerability results in total vulnerability. All indicators presented in the method are well collected, but the unemployment data are rather difficult because the data are dynamics. Monograph data from Sengon village is not cover this kind of data. Therefore, the data collection using basic information from Kartu Keluarga (household card) performed by village officers. Same case with poor people, the data are also slightly difficult to obtain in Sengon due to various standards used. Based on Statistics Indonesia, poor people are classified as people who cannot meet their daily basic needs. Using this standard, the village officer states that many residents will be classified as poor people. In this study, the poor and unemployed people data were generated from the type of their profession, which is in line with the number of informal workers data. Total vulnerability assessment shows that all levels of vulnerability are distributed similarly (Figure 5). In the center of the village, there were dominated by a low level due to socio- economic vulnerability. This location also dominated by the type of land use agricultural field. However, the total vulnerability is almost the same as the socio-economic vulnerability, only one hamlet at a different level, i.e. Belan. This condition was influenced by many critical facilities accumulated in this hamlet such as the village office. Belan hamlet also has greater building density.
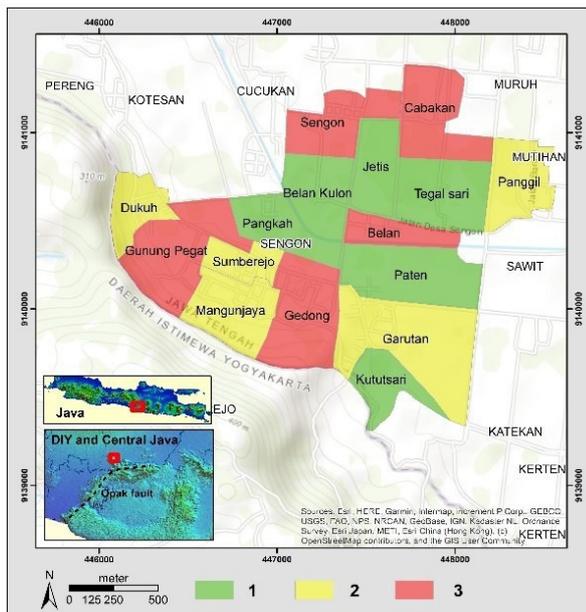
Fig. 5. Total vulnerability of earthquake hazard in Sengon village, six hamlets at low level (1), five hemlets in medium level (2) and five other in high level (3).

The advantage of vulnerability mapping is helpful to determine the action for reducing vulnerability. Since the study area is located in rural, earthquake impacts can lead to an increase in poverty due to destroyed household assets and livelihood [12]. In addition, this mapping will be a useful tool for disaster management for regional planning of future activities in the area, as well as their coping capacities and resilience of risk elements [13, 14]. A strategy that can be applied in Sengon villages for reducing poverty is to optimize the role of saving and loan cooperative managed by a village officer or resilient village group. This is important because >90% of the resident are informal workers, who suddenly can lose their job and income when a disaster occurs. For a rural area like Sengon village, disaster insurance program is the best way for reducing poverty. However, the problem is their willingness to buy [12]. Rural people might be not interested in disaster insurance. In contrast, for food stock, rural people tend to be prepared because they usually save their harvest for household needs or kept in farming shed. In the social characteristics, toddlers and elderly people in Sengon village are relatively high. This is also typical of resident composition in a rural area, where the people at a productive age are migration to the urban area. In this case, the vulnerability is increasing due to higher toddlers and elderly people. Disaster educational program is the best way for increasing preparedness because educated people are likely to have a subjective perception to evacuate from their house when an earthquake occurs [15].

4 Conclusion

Total vulnerability assessment in study area shows that at the center of the village, there is low-level dominance due to socio-economic vulnerability. Value of total vulnerability was almost the same as socio-economic vulnerability due to higher number of informal worker

and population. The differences of physical vulnerability mainly influenced by the accumulation of critical facilities. Some mitigation actions are needed to take into account for reducing the impact of vulnerability, i.e. (i) optimizing the role of savings and loan cooperatives managed by village officers or resilient village groups, (ii) disaster insurance programs, and (iii) disaster education programs.

References

1. R. Jena, B. Pradhan, G. Beydoun, Int. J. Disaster Risk Reduct., **46**, (2020).
2. X. Guo, N. Kapucu, Safety Science, **125**, (2020).
3. D.R. Hizbaron et al., Appl. Geogr., **97**:212–227 (2018).
4. W. Zhang, X. Xu, X. Chen, Int. J. Disaster Risk Reduct., **24**:361–372 (2017).
5. S. Zhang, C. Li, L. Zhang, M. Peng, L. Zhan, Q. Xu, Engineering Geology, **265**, (2020).
6. S.F. Aliabadi, A. Sarsangi, E. Modiri, Arab J Geosci, 10775–10787 (2015).
7. D. Mardiatno et al., IOP Conf. Series: Earth and Environmental Science **451**, 2020.
8. Y. Peyman et al. Symmetry, MDPI. **12**, 405 (2020).
9. I. Armas, Nat Hazards, 1129 –1156 (2012).
10. C. Semiha, T. Hannes, H. Stefan, R. Achim. 1st EARSeL Workshop of the SIG Urban Remote Sensing, Humboldt-Universität zu Berlin, 2–3 March. (2006).
11. M.C. Ningthoujam and R.P. Nanda, Structures, **15**: 329–340 (2018).
12. J. Yu, T. Sim, C. Guo, Z. Han, J. Lau, G. Su, Int. J. Disaster Risk Reduct., **40**, (2019).
13. K Thywissen, *Components of risk, a comparative glossary*, (University Institute for Environment and Human Security (UNU-EHS). (2006).
14. M. Sharifikia. J. Indian Soc. Remote Sens., **38(4)**:708– 716. (2010).
15. Y. Ao, K. Huang, Y. Wang, Q. Wang, I. Martek, Int. J. Disaster Risk Reduct., **46**, (2020).