Assessment of landslide risk in the mountainous area. Case study: Bumiaji Sub-District

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Abstract. Throughout 2016-2021, there were 31 landslides that have caused physical, economic, and social damages. Bumiaji Sub-District has several tourist destinations that are potentially exposed to landslides. This study aims to create a landslide risk map in Bumiaji Sub-District. This research was conducted during the COVID-19 pandemic situation. Therefore, the data collected was secondary data obtained from Google satellite images, Google Street View, the digital elevation model from the National Geospatial Institution, and other literature reviews. The data was then analysed using a landslide risk assessment based on Perka BNPB Number 2/2012. The results of this risk analysis show that Bumiaji Sub-District is dominated by low-level risk (48%), followed by high-level risk (30%), and medium-level risk (15%). High-risk level is affected by high hazards and vulnerabilities, especially in Giripurno Village. High hazard level is affected by high intensity of rainfall, slope degree, the sensitivity of soil to erosion, and the type of land cover. High vulnerabilities are affected by physical, social, and economic aspects susceptible to losses.

1. Introduction
Landslide is a phenomenon in which the mass of rocks, soil, or debris fall because of gravity [1]. Landslide is one of the disasters experienced regularly in Indonesia [2], and becomes one of the hydrometeorology disasters that has a rising trend in its occurrence in the last ten years. This is because of the global climate change characterized by a high level of rain that was worsened by damaged forests. These forests were converted into agricultural lands and the hills were converted into settlement areas [3].

Bumiaji Sub-District located in Batu City is one of the travel destinations in East Java and is characterized by its mountainous area with an average altitude of 1500 m above the sea level, dominated by more than 15% slope, and is prone to landslide [4]. The hill morphology with steep slopes becomes one of the factors that contribute to landslides. Human activities that caused a shift in the function of protected areas to cultured areas also result in a potentially high risk of landslides [5]. From 2016 to 2021, there were 31 landslides occurring in Bumiaji Sub-District that damaged houses, productive fields, roads, drainage, and electricity infrastructures [6]. Bumiaji Sub-District is vulnerable because it is a travel destination and the center of agriculture in Batu City. The tourism sector is the major support of the people’s economic activity. Landslide can cause large economic losses to the locals. There are a few travel destinations that was potentially impacted by the landslide, including natural tourism and man-
made tourism sites. Travel destinations that have a high potential of being affected by the landslide include Taman Rekreasi Selecta, Paralayang, Coban Talun, and Pemandian Alam Cangar [5] (Figure 1).

![Figure 1. Research location](image)

Sendai Framework 2015-2030 mandated disaster-risk studies as the priorities of disaster mitigation [7]. Reducing the risk of disaster is an effective approach to decreasing the damages caused by landslides [8]. This study aims to produce a landslide disaster-risk map in Bumiaji Sub-District. Disaster risk is defined as the potential loss of life, health, jobs, assets, and services possibly happening at a certain point of time that can happen in a community [9]. Disaster-risk assessment is regulated in Head of National Disaster Management Agency Regulation Number 2 of 2012 (Perka BNPB Number 2/2012).

2. Methods

This study employed a quantitative approach. The analysis technique used landslide risk criteria according to Perka BNPB Number 2/2012 and supported by other literature findings. This study was completed during the COVID-19 pandemic, therefore only collecting secondary data, such as Google satellite images, Google Street View, digital elevation models (DEM) from the Geospatial Information Agency, and other literature. The data was processed using ArcGIS software. This study didn’t employ the capacity variable in determining the landslide risk because of the social restrictions during the COVID-19 pandemic that prevents any primary survey in the field with local respondents. The landslide risk level can be seen in Equation 1 [10].

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\text{Risk Assessment} = \text{Hazard} \times \text{Vulnerability}
\]  

Hazard was assessed with 4 (four) parameters, such as soil type, precipitation, slope, and land cover [11]. Data from each variable was scored, weighted, and then overlayed to produced a hazard map. The score and weight from each indicator are explained in Table 1.

| Indicators (Weights) | Class | Scores |
|----------------------|-------|--------|
| Soil type (13%)      |       |        |
| Inceptisol, Mollisol | 5     |        |
| Yellowish-brown andosol, Glei Humus, Litosol | 4 | |
| Association of Grey & Greyish Brown Alluvial | 1 | |
| Slope (31%)          | >45%  | 5      |
Landslide vulnerability is a term used to explain the physical, economic, environment, and social condition that makes people vulnerable to landslides [13]. Table 2 explains about types of vulnerability and formation indicators. Each parameter was assessed and weighted, then overlayed to determine the total vulnerability level.

**Table 2. Vulnerability indicators**

| Vulnerability (Weights) | Parameters (Weights) | Classifications          |
|-------------------------|----------------------|--------------------------|
|                         |                      | Low         | Medium      | High         |
| Physical (25%)          | Road length rate (50%) | 0.01-0.06 km/km² | 0.07-0.12 km/km² | 0.13-0.17 km/km² |
|                         | Number of public utilities (50%) | 22-35 unit | 36-47 unit | 48-60 unit |
| Social (40%)            | Population density rate (60%) | 158-860 people/km² | 861-1,562 people/km² | 1,563-2,264 people/km² |
|                         | Ratio of women (10%) | 48.8-49.3% | 49.31-49.7% | 49.71-50.2% |
|                         | Disabled rate (15%) | 0.13-0.29% | 0.30-0.46% | 0.47-0.63% |
|                         | Population of vulnerable age group (15%) | 16.95-18.18% | 18.19-19.40% | 19.41-20.63% |
| Economy (25%)           | Productive land (50%) | 18-41% | 42-65% | 65-88% |
|                         | Poverty rate (50%) | 1.9-2.9% | 2.91-3.9% | 3.91-4.9% |
| Environment (10%)       | Forest area (50%) | 0-794.4 ha | 794.5-1,588.9 ha | 1,588.8-2,383.3 ha |
|                         | Thicket area (50%) | 5.42-239.02 ha | 239.0-472.6 ha | 472.6-706.2 ha |

Source: [2, 5, 14, 15, 16] adapted to study location

### 3. Results and Discussion

#### 3.1. Landslide Hazard Assessment

Landslide hazard was assessed based on the overlay of soil types, land cover, precipitation, and slope [11]. The results can be seen in Table 3 and Figure 2. The total area that has the high hazard level is 2,169 hectares (8%). High rainfall intensity disrupts the stability of the slope and increases the pressure on the soil pores [17]. These conditions were worsened due to the moor type of land cover because it doesn’t have strong roots to bind with the soils [18]. Bumiaji Sub-District has a total moorland area of 932 hectares, which means it has a high hazard level. The low and medium hazard levels each include
a total area of 16% and 66%, respectively. These areas are typically located in a relatively inclined slope (0-30%) with a protected forest as the land cover.

| Village    | Low (ha) | Medium (ha) | High (ha) | Total (ha) |
|------------|----------|-------------|-----------|------------|
| Bulukerto  | 233      | 651         | 57        | 940        |
| Bumiaji    | 270      | 732         | 143       | 1,146      |
| Giripurno  | 74       | 338         | 37        | 449        |
| Gunungsari | 33       | 253         | 350       | 635        |
| Pandanrejo | 39       | 320         | 31        | 390        |
| Punten     | 32       | 167         | 58        | 257        |
| Sumber Brantas | 445     | 2,138       | 430       | 3,012      |
| Sumbergondo | 172     | 1,141       | 130       | 1,443      |
| Tulungrejo | 718      | 2,344       | 932       | 3,995      |
| Total      | 2,016    | 8,084       | 2,169     | 12,268     |

3.2. Landslide Vulnerability Assessment
Landslide vulnerability was assessed by overlaying the physical, social, economic, and environmental aspects. The physical vulnerability was assessed using road length rate and the number of public facilities. Bumiaji Sub-District was dominated by low-level vulnerabilities, spread across 7 villages, which are Bulukerto, Bumiaji, Gunungsari, Pandanrejo, Sumberbrantas, Sumbergondo, and Tulungrejo village (Table 4). Sumbergondo Village has the lowest physical vulnerability because 871.56 ha (79%) of its land is used for a protected forest. The total built-up area is only 47.63 ha (3%), i.e., low physical vulnerability. The highest physical vulnerability is located in Giripurno Village, which has the highest settlement and infrastructure rate (102.17 ha/48.86%). Landslides had caused damage to the road infrastructure in Giripurno Village on February 14th, 2020, and hampered the locals' mobility [6]. This problem results in the loss in goods distribution and people. This is why Giripurno Village has a high physical vulnerability.

The social vulnerability was assessed using population density, women rate, disability rate, and the population of vulnerable age group, dominated with low categories in Bulukerto, Bumiaji, Sumberbrantas, Sumbergondo, and Tulungrejo villages (Table 4). These villages have a low population density (<860 population/km²). This is because those villages have a physical condition mostly
comprising steep slopes and their land use largely consists of protected forests with a total area of 6184.9 (59%) hectare. High social vulnerabilities are located in Giripurno and Punten village with high population density (>1563 population/km²). The land conditions are quite flat, thus allowing both villages to have a high ratio of settlements, especially in Giripurno Village. A high population shows more potential for locals to get affected by a disaster.

The economic vulnerability was assessed using productive land and poverty rate parameters. Disasters can lead to the loss of productive assets and jobs for the poverty-stricken population [19]. A population with poverty has limited access to economic diversification and limited savings [20], and usually couldn’t adapt to the disaster because of financial limitations. Economic vulnerability in Bumiaji Sub-District is dominated with the low category in 4 villages, which are Bulukerto, Sumbergondo, Punten, and Brantas villages (Table 4). Low economic vulnerability is visible in Bulukerto and Sumbergondo village caused by lands with low productivity (less than 40%), while Punten and Sumberbrantas village have a low poverty rate (less than 3%). High economic vulnerability is located in Giripurno village, which has productive land (449 ha/69%). The productive lands in Giripurno village are in the form of moorlands with horticultural and houseplants plant types. Agricultural lands are also used for agrotourism. The poverty rate in this village is also quite high (4.91%). The high rate of productive land and poverty are the cause of high economic vulnerability.

The environmental vulnerability was assessed using parameters of forest and thicket area. The environmental vulnerability in Bumiaji Sub-District is dominated by the low category in 6 villages, which are Bulukerto, Bumiaji, Giripurno, Gunungsari, Pandanrejo, and Punten village. The medium vulnerability level is found in Sumber Brantas and Sumbergondo villages. The high environmental vulnerability level is located in Tulungrejo village (Table 4). Tulungrejo village has a high thicket total area (more than 472 ha). Thickets have a weak root system, so they are more vulnerable to landslides [21].

From the overlay result of the physical, social, economic, and environmental vulnerability variables, it is found that Bumiaji Sub-District is dominated by the medium vulnerability level, which spreads across 5 villages such as Bumiaji, Gunungsari, Pandanrejo, and Tulungrejo village. The lowest vulnerability score is identified in Sumbergondo village because of its low physical, social, and economic vulnerability scores. The highest vulnerability level belongs to Giripurno village because of high physical, social, and economic vulnerability scores (Table 4 and Figure 3).

Table 4. Landslide vulnerability assessment

| Village       | Physical Class | Social Class | Economic Class | Environ Class | Final Score | Final Class |
|---------------|----------------|--------------|----------------|---------------|-------------|-------------|
| Bulukerto     | Low            | 1.30         | Low            | 1.5           | 1.00        | Low         |
| Bumiaji       | 1.5            | Low          | Low            | Med           | 1.58        | Med         |
| Giripurno     | 2.5            | High         | High           | Low           | 2.68        | High        |
| Gunungsari    | 1.5            | Low          | Low            | High          | 1.96        | Med         |
| Pandanrejo    | 1              | Low          | Med            | Low           | 1.65        | Med         |
| Punten        | 2              | Med          | High           | Low           | 1.92        | Med         |
| Sumber Brantas| 1              | Low          | Low            | 1.5           | 1.10        | Low         |
| Sumbergondo   | 1              | Low          | Low            | Med           | 1.18        | Low         |
| Tulungrejo    | 1.5            | Low          | Low            | 3             | 1.72        | Med         |
3.3. Landslide Risk Assessment
The hazard and vulnerability assessment scores are overlayed to determine the disaster-risk level. Areas with the low classification of landslide risk comprise 5871.48 ha (48%) of the total area of Bumiaji Sub-District, spread across 8 villages, which are Bulukerto, Bumiaji, Gunungsari, Pandanrejo, Punten, Sumberbrantas, Sumbergondo, and Tulungrejo village (Table 5). The land use in areas with low risk is dominated by protected forests, with a total area of 4529 ha (77%). Protected forests have low hazard value, so the risk level is also low.

Areas with a medium risk level span 1890.63 ha (15%) of Bumiaji District’s total area spread across the villages. The land use in medium-risk areas is dominated by moorlands with a total area of 1805.6 ha (40%) and forest with a total area of 1649 ha (37%). The existence of moor caused high hazard and vulnerability value, but protected forests decrease the disaster-risk score in the medium category.

Areas with high vulnerability risk levels are spread across 6 villages, such as Bumiaji, Giripurno, Gunungsari, Punten, Pandanrejo, and Tulungrejo village accounting for 30% (1890.6 ha) of the total area of Bumiaji Sub-District (Table 5 and Figure 6). The land use in villages with high risk is dominated with moor, amounting to 1365.6 ha (72%), which leads to high hazard and vulnerability value. Giripurno village has the highest risk rate as much as 375.17 ha (84%), caused by the high hazard and vulnerability value.

| Village       | Low (ha) | Medium (ha) | High (ha) | Total (ha) |
|---------------|----------|-------------|-----------|------------|
| Bulukerto     | 883.45   | 56.82       | 0.00      | 940.26     |
| Bumiaji       | 270.38   | 732.15      | 143.33    | 1,145.87   |
| Giripurno     | 0.00     | 73.57       | 375.17    | 448.74     |
| Gunungsari    | 32.70    | 252.54      | 350.12    | 635.36     |
| Pandanrejo    | 39.19    | 319.97      | 31.23     | 390.39     |
| Punten        | 31.52    | 167.30      | 58.29     | 257.12     |
| Sumber Brantas| 2,582.37 | 429.96      | 0.00      | 3,012.32   |
| Sumbergondo   | 1,313.50 | 129.72      | 0.00      | 1,443.22   |
| Tulungrejo    | 718.38   | 2,343.66    | 932.48    | 3,994.53   |
| Total         | 5,871.48 | 4,505.69    | 1,890.63  | 12,267.81  |
4. Conclusions and Suggestions
The conclusions and suggestions of this study are:
- The total area of Bumiaji Sub-District with low hazard level, medium hazard level, and high hazard level is 2016 ha (16%), 8084 ha (66%), 2169 ha (8%), respectively.
- The vulnerability level in Bumiaji Sub-District is dominated by the medium vulnerability, spreading across 5 villages, such as Bumiaji, Gunungsari, Pandanrejo, and Tulungrejo village. A high vulnerability level is located in Giripurno village.
- Information of hazard and vulnerability is overlaid to obtain landslide risk. Landslide risk is dominated with low category with a total area of 5871.48 ha (48%), medium risk with a total area of 1890.63 ha (15%), and high risk with a total area of 1890.6 ha (30%). High risk is caused by a high level of hazard and vulnerability, especially in Giripurno village.
- Suggestion and recommendation: Limitations on the field survey caused by the COVID-19 pandemic force the study on landslide risk to only be based on hazard and vulnerability variables. The capacity variable may be used to determine a risk map based on Perka BNPB 2/2012. The government is advised to arrange the spatial pattern based on risk assessment to reduce disasters caused by landslides. During the time of research, the issued RTRW has not accommodated the regulation of spatial use based on disaster-risk studies. Hopefully, there will be more planning documents integrated with disaster-risk study, so the spatial use will be on the same level as landslide countermeasures.

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