Analysis of lava flood risk distribution to support hazard mitigation

T Hariyanto¹, Z R Larasati¹, A Kurniawan¹ and C B Pribadi¹

¹Department of Geomatics Engineering, Faculty of Civil Engineering, Environment, and Geo-Engineering, Institut Teknologi Sepuluh Nopember Surabaya, Indonesia

Abstract. Flood lava is a collection of lava released by the volcano and reaches the lower surface with the help or encouragement of rainwater. The impact of lava flooding has a high risk because the material it carries can cause damage and potentially cause death, injury, illness, life threatened, loss of security, displacement, damage or loss of property, and disruption of community activities. Mapping the risk areas for lahar floods by utilizing the Geographic Information System (GIS) can be useful to support disaster mitigation activities. The lahar flood risk map was generated from an overlay of the lahar flood hazard map, lava flood kerawana map, lava flood vulnerability map, and lava flood capacity map which had each parameter which was then calculated using the scoring method and classified based on its scoring value. From the results of processing, the lahar flood risk map can be classified into 3 classes, namely high risk, moderate risk, and low risk. High risk occurred in November, mostly occurred in the Pasirian District area, especially in the area around the river and a little in the river area Pronojiwo District, with a total area of risk area is 28.983 or with a percentage of 4.24% of the total area of the study area, and areas that have risks high in January many occurred in the Pasirian District area, especially in the area around the river with a total area of risk area is 9.570 or with a percentage of 1.40% of the total area of research.

1. Background

Natural disasters are things that cannot be avoided by any country including Indonesia. Natural disasters that are quite common in Indonesia, one of which is lava flood. Mount Semeru is an active volcano in Indonesia which effectively produces lava. Lava flood is the carrying of pyroclastic materials by rain falling to mud. Lava is the result of a combination of volcanic and climate processes [1].

Lava floods that occur have the potential to produce power large enough to transport material that is on the slopes of Mount Semeru such as sand, gravel and even large chunks of rock. The impact caused by this disaster resulted in a fairly high disaster risk. Disaster risk is the potential loss caused by disaster in an area within a certain period of time which can be in the form of death, injury, illness, life threatened, loss of security, damage or loss of property, and disruption of community activities [2]. Considering the extraordinary impact, therefore the importance of the lahar flood disaster mitigation planning must be carried out using appropriate principles and methods so that material and life losses can be minimized or even avoided.

By utilizing the Geographic Information System (GIS) a Lahar Flood Risk Map can be produced to support disaster mitigation activities. Risk maps are generated from overlaying lava flood hazard maps,
lava flood hazard maps, lava flood vulnerability maps, and lava flood capacity maps that have each parameter. The respective parameters are: lava flood hazard maps have hazard intensity parameters, and watersheds. Vulnerability map of lahar flood has geological, land cover, rainfall, watershed and slope parameters. The lava flood vulnerability map has gender parameters, population density, vulnerable age groups, and the number of poor people. Whereas the capacity map has parameters for the number of public facilities (educational facilities, terminals, health facilities, places of worship, sub-district offices and village offices, police stations, post offices, and trade centers).

2. Methodology

This research location is located in Lumajang Regency, precisely in Pasrujambe District, Candipuro District, Pasirian District, Pronojiwo District, and Tempursari District. Map of the research location can be seen in the image below.

![Map of research location in a part of Lumajang regency.](image)

The vulnerability map of lava floods is obtained from the calculation of the number of scores for each parameter, including the score slope parameters, geology (rock hardness), river buffer, land cover, and rainfall. From the summing results, the score will get the total score, which is further classified into three classes, namely low, medium and high hazard classes. The scoring values for each vulnerability parameter are as follows

| Parameter | Classification | Information | Score |
|-----------|----------------|-------------|-------|
| Slope     | 0%-2%          | Flat        | 5     |
|           | 2%-7%          | slope       | 4     |
| Terrain   | 7%-13%         | slightly    | 3     |
|           | 13%-20%        | Median terrain | 2   |
|           | >20%           | High terrain | 1    |
Map of Lava Flood Capacity

Processing of lava flood capacity maps is obtained from data on infrastructure. The lava flood capacity map is classified based on the number of capacities of each sub-district, while the infrastructure included is: educational facilities, terminals, health facilities, places of worship, sub-district / village offices, police stations, post offices, and trade centers.

Lava Flood Vulnerability Map

Processing of lava flood vulnerability map derived from four parameters, namely: vulnerable age groups, the number of poor people, population density, and gender. Flood Map The danger of lava flood is the distribution of events that occur in the study area based on recapitulation and river buffer data, this is calculated because the lava flood disaster will occur earlier in the area around the river. Prediction of Lava Flood Flow Prediction. Lava flood flow path prediction is obtained from path analysis on lava flood hazard maps, rivers, water flow and altitude maps. The dome of Mount Semeru is predicted to overflow to the danger lane in processing lava flood hazard maps, this is due to the dome around Mount Semeru with steep slopes. Lava Flood Risk Map Processing lava flood risk map is the result of Overlay from lava flood hazard map, lava flood hazard map, lava flood capacity map and lava flood vulnerability map. The general formula for risk analysis in the Indonesian Disaster Risk book proposed by BNPB (BNPB,2012) is as follows:

$$ R = H \times \{V/C\} $$  

Information :
R: Disaster Risk
H: Hazard Threat. the likelihood of disasters likely to occur with a certain intensity (Lava Flood Hazard Map + Lava Flood Hazard Map)
V: Vulnerability
C: Adaptive Capacity
3. Results and analysis

There are two factors in this study of lava flood hazard maps, namely the lava flood hazard map in November and January. Based on the number of scoring for each parameter, the total range of scores is 4-21, with details of the total score of November vulnerability being 7-21 and January is 4-18. The total score will be classified into three classes namely low, moderate, and height based on the calculation of the interval, namely:

\[
\text{Interval Class} = \frac{\text{High Value} - \text{Low Value}}{\text{desired number of classes}}
\]

\[
= \frac{21 - 4}{3} = 6
\]

| Interval | Keterangan | Skor |
|----------|------------|------|
| 4 - 9    | Low vulnerability | 1    |
| 10 - 15  | Medium vulnerability | 2    |
| 16 - 21  | High vulnerability   | 3    |

The selection of three classes is based on the making of the Volcano Hazard Hazard Map issued by BNPB which consists of three classes, namely: low vulnerability class, moderate vulnerability and high vulnerability. The map of the lava flood hazard resulting from overlay and classification are as follows:

![Figure 2. The map of the lava flood hazard in January 2016.](image1)

![Figure 3. The map of the lava flood hazard in November 2016.](image2)

Areas that have high vulnerability to the moon November and January occur in many areas. Tempursari District and Pasirian District as well as in the regions around the river. Based on these classifications it can be calculated the total area of prone areas in November is as follows:

| No | Description       | Area in November (Km²) | Area in January (Km²) |
|----|-------------------|------------------------|-----------------------|
| 1  | Low Vulnerability | 98.033                 | 338.740               |
| 2  | Medium Vulnerability | 476.653             | 331.608               |
| 3  | High Vulnerability | 108.337                | 12.718                |

Determination of safe zones and lava flood evacuation routes is made based on the lava flood vulnerability map in November, this is considered based on the greatest possibility lava flood. In addition to the map of lava flood hazard, also used capacity parameters, roads, vacant land, and river. In addition to facilities from capacity maps, places which can be used as a safe zone is vacant land.
Determination of safe zones made as many as 25 points based on the number of settlements that are likely to enter into areas of high vulnerability. The details is Tempusari 5 Titik Subdistrict, Pronojiwo 5 Point, 3 Point Pasrujambe, 6 Point Pasirian and 6 Point Candipuro.

As for the determination of the evacuation route, the thing at pay attention only to the proximity of the path and not crossing the river from settlements on a level high hazard to safe zone. Based on these then the map of the safe zone and the lava flood evacuation route is as follows:

![Map of Lava Flood Safe Zone and Evacuation Route](image)

**Figure 4.** Map of the lava flood safe zone and evacuation route.

Map of Lava Flood Hazards and Lava Flow Lines

Based on the results of the disaster recap, a conclusion can be drawn that the subdistricts experienced the most events disaster is Pronojiwo District with an intensity of 10 times and lowest 2 times.

| No | Subdistrict     | Event intensity | Scoring |
|----|-----------------|-----------------|---------|
| 1  | Tempusari       | 2               | 1       |
| 2  | Pronojiwo       | 10              | 3       |
| 3  | Pasrujambe      | 2               | 1       |
| 4  | Pasirian        | 8               | 3       |
| 5  | Candipuro       | 4               | 1       |

The score for each parameter are then overlaid to produce lava flood hazard maps. Value can from the overlay results are 1 to 6, then on Classify into three levels, as follows:

| No. | Distance from river side | Score | Class   |
|-----|--------------------------|-------|---------|
| 1   | 300                      | 1     | low     |
| 2   | 400                      | 2     | Medium  |
| 3   | 500                      | 3     | High    |

| Score | Class      | Intensity | Buffer            |
|-------|------------|-----------|-------------------|
| 1-2   | Low danger | zero      | Beside river      |
Lava flood flow paths can be obtained from map analysis danger of lava flood, water flow or river and also mapsheight. Lahar from the dome of Mount Semeru is predicted will spread in all directions towards the lava flood hazard pathway, this is because of the dome around the Semeru Mountain steep slope. Not all danger lines are taken, this is on because of the influence of height on the region.

Map height can be obtained from the classification of DEM data, so that can be seen the appearance of elevation maps and flood flow paths lava in the image below.

### Table 7. Score of classification of lava flood capacity.

| Interval | Danger Level | Capacity |
|----------|--------------|----------|
| 3-4      | Low          | Medium from buffer river |
| 5-6      | High         | High river class scores |

![Figure 5. Processing Results of Lahar Flood Hazard Map.](image)

![Figure 6. Results of Prediction of Flow Path Prediction with Lava Flood Hazard Map and Altitude Map](image)
Table 8. Vulnerability scoring.

| Subdistrict     | Density Population | Man      | Woman    | Vulnerable Age | Poor Population | Score |
|-----------------|--------------------|----------|----------|----------------|-----------------|-------|
| Tempursari      | 269                | 13899    | 14053    | 5972           | 7660            | 7     |
| Pronojiwo       | 220                | 15868    | 16045    | 6585           | 10056           | 8     |
| Pasrujambe      | 215                | 17371    | 18311    | 6708           | 5593            | 7     |
| Pasirian        | 676                | 41958    | 43876    | 16158          | 12853           | 13    |
| Candipuro       | 442                | 30763    | 32440    | 11797          | 16000           | 11    |

From the calculation of the total score, the lowest score is 7 and the highest score is 13, then the results of the classification of the vulnerability class interval are

Table 9. Scoring of classification of vulnerability flood lava.

| No. | Sum of vulnerability Parameter | Remark          | Score |
|-----|--------------------------------|-----------------|-------|
| 1   | 7-8                            | Low vulnerability| 1     |
| 2   | 9-10                           | Medium vulnerability | 2    |
| 3   | 11-13                          | High vulnerability| 3    |
Based on the map and classification above, it can be concluded that the districts with the highest vulnerability are Candipuro and Pasirian Subdistricts, the districts with the lowest Vulnerability are Pasrujambe, Pronojiwo, and Tempursari Districts.

Map of Lava Flood Risk
From the results of the overlay of the four maps and calculation of risk scores, the November risk values range between 19-351 and January between 12-312. So for the range for risk classes is a value that is on both risk scores that are vulnerable 12-351. From the results of the calculation of the value of the risk score will get the total score which will then be classified into three classes, namely low risk class, medium risk, and high risk.

| No. | Interval  | Remark    | Class |
|-----|-----------|-----------|-------|
| 1   | 12 - 125  | Low risk  | 1     |
| 2   | 126 - 239 | Medium risk | 2     |
| 3   | 240 - 353 | High risk | 3     |

The selection of three classes is based on the creation of the Indonesian Hazard Risk Map issued by BNPB, which consists of 3 classes, low risk class, medium risk and high risk. Based on these classifications, the total area of November lava flood risk can be calculated as follows:

| No. | November (km²) | January (km²) | Remark     | Class |
|-----|----------------|---------------|------------|-------|
| 1   | 443,884        | 542,173       | Low risk   | 1     |
| 2   | 210,141        | 131,266       | Medium risk | 2     |
| 3   | 28,983         | 9,570         | High risk  | 3     |

Areas that have a High Risk in November occur mostly in the Pasirian sub-district area, especially in the area around the river and Slightly in the Sungai Pronojiwo sub-district area. Areas that have a high risk in January occur mostly in the Pasirian District area, especially in areas around the river. The Risk Descriptions for November and January are as follows:
4. Conclusion
The results of the lahar flood risk analysis area are:

1. The area most frequently experiencing lava flood hazard is Pronojowo District.
2. Areas that have a high level of capacity are Candipuro and Pasirian Districts, while the low capacity level includes Pasrujambe and Pronojowo Districts.
3. The regions that have the highest vulnerability are Candipuro and Pasirian, while those with the lowest vulnerability are Pasrujambe, Pronojowo, and Tempursari.
4. Areas that have high vulnerability to lava floods in November and January mostly occur in the District of Tempursari, Pasirian and in the area around the river.
5. Areas that have a high risk of lahar flooding in November mostly occur in the Pasirian District area, especially in the area around the river and a little in the River District Pronojowo with an area of 28,983 km² or with a percentage of 4.24% of the total area of the study. While in January many occurred in the Pasirian District area, especially in the area around the river with an area of 9,570 km² or with a percentage of 1.40% of the total area of research.
6. The lava flood hazard map has parameters of hazard intensity and watershed. Map of lahars flooding has parameters such as rock hardness, land cover, rainfall, watershed, and slope. The lahar flood vulnerability map has parameters of gender, population density, vulnerable age groups, and the number of poor people. While the lahar flood capacity map has parameters for the number of public facilities. Determination of safe zones and evacuation routes is based on hazard map parameters parameter maps Capacity, roads, vacant land, and rivers, while prediction of lava flow paths is made based on parameters of hazard maps, rivers and water flow.

5. References
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