Vulnerability mapping in kelud volcano based on village information

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Abstract. Kelud Volcano is a basaltic andesitic stratovolcano, situated at 27 km to the east of Kediri, Indonesia. Historically, Kelud Volcano has erupted with return period of 9-75 years, had caused nearly 160,000 people living in Tulungagung, Blitar and Kediri District to be in high-risk areas. This study aims to map vulnerability towards lava flows in Kediri and Malang using detailed scale. There are four major variables, namely demography, asset, hazard, and land use variables. PGIS (Participatory Geographic Information System) is employed to collect data, while ancillary data is derived from statistics information, interpretation of high resolution satellite imagery and Unmanned Aerial Vehicles (UAVs). Data were obtained from field checks and some from high resolution satellite imagery and UAVs. The output of this research is village-based vulnerability information that becomes a valuable input for local stakeholders to improve local preparedness in areas prone to improved disaster resilience. The results indicated that the highest vulnerability to lava flood disaster in Kelud Volcano is owned by Kandangan Hamlet, Pandean Hamlet and Kacangan Hamlet, because these two hamlets are in the dominant high vulnerability position of 3 out of 4 scenarios (economic, social and equal).

1. Introduction

The risks of volcanic disaster in Indonesia are caused by two main factors; (1) the potential for large volcanic hazards and (2) the social and economic conditions of the majority of the population vulnerable to hazards. The risks of volcano disaster most often hit the poor and gendered minorities, the disabled, the elderly and the community have no access to resources and means of protection. Vulnerability as indicated in Indonesian context are hidden among hazard and risk analysis, which in turn delimits number of work in the related theme. According to applied science approach, vulnerability is a quantitative measure towards any element at risk with degree of potential loss ranging from 0 or “not vulnerable” to 1 or “very vulnerable” [3][9][10][11][7]. Once we have hazard information and vulnerability information, it is easy to measure disaster risk. Risk itself defines as degree of damage or loss which was expected if there is potential hazard with certain degree of vulnerability [5][10].

Despite high risks, communities around the volcano have developed a wide range of skills, resources and knowledge, called capacity-based communities to reduce community-based disaster risks (CBDRR). Villages in Indonesia, nowadays, are no longer at rural area per se. Administratively, an area with agriculture activity predominantly and very limited support of basic infrastructure network addressed as rural. However, it is common to have village with very much unlikely description as such. Some areas in Java, where most of it has been rapidly developed somehow indicate urban characteristics. It is “desa-kota” theory which explains characteristics as such. The village information may also address not only necessity of rural development, it is also important to support urban development.

Gunungapi Kelud is located 27 km east of Kediri, Indonesia. The volcano erupts with repeated periods of 9-75 years, and nearly 160,000 people living in Tulungagung, Blitar and Kediri are at high risk of disaster [13] [4]. Located in three administrative boundaries (figure 1), Malang, Kediri and Blitar, East Java Province, it was recorded that in the last eruption of 2014 there were 87,629 people affected and 8,452 residential units were damaged [1] [12]. Previous research in the Kelud area, has indicated that at least 29 villages along river banks have high to moderate vulnerability (figure 2).

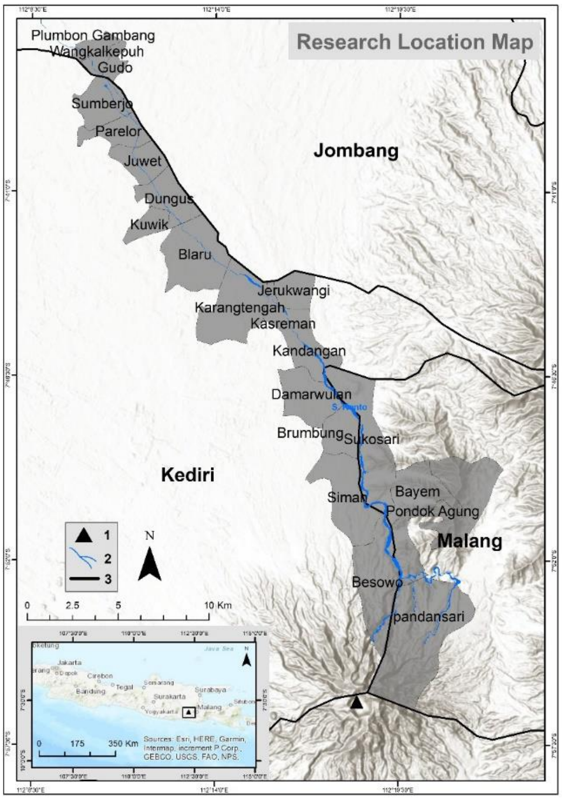

Figure 1. Research area 1- Volcano; 2- River; 3 - Regency boundary; 4 - Village boundary [7].

Taking into account towards current vulnerability distribution, this research shall also underscores the importance of adaptation strategies undertaken in local scale. The hazard and vulnerability assessments that have been carried out in the Superior Scheme of Higher Education Research entitled "Kelud Volcano Eruption 2014: Impacts, Hazards, Risks and Its Implications on Disaster Risk Reduction". The preliminary works upon the topics reveal that some part of the area surrounding Kelud had been very much subjected towards vast social and economic phenomenon. The previous research has conducted social economic vulnerability analysis towards lahar flood of Kelud Volcano in medium scale. Critically, conducting vulnerability analysis as medium scale hinders scholar to conduct physical vulnerability analysis. The physical vulnerability analysis focus to observe the element at risk of buildings at local scale. The condition of building, its location toward the river, its existing adaptive strategies are one among series of elements to be observed. Detailed vulnerability mapping, as argued within this research allows scholar to identify range of vulnerability at very micro or local scale using village information which has been established earlier.

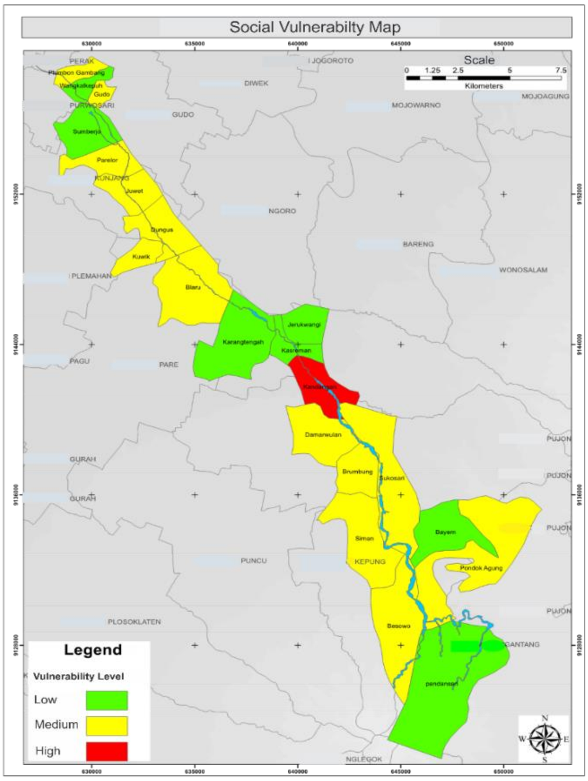

Figure 2. Social Vulnerability Scenario in Banjir Lahar at Kelud Volcano at Medium Scale [7].

The village information currently incumbent for Indonesia, taking into account “one map policy”, “one village one product” and “resilience village program”. There are several inline policies which establish based upon village unit. The main idea to introduce importance of village information are as follow: 1) village information either in urban and rural context should be equipped with various baseline information, including hazard, vulnerability and risk information as an integral part of development input; 2) village information is likely change local mindset to put more attention towards their environment; 3) village information generally conducted continuously, prior to support national statistic baseline data and many inter-sectoral policies in Indonesia.

2. Research Method

This study employed spatial and temporal approaches, applied participatory geographic information system or PGIS techniques to collect data. PGIS is a cartographic approach that involves local knowledge of disaster information related to adaptation strategies and disaster mitigation efforts [6]. In the context of risk analysis, there are two important aspects need to be evaluated, such as hazard and vulnerability. To come up with vulnerability, there are essential objects need to be observed entitled as element at risk. This research focused upon human being with their economic condition, buildings characteristics as well as environmental condition (figure 3). In detailed, there are three influential form of energy prior to cause hazard potentials, such as endogenous, exogenous energy and technological failure. This research as mentioned above focused upon lahar flood, which influenced both by endogenous (post earthquake and volcanic eruption), and endogenous (driven by flow of liquid and or mass into lahar flood). In return, there are several elements at risk potential to be threatened by the hazard potential as such. The elements at risks are divided into social, physical, economic or financial and environmental aspects. Herewith, the research observes level of inability from each element at risk to survive from lahar flood which entitled as vulnerability level.

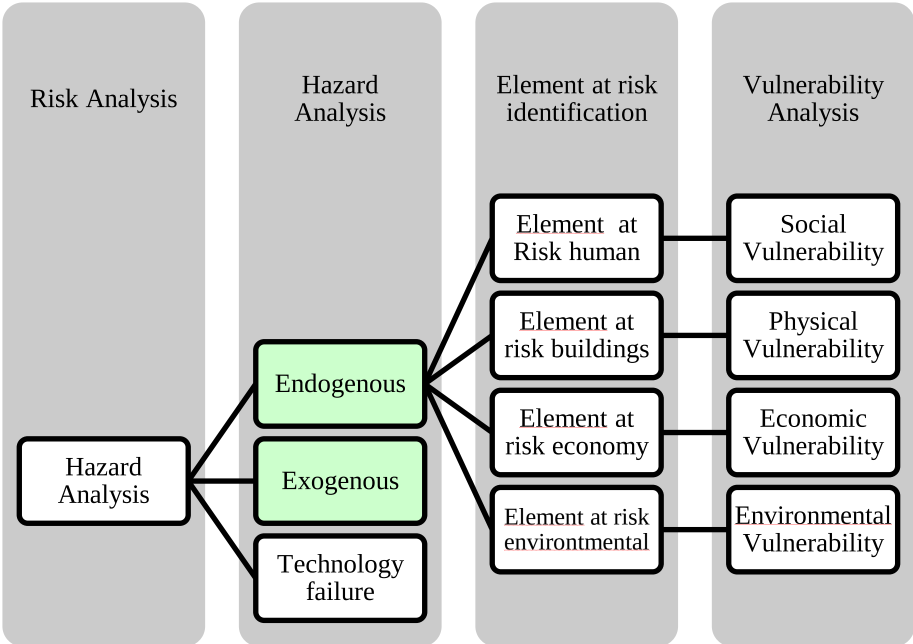

Figure 3. Research Framework.

Based upon previous studies, Ngobo River and Konto River are actually prone towards lahar flow [7]. The previous research generated social economic vulnerability using Spatial Multi Criteria Evaluation (SMCE). This research, hence, employed also SMCE to generate physical, social and economic vulnerability at local scale. SMCE assists in conducting multi criteria assessments that can facilitate the process of spatial tabular data and attribute data. The applied technique of SMCE consists of these following steps: problem definition, factor standardization, assign weighting, and generate vulnerability classification (figure 4).

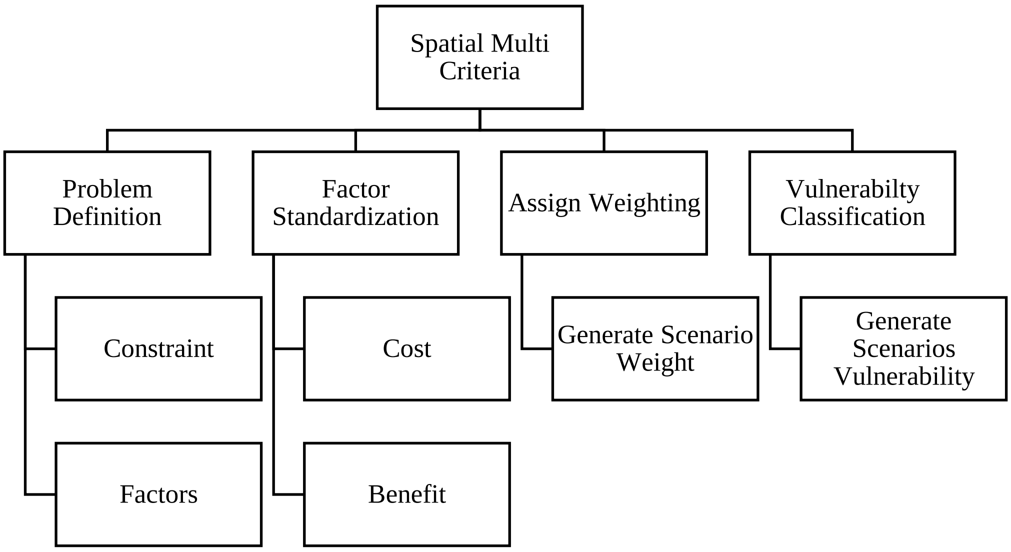

Figure 4. Aplied Technique of Spatial Multi Criteria Evaluation.

The use of the SMCE method begins with determining criteria, which can be constraint and factors (figure 4). There are social, physical and economic criteria. Each of criteria breaks down into multi factors, according to available data in the research area. Before assigning weight, criteria and factors are structured in a problem tree analysis in order to get clear objectives. The objectives aim at providing clear guidance towards setting up research assumption between each factor. The research set objective into measure total vulnerability between 0 (not vulnerable) – 1 (vulnerable or lethal). Henceforth, each factor for example total population get standardized using the logic assumption that the more population the higher its vulnerability (table 1). Standardization as such helps scholar to formulate accumulative assumption from diverse criteria, which then equips with weight. Multi criteria assessment also makes possible for scholar to generate more than a scenario using weighting scenarios. The main intention to generate more scenario is to ensure its robustness and foreseen possible overlapping areas from diverse assumption. This research employs four scenarios, such as vulnerability from social criteria, physical criteria, economic criteria, whereas each of the criteria assign dominant weighting. Meanwhile, the last scenarios are equal scenarios, which explains equal weighting between demographic, physical and social aspects.

Table 1. Factor and Research Assumptions.

No	Criteria	Factor	Research Assumptions
1	Social	Total population	The higher the population, the higher the vulnerability (+)
		Population density	The higher the population density, the higher the vulnerability (+)
		Disabled	The more disabled group, the higher the vulnerability (+)
		Infants	The more number of infants, the higher the vulnerability (+)
		Elderly	The more number of elderly, the higher the vulnerability (+)
		Education, knowledge	The higher the level of education and knowledge, the lower the vulnerability (-)
2	Physical	Number of buildings	The more numbers of buildings, the higher the vulnerability (+)
		Building density	The more of building density, the higher the vulnerability (+)
		Distance to river	The closer to the river, the higher the vulnerability (+)
		Affected area	The higher the area of impact, the higher the vulnerability (+)
3	Economic	Poor family	The higher the number of poor families, the higher the vulnerability (+)
		Agriculture area	The more agricultural land, the higher the vulnerability (+)
		Number of farmers	The higher the number of farmers, the higher the vulnerability (+)

What is the meaning of vulnerability from social aspects? This relates to an “if condition”. Many scholars aim at predicting future condition, which should be close to real situation. Herewith, if the real situation in the future heavily affected by dynamic social aspects, thus the spatial distribution of vulnerability for the area will be shown in the vulnerability from social aspects scenarios. There are in total 4 scenarios generated in this research, such as vulnerability from social, physical, economic, and equal vulnerability scenarios.

3. Results and Discussion

For preliminary observation, the research collected information from satellite imagery. Two images obtained from Worldview-2 Image Year 2014 and Unmanned Aerial Photo Image Year 2017 (figure 5). These images indicate comparative vertical transects towards the research area before eruption (2014) and after eruption (2017) of Kelud Volcano. Through this comparative image, Kandangan Village was clearly seen to have pile of sediment at 2014, while the riverbeds was lessen its depth in 2017 with wider area of alluvial plain. During field observation, the area along Konto River at

Kandangan was subjected to mining activities. The initial river flow of the subsequent river was narrowed down due to shifting river body. Such morphological dynamics towards Konto River was taken into account towards increasing element at risk upon lahar flood. Before the eruption the riverbed was quite steep, whilst it getting fairly steep these days due to this shifting characteristic. This refers to increasing potential of lahar flood towards the area once an eruption occurs.

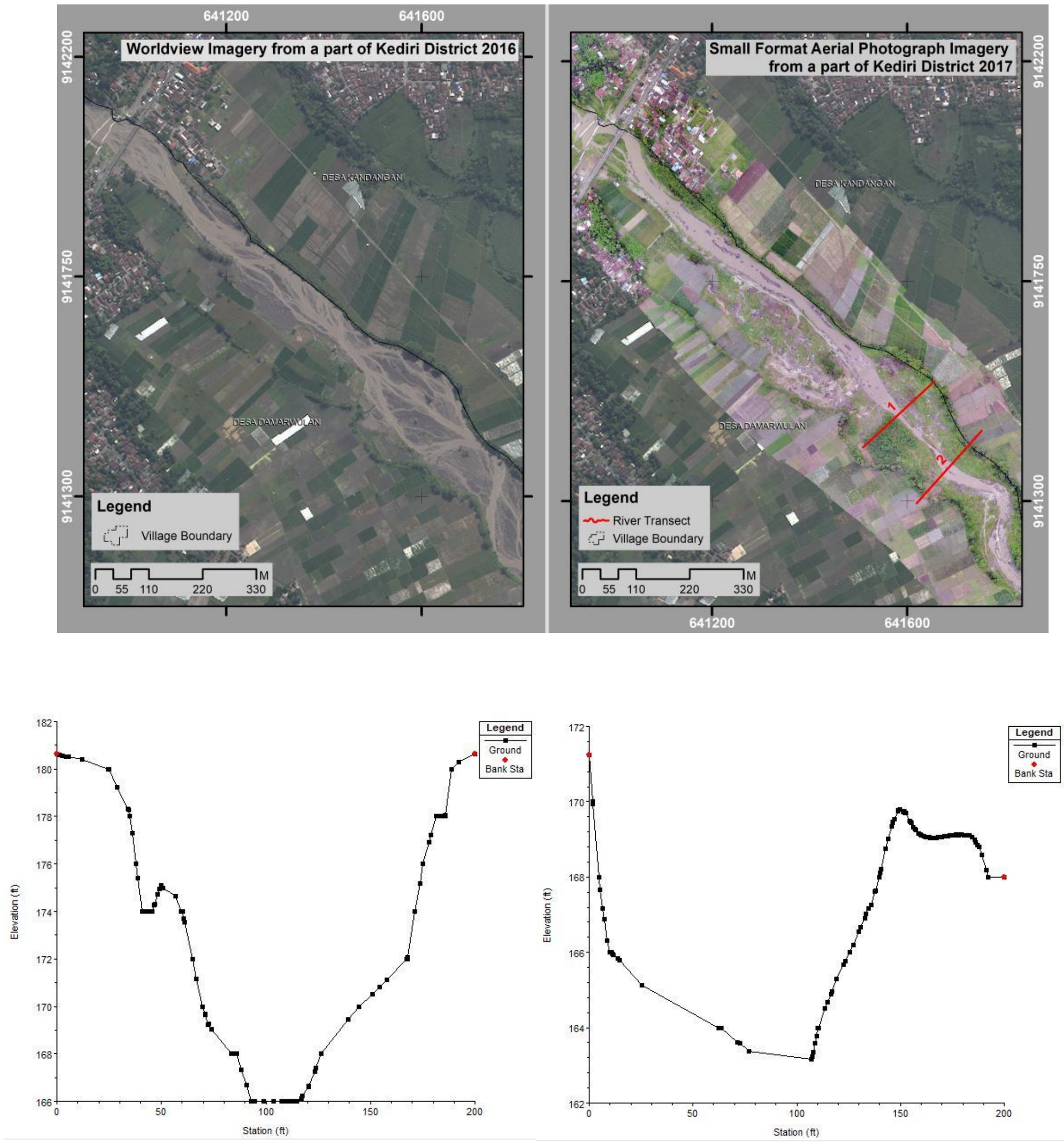

Figure 5. Worldview-2 Image 2014 (left) and Aerial Unmanned Photo 2017 (right) to depicts vertical transect towards Kandangan Village.

The possible aspects influential towards morphological setting of the river are flow velocity, structure of lava material, and river bed characteristics. The research conducted two transects areas, northern line and southern line. Northern line of transect indicated that Konto River experiencing massive accumulation of post-eruption material. It was indicated the middle riverbed, characterized by deeper and steeper topography, due to massive erosion at the riverbeds. Southern line of transect indicated that Konto River experiencing greater energy that shapes its riverbed into fairly steep and increase width compare to northern side. Along Konto River are utilized for agricultural land, and settlement area. To the south, potentials of getting more inundated land are greater compared to the northern area.

After observing research area using aerial photo, this research explores many ancillary data for the research area. Accordingly, its demographic feature was experiencing rapid population growth from 2013 to 2016. Village monograph recorded in 2013 total population in Kandangan was 46,352 people, with total density of 1,112 people/km². In 2014, total population increased into 46,586 people, and in 2015 increased into 48,333 lives. Meanwhile the latest village information recorded that total population of 2016 approached 50,010 people. This number is quite high for a village administrative, whereas population density rapidly increases up to 1,144 people/km² in 2014, 1,159 people/km² in 2015 and 1,200 people/km² in 2016.

Table 2. Demographic trend of Kandangan Village 2013-2016

Year	Total Population	Density (people/km²)	Paddyfield (ha)	Non paddyfield (ha)
2013	46,352	1,112	1,890	2,277
2014	46,586	1,144	1.848	2,319
2015	48,333	1,159	1,888	2,279
2016	50,010	1,200	1,888	2,279

In terms of land use, there are several actual activities such as agriculture area especially for paddy field, mix-cropping, fields and built up areas. The area has predominantly use for agriculture activities, and it has not much shifting after the eruption. Prior to this ancillary data, we may argue that agriculture activity has been very much resilience to support local livelihood although it had impacted heavily at the aftermath of Kelud Volcano eruption. The following figure 6 indicated that the number of buildings at the research area were severely decreasing since 2014. It indicated number of houses or buildings which had been damaged due to lahar flood of Kelud Volcano.

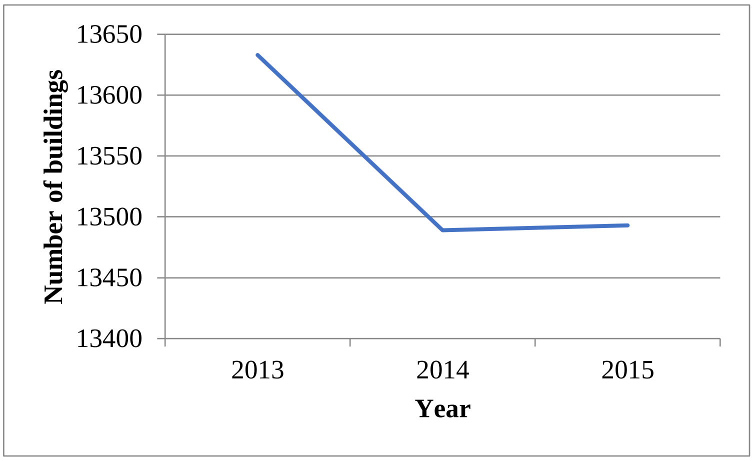

Figure 6. Building distribution at Kandangan Village, 2013 - 2015.

Evidently, this baseline information taken from village information provide brief overview of temporal dynamics within the area. Volcanic eruption did not change much the natural morphology, even the land use. However, the man-made morphology had been shifting at the aftermath of the eruption. Lahar flow, diverted river morphology, but not necessarily impacted so much to the land use. In fact, as noted earlier, lahar flow also put dynamic change towards alluvial plain along river streams.

Taking into such phenomena, the research thus tried to foreseen future condition of vulnerability. The vulnerability from physical aspects refers to condition of future vulnerability if physical criteria is dominant compared to other criteria. There are four factors supporting physical criteria, such as the distance of the hamlet to the river, the extent affected, the number of buildings and the density of the building. The assigned weights of each factors upon physical criterion are as follow, whereas, the distance to the river (0.56) and the weight of the affected area, the number of buildings, and the densities respectively are as follows, 0.26, 0.12 and 0.06. According to the physical scenario, the area to the north and to the south of the Konto River justified as highly vulnerable area. The main object evaluated in this scenario are buildings. Its location, distance and impacts were emphasized heavily within this scenario (figure 7). The red area shown on the map indicated a high vulnerable area. Additionally, the research was also looking for any reasoning that cause buildings at Kandangan Village become very much vulnerable towards lahar flood. In fact, according to field survey, there was no early warning system established in the research area. Prior to early warning system, it is important to monitor and control channel debit and material sedimentation before and during lahar flood occurrence. The remaining Sabo Dam was located at Biyoro Hamlet, the most populated neighbourhood unit in Kandangan Village. This Sabo Dam also not in good condition, although Biyoro Hamlet located directly adjacent to Konto River. Additionally, the research area also had not yet equipped with evacuation routes. The research also learned from Participatory Geographic Information System that the Pandean Hamlet and Biyoro Hamlet were the most impacted area in the aftermath of lahar flood.

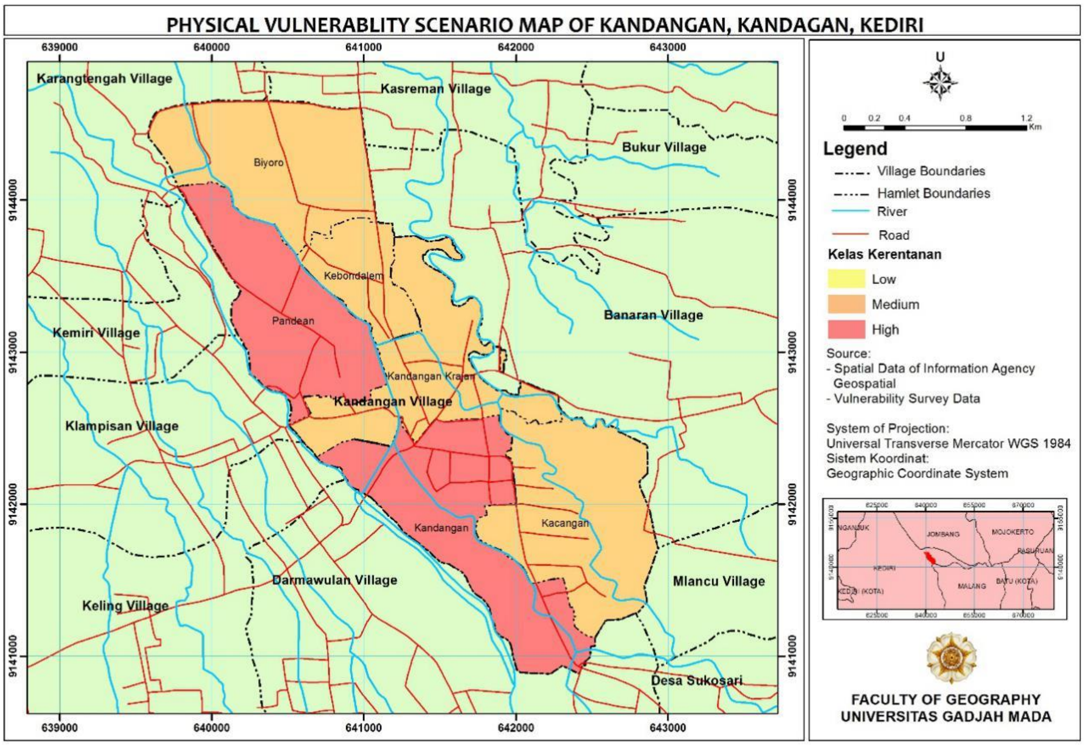

Figure 7. Physical vulnerability scenario map.

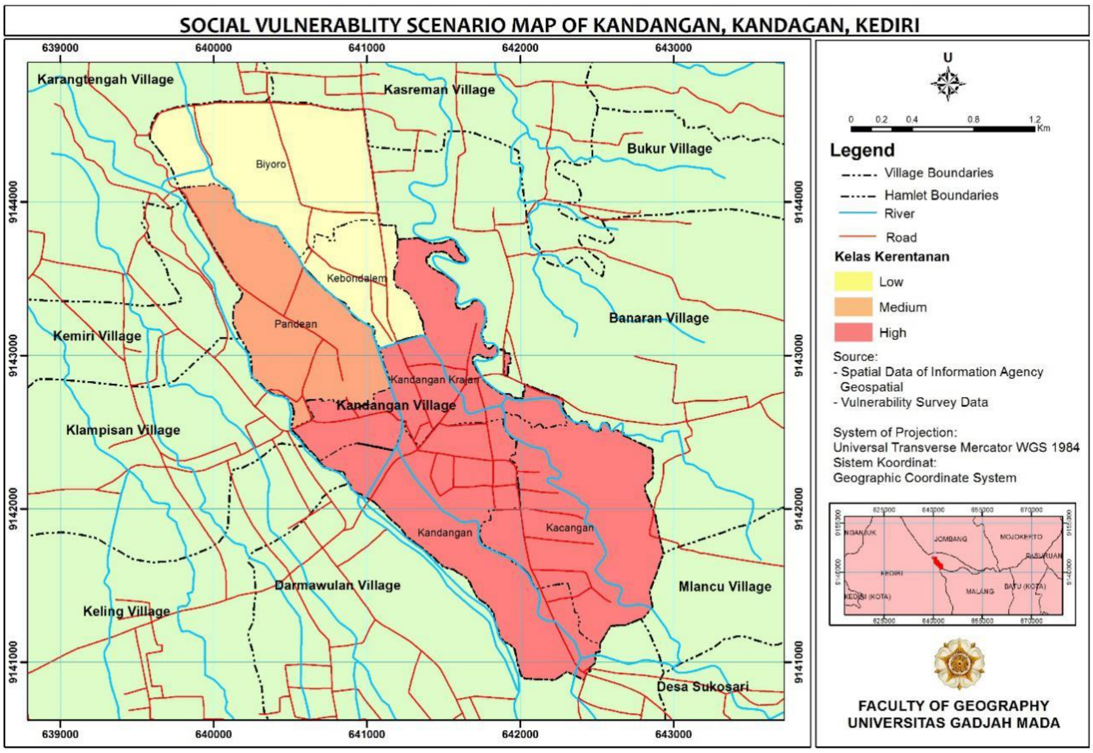

Figure 8. Social vulnerability scenario map.

The second scenario is vulnerability from social criteria. The overarching goals in determining social vulnerability is to evaluate spatial distribution of people's aggregate. Factors supporting this criterias are total population, density, disabled, elderly, and toddlers. The spatial distribution towards these selected demographic criteria off course quite different with physical criteria, therefore, the vulnerability pattern coming out of the computation also different to the previous scenarios (figure 8). Spatially, the southern part such as, Kandangan-Krajan Hamlet, Kacangan Hamlet, and Kandangan Hamlet subjected to high vulnerable area due to accumulation of demographic features and vulnerable groups. Meanwhile, the northern part of the research area is less vulnerable compared to the other area.

The third scenarios are vulnerability from economic criteria. As indicated by baseline information, the most impacted area is building, whereas each of the household livelihood fully dependant upon agriculture activities. Therefore, within this economic criterias, the factors address farmer as subjected groups together with poor families as vulnerable groups from economic perspective. Administratively, number of farmers and poor families are accumulated in two neighbourhood units at Kandangan Village as show at figure 9.

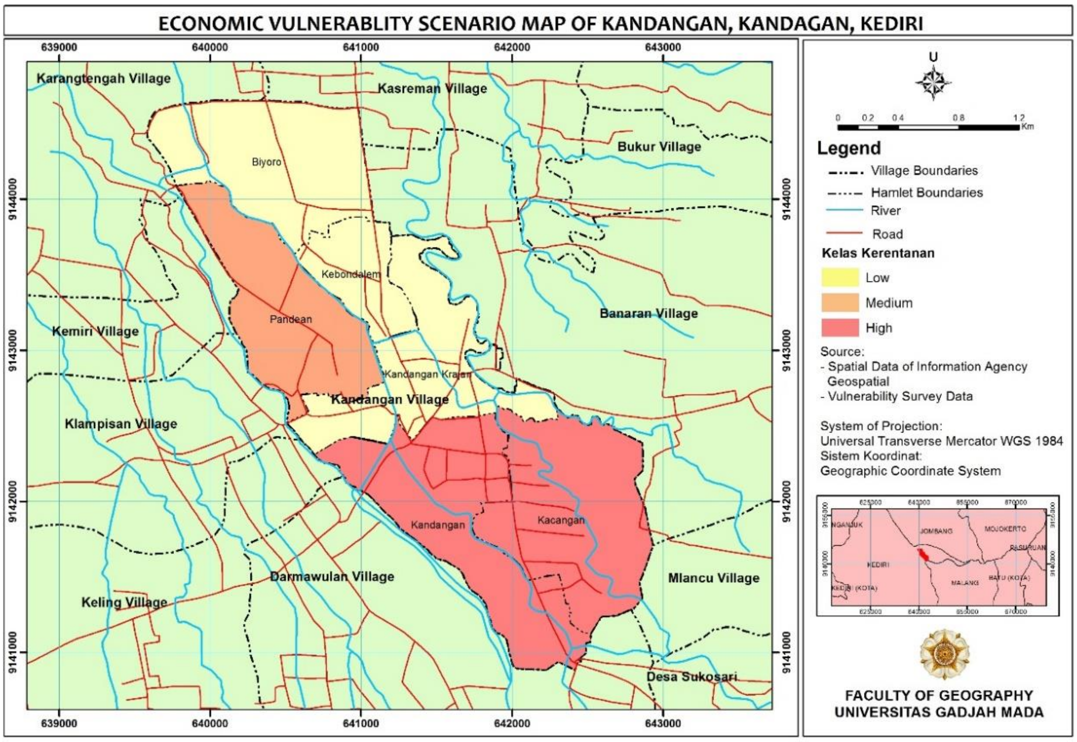

Figure 9. Economic vulnerability scenario map.

According to table 2 below, some of the villages exposed to composite types of vulnerabilities. Kandangan for example, whereas it exposed to high physical, social and economic vulnerability at once. Meanwhile, Biyoro is exposed to low physical, social and economic vulnerability. This indicated that these villages have robust vulnerability pattern.

Table 2. Recapitulation of vulnerability by village.

Type of Vulnerability		Low	Medium	High
1.	Physical	Biyoro Kebondalem Kandangan-Krajan Kacangan	-	Kandangan, Pandean
2.	Social	Biyoro Kebondalem	Pandean, Kacangan	Kandangan, Kandangan-Krajan
3.	Economic	Biyoro Kebondalem Kandangan-Krajan Pandean	-	Kandangan, Kacangan

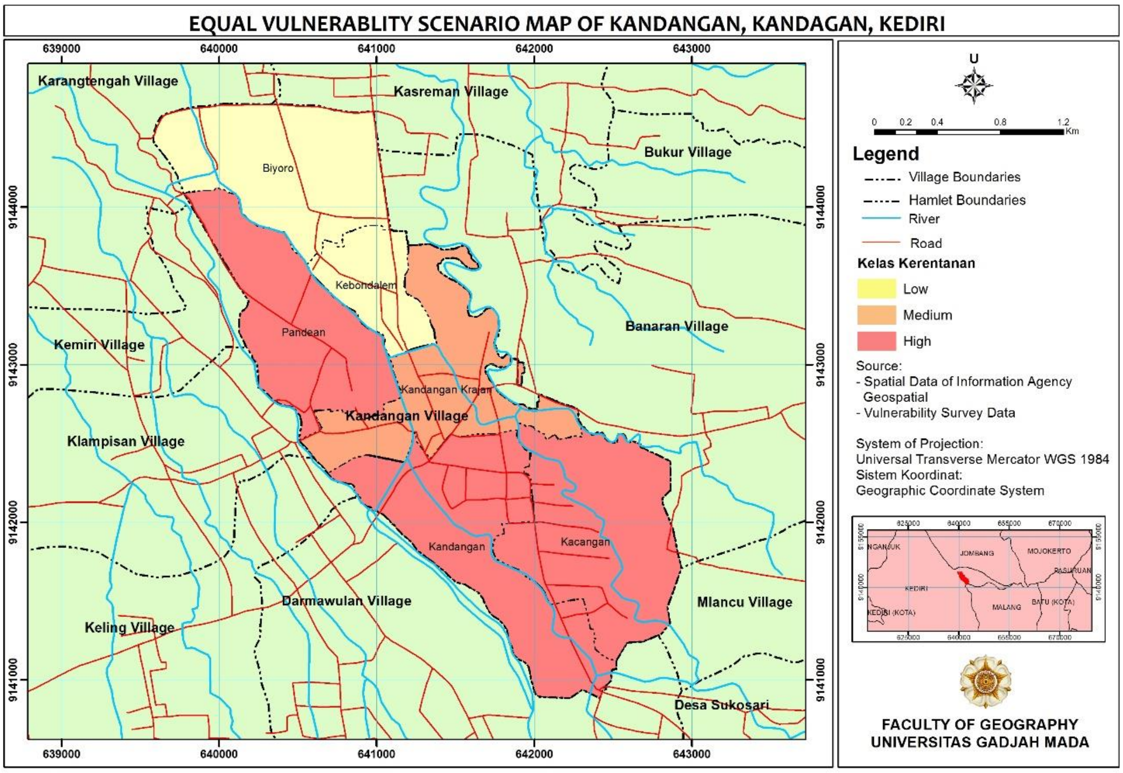

Figure 10. Equal vulnerability scenarios.

The equal scenarios steward scholar to understand fairly common spatial pattern with one or more spatial pattern shown in the previous scenarios. Administratively, Kandangan Hamlet justified as the most common vulnerable area from different scenarios (figure 10). If the research compared four scenarios at once, it is clearly seen that Kandangan Hamlet deserve to have priority action in the future if any lahar flow occurs. This highest vulnerability area, followed by Pandean Hamlet. While the rest of area considerably less vulnerable.

Derived from this result, the village information is considered essential to predict future trends of vulnerability. The availability of village information should not be limited to statistics ancillary data. It should also be equipped with spatial information, either taken directly from satellite imagery or unmanned vehicle imagery. Additionally, spatial data also possible to be taken from participatory process.

Taken back the result to the “desa-kota” theory, whereas urban and rural areas are differed from its accumulation of assets and vulnerability, it is argued that, the most populated and developed area among these rural setting are happened to be the most vulnerable. It means that this pseduo-urbanization process occurs in the area somehow put more burden on the area.

For what its worth, the vulnerability analysis itself is easily conducted using multi criteria evaluation. The advantage of applying such method is to reduce the possibility of non-exist datasets in village information. Multi-criteria make possible for scholar to select any available data using standardization to construct the logic with its main objectives. The disadvantage of applying multi criteria evaluation has been very much political. The Indonesian Government provides guidelines to evaluate vulnerability analysis which employed mainly weighting scenarios to particular element at risk observation. Therefore, such method will be very much challenging to add into the formal datasets.

4. Conclusion

1. The highest vulnerability to the lava flood disaster in Gunungapi Kelud is owned by Kandangan Hamlet, Pandean Hamlet, and Kacangan Hamlet, as these two hamlets are in the dominant high vulnerability position of 3 out of 4 scenarios (economic, social and equal).
2. The vulnerability analysis indicated that for any chance of lahar flood in the future, the Kandangan Hamlet, Pandean Hamlet and Kacangan Hamlet should be prioritized in order to minimize potential risk arisen in the area.

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