A Study of the Hazard Level and Vulnerability of the Society Against Debris Flow of Merapi in the Putih River Watershed, Indonesia

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Abstract. Mount Merapi is one of the most active volcanoes in Indonesia with a relatively fast period of around 2-7 years. The impact of hazards arising from a fire eruption, such as primary hazards, namely hazards that occur directly, secondary hazards, namely hazards that occur indirectly or take place after an eruption, tertiary hazards, namely environmental damage around the volcano. This study aims to determine the value of the hazard level and vulnerability to debris flow in the Putih River watershed. The research method used in this study is to use the scoring and weighting method. The results obtained from the scoring and weighting methods, Srumbung and Mranggen villages have a debris flow hazard with a total value of 2.6 which falls into the high hazard level category. The results show that Srumbung Village obtained a total value of 7.92 which is included in the medium level of vulnerability category. Parameters that have a big influence on the level of community vulnerability to debris flows in the two villages are social aspects with a value of 3 and economic aspects with a value of 2.4.

1. Introduction
Mount Merapi is a volcano located on the border of the two provinces of the Special Region of Yogyakarta and Central Java, which has a type of volcano with a lava dome and is one of the most active volcanoes in Indonesia with a relatively quick period of about every 2-7 years [1]. Hazards caused by volcanic eruptions consist of primary, secondary, and tertiary hazards. The level of hazard of a volcano is highly dependent on the density of the population living around the volcano [2]. According to Law No. 24 of 2007 disaster is an event or series of events that threaten and disrupt people's lives and livelihoods caused, both by natural factors and/or non-natural factors as well as human factors, resulting in human casualties, environmental damage, property losses, and psychological impact.

It is unavoidable that after a volcanic eruption, volcanic material will settle in the upper reaches of the river on the slopes of Mount Merapi. If it rains in the upper reaches of the river, then the volcanic material will be carried away by rainwater flowing down to the downstream. This mixture of rainwater and volcanic material is known as debris flow. Debris flows always threaten areas along the river flow through which volcanic material passes so that the watershed (DAS) is an area prone to debris flows. According to BMKG data, debris flows reach more than 65 kilometers per hour and can flow as far as 80 kilometers [3].
Disasters are a series of events resulting in victims of human suffering, loss of property, damage to the facilities and infrastructure environment, and can cause disturbances to the lifestyle and community livelihoods [4]. Flooding is one of the natural phenomena that occurs due to high rainfall intensity causing excess water and causing inundation which causes losses to the community [5]. Debris flow is a significant volcanic hazard due to its long range and high velocity from the eruption source. So that volcanic material will mix with rainwater so that it becomes dangerous when carrying volumes of material flowing in rivers [6]. Debris flow will occur when Mt. Merapi is still active. The impact of damage, losses to the community and damage to watersheds and river systems are disasters that occur due to debris flow [7]. Debris flows are formed from deposits of pyroclastic material from the eruption of Mt. Merapi which is located upstream of the river flow. Debris flows are deposits of pyroclastic material mixed with rainwater with a long duration so that these deposits become debris flows [8].

The immediate dangers of volcanic eruptions are debris avalanches, lateral eruptions, mudflows, debris flows, pyroclastic flows, pyroclastic falls, toxic volcanic gases. Indirect hazards from volcanic eruptions include secondary mudflows, atmospheric effects, earthquakes caused by magma and volcanic avalanches [8]. There are five types of hazard interactions through natural hazards, namely tropical storms, floods, landslides, and volcanic eruptions that will trigger secondary hazards [9]. Vulnerability is the inability to deal with disaster threats that occur in the condition of a community or society. A state of insecurity that is influenced by physical, social, economic, and environmental processes that increase vulnerability. Height, time of inundation and frequency of flooding can affect the level of vulnerability of risk elements in this case settlements and infrastructure [10].

According to Law Number 24 of 2007 the definition of mitigation is a series of efforts to reduce disaster risk, both through physical development as well as awareness and capacity building in dealing with disasters. Disaster mitigation can be defined as efforts made to prevent disasters or reduce the impact of disasters [11]. Activities that are active protection to anticipate disasters through appropriate and useful steps and can provide short-term solutions as long-term disaster recovery [12].

A watershed called DAS is a land area that is one unit with a river and its tributaries, which functions to accommodate, store and drain rainwater into lakes or to the sea naturally, and serve as a topographical separator on land and boundaries at sea to areas of water that still affected by land activities [13]. Gives a weight value for each of the parameters. The weighting can be done objectively or subjectively depending on the considerations that will be made. The scoring method is to assess the level of ability for each parameter using a score or value assessment based on predetermined criteria [14].

Based on the above background, it is necessary to develop a model to calculate the level of community hazard and vulnerability due to debris flow, especially in the Putih River watershed area. This study tries to develop a model that is expected to be able to measure the level of hazard and vulnerability due to debris flow, so that the model can be used as a reference in reducing disaster risk due to debris flow.

2. Research Methods

2.1. Location

The research was conducted in the Putih River watershed, entirely located in Magelang Regency, Central Java, with the UTM WGS 1984 49S zone. The area of the Putih River watershed is 23.791 km², with the length of the Putih River is 23.5 km. The research location is shown in Figure 1.
Figure 1. Location of the Putih River watershed, Magelang Regency, Indonesia

2.2. **Material**

2.2.1. **Data Collection**
In conducting research on the level of danger and vulnerability to debris flows for data collection sourced from agencies such as, Center for Research and Investigation of Volcanic Technology (BPPTK), Central Statistics Agency (BPS), Regional Disaster Management Agency (BPBD), and District Offices.

2.2.2. **Scoring dan Weighting**
The use of the selected scoring method to assess the vulnerability of an area under study by determining the weight aspects of each parameter with reference to the priority level of each variable. Rainfall, material volume, slope, and frequency of occurrence are aspects that can determine the level of debris flow hazard. Social aspects, economic aspects, physical aspects, and environmental aspects are factors to determine the level of vulnerability of an area to the danger of debris flow.

2.2.3. **Debris flow Hazard Analysis**
According to [15], the Disaster Threat Index is designed based on two components including, the potential for a threat to occur and the magnitude of the impact that has been recorded for the disaster that has occurred. It can be concluded that the disaster threat index is designed based on data and historical records of events that occurred in an area. In determining the level of danger of debris flowing in Merapi, it is done by analyzing the factors that become the assessment parameters, namely rainfall, volume of material, slope and frequency of events that occur in Putih River.

2.2.4. **Society Vulnerability Level Analysis**
As with the hazard level analysis, the vulnerability level analysis is also determined using a scoring and weighting analysis that can affect an area. The level of vulnerability of an area can be seen and assessed from various aspects including social aspects, economic aspects, physical aspects, and environmental aspects.
3. Result and Discussion

3.1. Weighting

From the results of questionnaire data that have been obtained in previous research in [16], through relevant agencies regarding debris flow vulnerability, the average weighting percentage value of the debris flow vulnerability level parameter is 42% rainfall, material volume by 26%, the slope of the slope by 24%, and the frequency of occurrence of 8%.

3.2. Analysis of the Hazard Level of Debris Flow

3.2.1. Rainfall Data

In this study, the rainfall data obtained from Srumbung District is in the number 2020 with units of mm while for the provision of rainfall weight values obtained through the average value generated from expert interviews/questionnaires. The classification and results of rainfall can be seen in Table 1.

| Rainfall (mm) | Classification | Score Standard | Weight (%) | Data (mm) | Score | Value | Class |
|---------------|----------------|----------------|------------|-----------|-------|-------|-------|
| <1000         | Dry            | 1              | 42         | 3380      | 3     | 1.26  | Very Wet |
| 1000-2500     | Wet            | 2              | 42         |           |       |       |       |
| >2500         | Very Wet       | 3              |            |           |       |       |       |

In Table 1, the results of scoring the intensity of rainfall in the Putih River area are obtained a score of 3 which is > 2500 and is included in the very wet class. The result of the value in Table 1 is the calculation of the score multiplied by the weight divided by 100.

3.2.2. Material Volume

Classification and results of material volume can be seen in Table 2.

| Volume (%) | Classification | Score | Weight | Volume Data (%) | Score | Value | Class |
|------------|----------------|-------|--------|-----------------|-------|-------|-------|
| 1 - 5      | Low            | 1     | 26%    | 14.83           | 3     | 0.78  | High |
| 5 - 10     | Medium         | 2     |        |                 | 3     |       |       |
| >10         | High           | 3     |        |                 |       |       |       |

In the data obtained through the BPPTKG agency the volume of material contained in the Putih River watershed is 9.3 million m³ and for the total volume of material released by Mount Merapi on all rivers is 62.7 million m³. From the resulting data, the following calculations are performed.

\[
\frac{\text{Material Volume in the Putih River Merapi Watershed (} M^3\text{)}}{\text{Material Volume in the river (} M^3\text{)}} \times 100
\]

\[
\frac{9.3 \text{ Million } M^3}{62.7 \text{ Million } M^3} \times 100 = 14.83
\]
So, from the above calculation, the percentage of material volume in Putih River is 14.83% which includes a score of 3 with a material volume of >10% and has a high class with a vulnerability value of 0.78. The value of vulnerability is the calculation of the score multiplied by the weight divided by 100.

3.2.3. Slope
Slope is a slope condition at the research location. Slope data obtained through the Google Earth application and classified into three classes, namely low, medium, high, with a score of 1, 2, 3, and a weight value of 22.5%. The slope scoring table and its calculation can be seen in Table 3.

| Table 3. Classification of slope |
|-------------------------------|
| Percentage | Classification | Score | Weight |
| 0 - 2%     | Low            | 1     |        |
| 2 - 4%     | Medium         | 2     | 24%    |
| > 4%       | High           | 3     |        |

The slope data is obtained through the Google Earth application by looking at the elevation at two points and the distance between the two points. From measurements using Google Earth, the top elevation is 511 m, and the bottom elevation is 446 m, while the distance is 1690 m. So, the results of the calculation of the slope obtained are 3.8% which is included in the low class (0 - 2%) and the hazard level value is 0.45% which is included in the medium class. The calculation of the slope can be seen as below.

\[
\frac{311 M - 260 M}{2198 M} \times 100 = 2.32 \%
\]  

(2)

3.2.4. Occurrence Frequency
The frequency of occurrence is the number of debris flows that occur in one year, the information is obtained through BNPB or other mass media, then classified into three classes including low, medium, high and with a weight score of 8.75%. The occurrence frequency scoring and its calculation can be seen in Table 4.

| Table 4. Classification of frequency of occurrence |
|--------------------------------------------------|
| Occurrence Times | Classification | Score Standard | Weight | Data | Score | Value | Class |
| 0-1               | Low            | 1              |        | 0    | 1     | 0.08  | Low   |
| 2-5               | Medium         | 2              | 8%     | 0    | 1     | 0.08  | Low   |
| >6                | High           | 3              |        |      |       |       |       |

Based on information obtained through BNPB and the mass media, in the past year there was no debris flow in Putih River, resulting in a score of 1 (0-1 occurrence) and entering the low class and then the hazard level value of 0.08 was obtained.

3.3. Debris flow Danger Level
The analysis of the debris flow hazard level that has been obtained through the calculation of each parameter is then summed and the final value of the debris flow hazard level is obtained. Debris flow hazard level is divided into three classes, namely, low hazard level (score<1.67), medium hazard level (1.67<score<2.34) and high hazard level (2.34<score<3). Calculation of the level of debris flow hazard in the Putih River watershed can be seen in Table 5.
Table 5. Scoring result of debris flow hazard level

| Rainfall | Material Volume | Slope | Occurrence Frequency | Total |
|----------|-----------------|-------|----------------------|-------|
| 1.26     | 0.78            | 0.48  | 0.08                 | 2.6   |

3.4. Analysis of the Level of Community Vulnerability to Debris flow

The analysis of the level of community vulnerability to debris flows in this study refers to the Regulation of the Head of BNPB No. 2 of 2012 and previous research. To assess vulnerability is to look at four aspects of them, social aspects, economic aspects, physical aspects, and environmental aspects as stated in the Head of BNPB Regulation No. 2 of 2012. The data used in this study were sourced from the Central Statistics Agency (BPS), Village Office, and other agencies.

3.4.1. Social Aspect

Social vulnerability is a condition that indicates a threat of danger or disaster due to the vulnerability of an area that can harm, damage, and disrupt social life [17]. Analysis to assess the social aspect is to use the component of building density, the percentage of the population of vulnerable groups. Indices that can be used to determine or assess social vulnerability are population density and vulnerable groups (gender ratio, under-five age population ratio, elderly population ratio, and ratio of people with disabilities). Mental health or population health in a place can be used as an estimate to show social vulnerability in an area [18]. These parameters can be seen in Table 6.

Table 6. Scoring and social aspect weight

| Parameter       | Index Class | Classification | Score | Weight (%) |
|-----------------|-------------|----------------|-------|------------|
| Population Density | <500 inhabitants/km² | Low | 1       | 60         |
|                 | 500-100 inhabitants/km² | Medium | 2     |            |
|                 | >1000 inhabitants/km² | High | 3      |            |
| Vulnerable Group | <20% | Low | 1       | 40         |
|                 | 20-40% | Medium | 2     |            |
|                 | >40% | High | 3      |            |

Based on the data obtained from BPS [19] and calculations as above, the resulting Srumbung Village and Mranggen Village are classified as high-class population density (>1000 people/km²) with a score of 3 and a vulnerability value of 1.8. Based on data obtained from BPS and calculations as above, the resulting Srumbung Village and Mranggen Village are included in the high-class vulnerable group population (>40%) with a score of 3 and a vulnerability value of 1.2.

3.4.2. Economic Aspect

The economic aspect includes two parameters including poor households and vulnerable sector workers consisting of (miners, farmers, planters). The parameters of the economic aspect can be seen in Table 7.
### Table 7. Classification of economic aspects

| Parameter          | Index Class | Classification | Score | Weight (%) |
|--------------------|-------------|----------------|-------|------------|
| Poor Population    | <5%         | Low            | 1     | 40         |
|                    | 5-10%       | Medium         | 2     | 50.5       |
|                    | >10%        | High           | 3     | 60         |
| Vulnerable Sector  | <20%        | Low            | 1     | 40.5       |
| Workers            | 20-40%      | Medium         | 2     | 60         |
|                    | >40%        | High           | 3     | 60         |

Based on the data obtained from BPS and the calculations as above, the resulting Srumbung Village and Mranggen Village are included in the percentage of the high-class poor population (>10%) with a score of 3 and a vulnerability value of 1.2. Based on data obtained from BPS and calculations as above, the resulting Srumbung Village and Mranggen Village are included in the percentage of workers in the medium-class vulnerable sector (20-40%) with a score of 2 and a vulnerability value of 1.2.

### 3.4.3. Physical Aspect

The vulnerability of physical aspect can describe the condition of physical fragility in a threatened area. The parameters used in assessing the vulnerability of the physical aspect are the density of buildings and the condition or presence of water control buildings. The classification of physical aspect data can be seen in Table 8. Based on the data obtained as listed and the calculations as above, the resulting Srumbung and Mranggen villages are included in the low class building density (<500 units/km²) with a score of 1. The data generated as contained in Table 8 is by direct survey to the field and there are water control buildings, namely gabions in Srumbung Village and Mranggen Village with good conditions which are included in the low class with a score of 1 and a vulnerability value of 0.40.

### Table 8 Scoring and weighting physical aspects

| Parameter          | Index Class | Classification | Score | Weight (%) |
|--------------------|-------------|----------------|-------|------------|
| Building Density   | <500 units/km² | Low            | 1     | 40         |
|                    | 500-100 units/km² | Medium         | 2     | 50.5       |
|                    | >1000 units/km²  | High           | 3     | 60         |
| Condition of Water Control Buildings | Good | Low | 1 |
|                    | Bad          | Medium         | 2     | 40.5       |
|                    | Very Bad     | High           | 3     | 60         |

The data generated as contained in Table 8 is by direct survey to the field and there are water control buildings, namely gabions in Srumbung Village and Mranggen Village with good conditions which are included in the low class with a score of 1 and a vulnerability value of 0.40.
3.4.4. Environmental Aspects

The parameters used in this study are topographical altitude, distance from the river, land use, and river surface. The data collected from these parameters are sourced from field surveys or related agencies. The classification of environmental aspects can be seen in Table 9.

Based on data obtained from BPS, the results of the height of Srumbung Village at 440 m and Mranggen Village 508 m so that it is included in the low-class topography (>300 m) with a score of 1 and a vulnerability value of 0.21. Based on the data obtained from Google Earth, the resulting Srumbung Village and Mranggen Village are included in the distance from the high-class river (<100 m) with a score of 3 and a vulnerability value of 0.99. Based on the data obtained from the village office, the resulting Srumbung Village and Mranggen Village are classified as medium class land use (Agriculture > 50%) with a score of 2 and a vulnerability value of 0.99. Based on the data obtained through field surveys, Srumbung Village and Mranggen Village are included in the medium class river surface with a score of 2 and a vulnerability value of 0.42.

| Parameter | Classification | Index Class | Score | Weight (%) |
|-----------|----------------|-------------|-------|------------|
| Elevation | Low            | >300 m      | 1     |            |
|           | Medium         | 20-300 m    | 2     | 21.5       |
|           | High           | <20 m       | 3     |            |
|           | Low            | >500 m      | 1     |            |
| Distance From River | Medium | 100-500 m | 2 | 33 |
|                | High           | <100 m      | 3     |            |
| Land Use     | Low            | Vacant land, etc. (>50%) | 1 | |
|           | Medium         | Agriculture (>50%) | 2 | 24.5 |
|           | High           | Residential, industrial (>50%) | 3 | |
| River Surface | Low           | Rough       | 1     |            |
|                | Medium         | Medium      | 2     | 21         |
|                | High           | Smooth      | 3     |            |

3.5. Community Vulnerability Level to Debris flow

The analysis of the vulnerability level of debris flows in this study uses various parameters that are added up from each parameter to determine the final value consisting of social aspects, economic aspects, physical aspects, and environmental aspects. Classification of vulnerability levels are low (score is 4-6.67), medium (score is 6.67-9.34) and high (score is 9.34-12).

| Location       | Social | Economic | Physical | Environmental | Total |
|----------------|--------|----------|----------|---------------|-------|
| Srumbung Village | 3      | 2.4      | 0.90     | 1.62          | 7.92  |
| Mranggen Village | 3      | 2.4      | 0.90     | 1.62          | 7.92  |
Based on the results of the calculation analysis that has been carried out as contained in Table 10, the final vulnerability value of Srumbung Village and Mranggen Village is 7.92 which is included in the medium vulnerability level (6.67-9.34). Parameters that have a major influence on the level of vulnerability to debris flows are the social aspect with a high population density and a high population of vulnerable groups.

4. Conclusion
From the results of the analysis of research data, the level of debris flow hazard and debris flow vulnerability in Srumbung Village and Mranggen Village can be concluded as follows: (a) The danger level of debris flow in the Putih River watershed has a total value of 2.6 which is included in the high hazard level (2.34-3), from the obtained value, the condition of Putih River can be said to be in a state prone to the danger of debris flow of Mount Merapi. (b) The level of community vulnerability to debris flow in Srumbung and Mranggen Villages are included in the criteria for a moderate level of vulnerability (6.67-9.34) with a total vulnerability value of 7.92. From the scoring analysis of the community's vulnerability level to debris flow in Srumbung and Mranggen Villages, it is known that the most influential aspect is the social aspect. (c) From the results of the level of community vulnerability to debris flows in Srumbung and Mranggen villages, the same vulnerability value was obtained because the locations were opposite each other or only separated by the presence of Putih River. The number of residents is not much different. The physical aspect of the condition of the water control building and the condition of the river surface also has the same assessment.

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