Analysis of Landslide Disaster at the Quaternary Volcanic Landform

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Abstract. Indonesia as a country that has two seasons, namely the rainy and dry seasons, making it vulnerable to natural disasters such as hydrometeorological disasters where disasters occur due to conditions and weather such as landslides. This study aims to analyze the vulnerability of landslides and its relationship with the quaternary volcanic landform in Gandusari District, Blitar Regency. The method used is quantitative with a scoring that refers to the estimation model of Puslittanak, 2004 with parameters that consist of rainfall, geology, slope, land cover, and soil type. After getting the results of the landslide hazard map, validation was carried out with interviews and then the map results will also be analyzed with the condition of population density in Gandusari District, Blitar Regency. The results showed that landslide hazard classes are divided into three classes, namely high, medium, and low. Population densities in several locations are found in areas of high soil susceptibility so that efforts are needed to reduce population density, especially in mountainous slope areas.

1. Introduction
Landslides are one of the natural disasters that often occur in Indonesia, landslide disasters are one block or mass that slides into another mass because of the weak adhesive force between layers of soil to withstand changes in mass in the soil structure [1]. Several factors that can affect the level of landslide susceptibility are mentioned in research [2] in West Bandung, West Java such as rainfall with moderate to high intensity, land use dominated by settlements, volcanic and sedimentary rock types, and soil types such as pedsolic and andosol, which are generally found in mountainous areas with steep slopes. These factors also have similarities with research [3] in Sumedang Regency, West Java that several factors that influence landslide susceptibility include high rainfall in the range of 4,201-5,196 mm/year, volcanic rock types, alluvial soils, and the slope of the majority 15 - 30% i.e. undulating to hilly areas. There are different characteristics of the types of landslides, such as translational landslides with the characteristics of rock and soil mass movements on the slip plane in the form of sloping or flat waves, while in rotational landslides the movement of soil and rock material downwards from high to low places is concave [4].

This landslide disaster brought several adverse impacts such as loss of life, property, and damage to infrastructure so that the threat to landslides needs to be minimized by mitigation and community preparedness accompanied by local government support [5]. Residential areas should not be in areas with steep slopes because to reduce the risk of landslides in this area it is used for planting perennials with strong root systems to withstand slopes and reduce soil loads, [6]. Research [7] suggests that preventive actions related to landslides can be carried out by taking into account the regional use plan, the suitability of the RTRW of Cisarua District is shown in areas with steep slopes, the spatial pattern is dominated by vegetation, while in areas with flat to gentle slopes for residential areas. In research [8] landslide-prone areas in Plasansari Village also found settlements using paving and cement in the yard, this is not good and can be reduced by a vegetative approach through planting taproot plants that have various benefits such as avocado, cloves, lamtoro, waru, breadfruit, durian, cempedak, and jackfruit. Safe development planning is needed including structuring landslide-prone areas such as doing reforestation, choosing relocation routes and areas that are safe from landslide risk, paying attention to water and drainage management in lower places such as under hills [9].

In research [10] related to the analysis of landslide susceptibility based on spatial planning in Karanganyar Regency using GIS with a tiered scoring technique, the results of the landslide risk class
zoning results from research with the RTRW of Karanganyar Regency are quite appropriate. GIS with overlay technique shows that some settlements are still in landslide-prone areas which is not in accordance with the RTRW of Kulonprogo Regency in 2012-2023 so it is important to pay attention to development in accordance with the existing RTRW in supporting the sustainability area. Research [12] related to the building layout planning system in the landslide area layout, the safe category is allowed for buildings, the low category is allowed for buildings while maintaining a protected/open area of 30%, and the medium area is allowed for buildings while maintaining the protected area. /open 30% and tighten building management permits. Another study by [13] related to landslide susceptibility in Magelang Regency was carried out with GIS which compared the Indonesian National Standard method with the Analythical Hierarchy Process, which resulted in differences in the level of accuracy from the validation of rainfall parameter maps using the Thiessen polygon method with slope parameters.

This landslide susceptibility mapping has also been carried out using the fuzzy logic method using the parameters of slope, height, rainfall, soil type and land cover which divides the level of vulnerability into 4 classes, namely not vulnerable, low prone, moderate prone, and high prone [14].

While in the study [15] of landslide susceptibility using the DInSAR (Differential Interferometry Synthetic Aperture Radar) method, the results of soil subsidence in Agam Regency were marked by ground movement of 0 to -0.737017 cm/year. Many studies related to landslide hazard analysis have been carried out. However, studies of landslide susceptibility in relation to population density are still rarely carried out, especially in the Gandusari District, Blitar Regency so that this study aims to analyze landslide susceptibility and its relation to population density in Gandusari District, Blitar Regency.

2. Methods

2.1 Types of research

This research is included in the quantitative type which was carried out with a scoring system for each parameter referring to the Puslittanak estimation model (Center for Soil Research and Development and Agroclimate), 2004. Data processing was carried out using a Geographic Information System (GIS) application to process data, namely bulk maps, rainfall maps, geological maps, slope maps, land cover maps, and soil type maps. These data are then input into the ArcGIS 10.8 application to create a landslide hazard map. In processing the data will be classified based on the score then given a weighted score and analysis will be carried out, the parameters used refer to the 2004 Puslittanak estimation model, with the parameters of rainfall, geology, slope, land cover, and soil type. After getting the results in the form of a landslide hazard map, Gandusari District, Blitar Regency, the next step is to validate the map results and then analyze the population density conditions. This validation was carried out by conducting interviews with the community and village officials in several villages in the Gandusari District by considering the landslide hazard class obtained. The calculation of the disaster hazard map is carried out using an estimation model that refers to the research of the Research Center for Research and Development in 2004 with the Eq. 1

\[
\text{Puslittanak, 2004 : Total Score = 0.3FCH+0.2FBD+0.2FKL+0.2FPL+0.1FJT} \]

\[
\text{Description : FCH = Rainfall Factor} \\
\text{FBD = Rock Type Factor} \\
\text{FKL = Slope Factor} \\
\text{FPL = Land Cover Factor} \\
\text{FJT = Soil Type Factor} \\
0.3;0.2;0.1 = Weighted Value}
\]
### Table 1. Rainfall Classification (mm/Year)

| Parameter      | Weight | Score |
|----------------|--------|-------|
| Really wet     | 5      |       |
| Wet            | 4      |       |
| Moderate       | 30%    | 3     |
| Dry            |        | 2     |
| Very dry       |        | 1     |

Source: Puslittanak, 2004

### Table 2. Classification of Rock Types

| Parameter            | Weight | Score |
|----------------------|--------|-------|
| Volcanic rock        | 3      |       |
| Sedimentary rock     | 20%    | 2     |
| Alluvium             |        | 1     |

Source: Puslittanak, 2004

### Table 3. Classification of Slope

| Parameter (%) | Weight | Score |
|---------------|--------|-------|
| >45           | 5      |       |
| 30-45         | 4      |       |
| 15-30         | 20%    | 3     |
| 8-15          |        | 2     |
| <8            |        | 1     |

Source: Puslittanak, 2004

### Table 4. Land Cover Classification

| Parameter                              | Weight | Score |
|----------------------------------------|--------|-------|
| moor, rice field                       | 5      |       |
| Shrubs                                 | 4      |       |
| Forest and plantation                  | 20%    | 3     |
| City/residential                       |        | 2     |
| Ponds, reservoirs, waters              |        | 1     |

Source: Puslittanak, 2004
Table 5. Classification of Soil Types

| Parameter                      | Weight | Score |
|--------------------------------|--------|-------|
| Regosol                        | 5      |       |
| Andosol, podsolik              | 4      |       |
| Brown Latosol                  | 3%     | 3     |
| Brown latosol association      | 2%     | 2     |
| Aluvial                        | 1      |       |

Source: Puslittanak, 2004

At the end of the classification analysis of landslide hazard maps will be divided into 3 classes, namely low, medium, and high. In the final score, if the total score is high, the level of vulnerability is higher, with the determination of the score interval as follows (Eq. 2):

**Highest score – Lowest score**

Number of classification classes

(2)

2.2 Research Location and Time

This research was conducted in the Gandusari Sub-district which has 14 villages, the western part is bordered by Talun and Garum Districts, the northern part is Kediri District and Malang District, the southern part is Talun and Wlingi District, and the eastern part is bordered by Wlingi District and Malang District. Gandusari Subdistrict, Blitar Regency is included in the northern region,
namely the Central Depression zone of Java, Solo, and Randublatung. Gandusari Sub-district, Blitar Regency is included in the solo zone in which there is the Blitar subzone which is part of a depression line connected to the southern mountains in the southern part of the area covered by alluvial deposits. The solo zone includes quarterly deposits, there are quarterly volcanoes, one of which is Mount Kelud. This mountain is located between Blitar Regency and Malang Regency, East Java. Mount Kelud has a height of about 1,731 meters above sea level with a stratovolcano type, namely type A. The geological conditions of the Gandusari District are old Kelud volcanic rocks, Kawi-butak volcanic rocks, Marikeng volcanic rocks, land deposits, young Kelud volcanic rocks, Kelud debris, and parasitic young volcanic rocks. The research was conducted during October-November 2021.

2.3 Research Sample

Interview samples were taken by random sampling of 8 samples spread over several villages in Gandusari District, Blitar Regency. This sampling was carried out by one sample in each village in Gandusari District by prioritizing areas with a high level of vulnerability to landslides, such as in Gondang Village, Ngaringan Village, Tulungrejo Village and Krisik Village.

3. Results and Discussion

Landslide susceptibility mapping which refers to the estimation model of Puslittanak, 2004 with parameters of rainfall, geology, slope, land cover, and soil type. The making of a rainfall map (figure 2) was carried out using BMKG rainfall data by taking 3 points, namely the Malang Climatology Station, Malang Geophysics Station, and Nganjuk Geophysics Station.

![Rainfall Map of Gandusari District](rainfall_map.jpg)

The results of the rainfall data were analyzed using the IDW Interpolation method and obtained 5 classes, namely very high, high, medium, low, and very low. Very high intensity rainfall is in the Krisik Village area, while the very low intensity rainfall is in the Sumberagung, Kotes, and Gondang villages. The higher the intensity of rainfall also encourages a high level of vulnerability to landslides [16]. For the geological map of Gandusari District (figure 3), it was made by referring to the Kediri geological map of Indonesia.
Figure 3. Geological Map of Gandusari District

Geological conditions in Gandusari District are dominated by young Kelud volcanic rocks in some parts of the west to the north which are the slopes of Kelud Mountain. While the eastern area is dominated by Kawi-butak volcanic rocks on the slopes of Mount Kawi, which is around Krisik Village. Furthermore, the slope map (figure 4) is made referring to the DEM data of Gandusari District.

Figure 4. Slope Map of Gandusari District

The slope at the study site is divided into 5 classes, namely flat, sloping, slightly steep, steep, and very steep. Very steep slope areas are located in Krisik village and steep slopes in several
villages, namely Ngaringan Soso, Tulungrejo, Semen, and Gadungan villages. As for the flat areas in the areas of Sumberagung Village, Kotes, Gondang, Sukosewu, Tambakan Gandusari, and Butun. The land cover map (figure 5) was made referring to the Landsat 8 satellite image of Gandusari District obtained from the USGS (United States Geological Survey).

Figure 5. Map of Land Cover in Gandusari District

Land cover in high topographic areas is secondary dry land forest and plantation and shrub forest. Mixed dry land agriculture almost dominates from flat areas to high areas, while dry land agriculture is only slightly located in the Sukosewu Village area. Plantations are found in the villages of Gadungan, Ngaringan, and Soso with coffee, banana and tea commodities. For settlements, it is often found in flat areas with an elongated pattern following the highway. Furthermore, the soil type map (figure 6) is made with reference to the soil classification by FAO (Food and Agriculture Organization).

Figure 6. Map of Soil Types in Gandusari District

The distribution of soil types in the Gandusari District mapped is divided into 2 types, namely gleysols with the Eutric gleysols classification, and Andosols with the Mollic andosols, Ochric andosols, and Vitric andosols classifications. Gleysols soil is one type of soil that is usually located in low topographic areas or basins that are always waterlogged which has characteristics of gray to
yellowish color, medium soil solum, and loam to clay texture. This Andosol soil is formed due to volcanic activity from a volcano which has black characteristics, high organic content, has a thick soil solum.

Based on several parameters described above, the scoring system is carried out by assigning a weight to each parameter according to the conditions in the study area. After scoring each parameter, a total weighting is carried out with a map overlay for each parameter so that a landslide hazard map is obtained, Gandusari District, Blitar Regency (figure 7) with low, medium, and high vulnerability classes.

Based on the landslide hazard class, the high vulnerability class is in Soso Village, Ngaringan, northern Gadungan, and the areas of Tulungrejo and Krisik villages. The moderate vulnerability class was found in the areas of Gandusari Village, Butun, Slumbung, Semen, and Soso Village, Gadungan Ngaringan in the south. The areas with low vulnerability are Gondang, Kotes, Sumberagung, and Sukosewu villages. The results of the disaster hazard map obtained were then validated by interviewing residents and village officials in Gandusari District. The interview instrument was made with 5 questions to make it easier for researchers to find information to make it more structured. The following is an outline of the results of the interview which became the points for validating the landslide susceptibility map that had been made.
Table 6. Interview Results

| No. | Respondent   | Address                                | Results                                                                                                                                 |
|-----|--------------|----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| 1.  | Mrs. Lilis Anjarwati | RT 05 RW 01 Sukosewu Gandusari Village Blitar | Sukosewu Village rarely and almost never occurs landslides, landslides often occur in the Tulungrejo and Semen Village areas.                |
| 2.  | Mr. Dedi Arifin     | RT 01 RW 01 Gondang Gandusari Village Blitar | Gondang Village, although it has a fairly high population density, landslides almost never occur due to the flat topography, for landslides often occur in the northern part of Gandusari. |
| 3.  | Ms. Sandy          | Kotes Gandusari Village, Blitar        | Kotes Village has never experienced a landslide, which often occurs in the Sumberagung village area due to ongoing sand mining activities. |
| 4.  | Mrs. Venti         | Gandusari Village, Blitar              | The area of Gandusari Village rarely occurs landslides, maybe only occasionally during the rainy season in the Kruwuk area.                |
| 5.  | Ms. Nindi          | Butun Gandusari Village, Blitar        | Butun Village has never happened before for landslides that often occur in the Krisik Village area.                                   |
| 6.  | Mrs. Ni’mah        | RT 01 RW 01 Gadungan Gandusari Village Blitar | Gadungan Village is prone to landslides but only at certain points such as in Hamlet Njari.                                      |
| 7.  | Mrs. Atik          | Krisik Gandusari Village, Blitar       | Including prone to landslides because there are many residential areas on slopes and landslides occur every year.                    |
| 8.  | Mrs. Susi          | Ngaringan Village, Blitar              | Ngaringan village is prone to landslides in the northern part of the Kelud slope area.                                                 |

The results of the map and validation obtained high landslide susceptibility results in areas with high topography as mentioned in the northern part of Gandusari District such as Krisik, Ngaringan, Tulungrejo, Gadungan villages which are on slopes, this area has Andosol soil types as a result of mountain activity. existing fire. High rainfall every year also pushes Gadusari District to frequent landslides. The results of the interview validation also concluded that areas with flat topography have a low level of vulnerability that has never even occurred, in areas with flat topography the intensity of rainfall is low, the soil type itself is still classified as Andosol soil, but for many residential and agricultural land uses. dry land. Although some of these villages have a fairly high population density, several other factors have low values so that they are in the low landslide hazard class. The construction of settlements, schools, village offices, factories and so on is generally built on land with a flat slope [17].

Reviewing the population density in Gandusari District, this data is also compared with data on population density conditions in each village in Gandusari District obtained through the results of BPS publications [18] where the highest population density is in Tambakan Village with 2,012 inhabitants/km² then followed by Sukosewu Village is 1,418 people/km² and Butun Village is 1,329 people/km². Meanwhile, the population density with the lowest value is in Tulungrejo Village, which is 465 inhabitants/km². This area with a low level of vulnerability to landslides has a high population density, but this does not have a significant effect on making this area a potential landslide disaster. In areas with a high level of vulnerability to landslides, there are also those with a fairly high population
density, namely Soso Village, Ngaringan, Krisik, Gadungan which have a low population density of 588 – 680 inhabitants/km2. However, Krisik Village has a fairly high density with 1,297 inhabitants/km2, although the low and high population density in this area with high landslide susceptibility has an influence to encourage landslides, this is due to regional physical factors and climatic conditions. has the potential that if many existing settlements are built on slopes and remove some of the existing vegetation, it will cause increased disaster vulnerability due to inappropriate land use. Therefore, in anticipating this, it is necessary to pay attention to the construction of settlements in areas prone to landslides.

Based on the results of interviews from several respondents, it is also related to the impact of landslides that have occurred in Gandusari District, namely damaged and buried agricultural land, damage to houses, animal cages, and road access. Responding to disaster events that occurred, the response from the local village government was to provide assistance to affected victims in the form of basic necessities and house repairs, village officials also went directly to the field and reported related incidents to the parties concerned such as BPBD and there were also several collaborations with natural communities such as jangkar kelud. Research [19] also stated that the agroforest community was sustainable in mitigating landslides in Samudera Kulon Village by making a strong village team and making ronjong for retaining the soil. Handling or mitigation efforts that have been carried out in several villages that are prone to landslides such as planting perennials, not building settlements on steep slopes and providing distance from house construction to cliffs, conducting socialization to community members regarding potential disasters that occur.

4. Conclusion
Making a landslide hazard map refers to the Puslittanak, 2004 estimation model, with parameters of rainfall, geology, slope, land cover, and soil type. The landslide hazard map produced is divided into three classes, namely low, medium, and high. Furthermore, the landslide hazard map will be validated and analyzed with population density conditions in Gandusari District. The high population density in several villages such as Tambakan, Sukosewu, and Butun villages have a low level of vulnerability to landslides, while some villages with high vulnerability levels such as Soso, Ngaringan, Krisik, Gadungan villages have low population densities except in Krisik village. Although low population density in areas with high landslide susceptibility levels can be an influence to encourage landslide disasters due to regional physical factors and climatic conditions that have the potential so that if many existing settlements are built on slopes and remove some of the existing vegetation, it will cause disaster vulnerability, increased due to inappropriate land use. Therefore, in anticipating this, it is necessary to pay attention again to reduce residential development in slope areas.

Acknowledgement
This article’s publication is supported by the Institute of Research and Community Service (LP2M), University of Jember.

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