



Analysis of Landslide Prone Areas in Tampahan, Toba Samosir Regency, North Sumatra Province

Winda Lestari Turnip¹, Stevanus Nalendra Jati¹

¹Department of Geological Engineering, University of Sriwijaya (UNSRI)

e-mail: windalestariturnip25@gmail.com

DOI: 10.31284/j.jemt.2020.v1i1.1149

Article info

Received:

8 June 2020

Revised:

13 August 2020

Accepted:

15 August 2020

Published:

3 September 2020

Keywords: slope weighting, scoring, landslide

Abstract

The topography of the Tampahan area which tends to be steep and dominated by tuff lithology can result in a landslide. The intensity of landslides and the resulting losses can be reduced by the analysis of landslide-prone areas in Tampahan. The administration of the area is located in Toba Samosir Regency, North Sumatra Province which is included in the Toba Caldera Region. Analysis of landslide-prone areas is carried out with five parameters namely slope, land use, morphological elevation, lithology, and rainfall. The data processed in this analysis comes from field data, DEMNas (National Digital Elevation Model), and other spatial data. Classification of each parameter and weighting based on literature is away in the analysis of landslide-prone areas of Tampahan. Then do each parameter overlay to get the value of landslide-prone and distinguished based on the calculation of the landslide class interval. The results are divided into five classes that are prone to landslides, namely classes not prone (1-1,8), rather prone (1,8-2,6), quite prone (2,6-3,4), prone (3,4-4,2), and very prone (4,2-5). Based on the analysis that has been done, some areas are very prone to landslides in the southeast while areas that are not prone to landslides are in the southwest of the study area. Therefore, landslide-prone studies are categorized as high landslides with almost 60% coverage of the study area.

1. Introduction

The sloping topography formed on the island of Sumatra is the result of activities that occur on the surface and below the surface of the earth. This is what can cause landslides in an area. Landslides can be triggered by a downward movement of soil mass in steep-sloped areas [9]. Tampahan area is one area that can experience landslides. The location of the Tampahan area in Toba Samosir Regency (Figure 1) is in the Toba Caldera zone which has a fairly steep slope. Therefore, this area is an object that needs to be reviewed regarding landslide-prone.

The formation of the Toba Caldera is influenced by the tectonic activity of the island of Sumatra. The subduction between the Indo-Australian Plate and the Eurasian Plate in the Late Cretaceous formed the Barisan Hills on Sumatra Island [1]. Subduction that continued on 74,000 years ago caused a massive eruption on Mount Toba [4]. Evidence resulting from this devastating eruption in the form of Toba Caldera is quite large. The Tampahan area is dominated by lithology tuff originating from the eruption of Mount Toba. The lithology formed during the quarter period has non-resistant characteristics so that it can trigger landslides in Tampahan.

Landslides can be analyzed with several parameters. The parameters that influence the analysis of landslides are slope, land use, rainfall, morphological elevation, and lithology [2]. These parameters were analyzed by the Analytical Hierarchy Process (AHP) method [8]. This method explains the data analysis by weighting each parameter to get the intensity value of the cause of the landslide. So this method can be used to determine the class of landslide-prone in the area of Tampahan, Toba Samosir Regency, North Sumatra Province.

2. Methodology

The method used in the analysis of landslide-prone is geological mapping and collecting supporting data from several sources. The geological formation in the Tampahan area of Toba Samosir Regency is the result of geological mapping. The data entered in the form of outcrop data, lithology, and landscape image capture. Supporting data in the form of National Digital Elevation Model data and spatial data are used for analysis using ArcGIS software. Then the data is analyzed by the Analytical Hierarchy Process (AHP) method [5]. So the results of this analysis will get the value of landslide-prone classes in Tampahan, Toba Samosir Regency, North Sumatra Province.

AHP method is a weighting method that compares the parameters of each paired comparison matrix to the value of the specified criteria [8]. The parameters used are lithology, rainfall, slope, land use, and morphological elevation [2]. The following parameters are used for landslide hazard analysis in Tampahan, Toba Samosir Regency:

1. Lithology, where different cohesiveness is interpreted for physical analysis in the form of lithology in the field which is reflected in the geological map.
2. Rainfall, water content, and humidity of an area greatly affect the potential for landslides. Rainfall data used in the form of an annual average and interpolated with Inverse Distance Weighting (IDW) in the ArcGIS application.
3. Slope, this map is made using the National Digital Elevation Model data inputted in ArcGIS software. Mapmaking using the arctoolbox menu, spatial analyst tools, surface, and slope which is then divided into five classes.
4. Land use, class selection to settlements, and rice fields rank highest as a result of human activities with a higher probability of landslides such as felling trees or so on [6]. Then interpreted using the ArcGIS application to get the land-use class.
5. Morphological elevation, use of National Model Digital Elevation data by inputting into the ArcGIS application. Then divided into 5 morphological elevation classes in the study area.

Table 1. Weight of landslide hazard parameters [7].

| No | Parameter Type | Value (%) |
|----|-------------------------|-----------|
| 1 | Lithology | 27 |
| 2 | Rainfall | 13 |
| 3 | Slope | 33 |
| 4 | Land use | 20 |
| 5 | Elevation of morphology | 7 |

3. Results

Landslides are identified through weighting aimed at determining the most prone areas. This can interpret the importance of each parameter in the analysis of landslide-prone areas. The interpretation of landslide hazard analysis is described in table 1.

Table 2. Weighting by type of lithology in Tampahan

| No | Lithology Type | Value (%) | Weight | Score |
|----|------------------------|-----------|--------|-------|
| 1 | Haranggaol Andesite | 1 | 27% | 0,27 |
| 2 | Tapanuli Slate | 2 | 27% | 0,54 |
| 3 | Sibaganding Limestone | 3 | 27% | 0,81 |
| 4 | Peutu Sandstone | 4 | 27% | 1,08 |
| 5 | Samosir Tuff Sandstone | 5 | 27% | 1,35 |
| 6 | Toba Tuff | 5 | 27% | 1,35 |
| 7 | Alluvial deposits | 5 | 27% | 1,35 |

Analysis of each parameter of landslide-prone disaster is used to get a score by giving a weighting. The score was obtained from the result of the multiplication between the weight of the parameters with the value of each type of parameter. Then the classification of landslide-prone levels is obtained from previous calculations. Therefore, it can be described in the form of a landslide-prone map.

3.1. Lithology

The geological mapping that has been carried out in Tampahan, Toba Samosir District, shows seven different types of lithology seen in Table 2. This is indicated through the characteristics and level of resistance of rocks found in the study area. The seven lithologies were analyzed to identify landslide hazards in the study area.

When viewed from the geological map of the Tampahan area, the results of the geological mapping reflected that lithology in the form of tuff predominates in the study area (Figure 2). This can show the inconsistency of the lithology. However, there are also other types of lithology in the form of alluvial deposits which indicate deposition is still ongoing today. Thus, it can indicate landslides in the study area as a result of rock cohesion which is quite low.

3.2. Rainfall

The level of importance in the interpretation of rainfall is the same as lithology. This can be seen from the high level of rainfall which can increase the saturation point or rock saturation which can affect landslides. The magnitude of the average annual rainfall in the study area becomes the focus of the distribution of values and weighting. Moreover, there is a large average rainfall that can cause a higher probability of a landslide disaster. Therefore, the highest amount of rainfall is given the highest value to get an effect on landslides that can occur in Tampahan (Table 3).

Table 3. The weighting of rainfall per year in Tampahan, Toba Samosir Regency.

| No | Average rainfall/year | Value | Weight | Score |
|----|-----------------------|-------|--------|-------|
| 1 | 194,11 mm/year | 1 | 13% | 0,13 |
| 2 | 195,89 mm/year | 2 | 13% | 0,26 |
| 3 | 197,67 mm/year | 3 | 13% | 0,39 |
| 4 | 199,45 mm/year | 4 | 13% | 0,52 |
| 5 | 201,23 mm/year | 5 | 13% | 0,65 |

The distribution of rainfall in the study area is reflected in the 2019 annual rainfall map (Figure 3). The map shows that the highest rainfall occurred in the northeastern part of the study area while the lowest rainfall occurred in the southwest of the study area. So that shows the highest risk of landslides occurs in the northeast of the study area.

3.3. Slope

The slope parameters are the most influential towards landslides in Tampahan. When field observations show some areas have steep slopes. This is what can indicate a landslide in the Tampahan area. So the greater the value of the slope the greater the potential for landslides. Weighting is carried out based on the slope classification with modifications to adjust to the AHP method [10] (Table 4).

Table 4. Slope weighting with modification [10].

| No | Slope | Value | Weight | Score |
|----|---------------------------|-------|--------|-------|
| 1 | Flat (0-2%) | 1 | 33% | 0,33 |
| 2 | Gently Sloping (3-7%) | 2 | 33% | 0,66 |
| 3 | Sloping (8-13%) | 3 | 33% | 0,99 |
| 4 | Moderately Steep (14-20%) | 4 | 33% | 1,32 |
| 5 | Steep (21-140%) | 5 | 33% | 1,65 |

Slope distribution is reflected in the slope map of the Tampahan area (Figure 4). It can be seen that the Tampahan area has a steep slope level with a percentage of slope values ranging from 21% -140%. When reviewed in the middle of the study area occupying the slope of a steep slope. So areas that have high slope rates can cause landslides.

3.4. Elevation of Morphology

Morphological elevation analysis aims to identify the effect of elevation on the humidity in the Tampahan area. The higher the elevation of an area the higher the humidity level. This influence can

cause the process of denudation through water media making it possible for landslides to occur from high to low. The elevation classification value becomes 0-1000 as the lowest elevation classification while the highest elevation classification is 1300-1400 meters above sea level as summarized in table 5.

Table 5. Morphological elevation of Tampahan area.

| No | Elevation of morphology (mdpl) | Value | Weight | Score |
|----|--------------------------------|-------|--------|-------|
| 1 | 0-1000 | 1 | 7% | 0,07 |
| 2 | 1000-1100 | 2 | 7% | 0,14 |
| 3 | 1100-1200 | 3 | 7% | 0,21 |
| 4 | 1200-1300 | 4 | 7% | 0,28 |
| 5 | 1300-1400 | 5 | 7% | 0,35 |

The highest distribution is in the southern part of the study area and the lowest elevation in the northern part of the study area.

3.5. Land Use

The variable in the analysis of landslide-prone is land use. Usually, land use is managed by humans for a purpose. Land use can be in the form of plantations, fields, or settlements. This can cause landslides because the presence of plants or forests decreases. The land use classification has been modified according to the study area [2] (Table 6).

Table 6. The weighting of land use in Tampahan area.

| No | Land Use | Value | Weight | Score |
|----|--------------------|-------|--------|-------|
| 1 | Jungles and shrubs | 1 | 20% | 0,20 |
| 2 | Garden | 2 | 20% | 0,40 |
| 3 | Field | 3 | 20% | 0,60 |
| 4 | Rice fields | 4 | 20% | 0,80 |
| 5 | Settlement | 5 | 20% | 1 |

Land cover in the study area is dominated by fields and settlements. This has greatly affected the landslide occurrence in the study area (Figure 6).

3.6. Analysis of Landslide Prone

All parameters in the landslide analysis are overlaid in ArcGIS software so that the highest and lowest scores are 5 and 1. The results are calculated to get the class classification of the area of the research area as follows:

Class interval = (highest value-lowest value) / class range

Highest score = 5, Lowest score = 1, Class range = 5

Then, the class interval = $(5-1) / 5 = 0.8$.

The results of these calculations are in the form of a class of landslides with a range of 0.8 as shown in table 7.

Table 7. Landslide Prone classes in Tampahan, Toba Samosir Regency.

| No | Landslide hazard class | Value |
|----|------------------------|---------|
| 1 | Not Prone | 1-1,8 |
| 2 | Rather Prone | 1,9-2,6 |
| 3 | Quite Prone | 2,7-3,4 |
| 4 | Prone | 3,5-4,2 |
| 5 | Very Prone | 4,3-5 |

The overlay results of all parameters in the form of landslide-prone maps with a scale of 1: 50,000 are reflected in figure 7. Landslide-prone areas in the study area are in the southeast as a very landslide-prone area while areas that are not prone to landslides are in the northwest-north part of the research area.

The study area is classified as an area prone to landslides in terms of the results of field observations (Figure 8). This is evidenced by the existence of field photos in several villages namely Meat Village, Aek Bolon Jae Village, Pohan Julu Village, and Pohan Julu Siboruan Village. Meat Village in Tampahan Subdistrict has a sloping morphological formation surrounded by caldera hills and this village did not find any landslides during field observations (Figure 8.1). In the Landslide Hazard Map that was made previously, Meat Village is included in the category of landslide-prone, this could be due to large erosion of the caldera hills around the village. Unlike the case with Meat Village, the three other villages have evidence of landslides and even found the results of the landslides. Land use in Aek Bolon Jae Village (Balige Subdistrict) is dominated by fields and lacks compact lithology.

Based on the landslide hazard map, the village is classified as a landslide-prone, which can be identified from field observations (Figure 8.2). The next level of landslide-prone is landslide-prone that occurred in Pohan Julu Village which has a fairly steep slope and can be indicated from observations in the village (Figure 8.3). The village that has a very prone level of landslides is in the village of Pohan Julu Siboruan (Figure 8.4) with an avalanche in the form of debris flow. This is due to the steep slope of the tuff lithology that is not resistant. The villages of Pohan Julu and Pohan Julu Siboruan are in Siborong-borong Subdistrict.

4. Conclusions

Based on the discussion on the analysis of landslides in the Tampahan area, it was concluded that there was a steep morphological relief in the Toba Caldera as a result of the eruption of 74,000 years ago with seven formations and dominated by lithology in the form of tuffs. Tampahan and its surroundings become one of the areas of Sumatra with the potential for landslides based on AHP (Analytical Hierarchy Process) analysis with five parameters. The parameter data collection is done by geological mapping and the use of spatial data. The five parameters are slope, lithology, rainfall, land use, and morphological elevation. Overlay conducted from the five parameters resulted in five classes of landslide-prone namely not prone (1-1,8), rather prone (1,8-2,6), quite prone (2,6-3,4), prone (3,4-4,2), and very prone (4,2-5). Very prone areas are in the southeast of the study area while areas that are not prone to landslides are in the southwest-north of the study area. When viewed administratively, areas that are not landslides are in the Tampahan sub-district while areas that are very prone to landslides are in Siborong-borong sub-districts. Thus, this study can be classified in landslide-prone areas with almost 60% coverage of the study area.

5. Acknowledgments

The authors sincerely thank to the Subdistrict head of Tampahan and Regency head of Toba Samosir as those who permitted to research landslide-prone.

References

- [1] Barber, A.J, Crow, M.J, Milsom, J.S. 2005. Sumatra, Geology: Resources and Tectonic Evolution, Geological Society Memoir No.31. The Geological Society, London.
- [2] Basofi, et al. 2017. *Landslide Susceptibility Mapping using Ensemble Fuzzy Clustering: A Case study in Ponorogo, East Java, Indonesia*. 2nd International Conferences on Information Technology, Information Systems and Electrical Engineering (ICITISEE), p.412-416.
- [3] Chesner, C.A. 2012. *The Toba Caldera Complex*. United State :Eastern Illinois University
- [4] De Silva, S.L., A.E. Mucek, et al. 2015. Resurgent Toba –field, chronologic, and model constrains on time scales and mechanisms of resurgence at large calderas. *Frontiers Earth sci.* 3,25, p.1-17.
- [5] Kumar, et al. 2015. Mapping of Landslide Susceptibility Using Analytical Hierarchy Process at Kothagiri Taluk, Tamil Nadu, India. *International Journal of Applied Engineering Research*, p.5503-5523
- [6] Nugroho, et al. 2010. *Pemetaan Daerah Rawan Longsor Dengan Penginderaan Jauh dan Sistem Informasi Geografis*. Institut Teknologi Sepuluh Nopember (Unpublished Undergraduate Thesis).
- [7] Rincon, D., Khan, U.T., dan Armenakis, C. 2018. Flood Risk Mapping Using GIS and Multi-Criteria Analysis: A Greater Toronto Area Case Study.
- [8] Saaty, T.L. 1990. How to Make a Decision: The Analytic Hierarchy Process. *Eur. J. Oper. Res.* 48, 9–26.

- [9] Suripin. 2002. Pelestarian Sumber Daya Tanah dan Air. Yogyakarta: Andi.
- [10] Widyatmanti et al.. 2016. Identification of Topographic Elements Composition Based on Landform Boundaries From Radar Interferometry Segmentation (Preliminary Study on Digital Landform Mapping). IOP Conference Series Earth and Environmental Science 37(1):012008.