The analysis of landslide vulnerability level distribution in the Labuhanbatu Utara Regency, North Sumatera Province, Indonesia

A S Thoha*, B Slamet, M M Harahap, T Y Sari and D L N Hulu

Faculty of Forestry, Universitas Sumatera Utara, Medan, North Sumatera 20155, Indonesia

* Email: a.siddik@usu.ac.id

Abstract. Forest degradation can increase the level of disaster risk, particularly landslides. The impact of landslides, especially in Labuhanbatu Utara Regency, North Sumatera Province, socio-economic, physical and environmental losses that are directly perceived by the community in the disaster site. The study objective was to analyze the distribution of landslide vulnerability levels in the Labuhanbatu Utara Regency. The spatial distribution of landslide vulnerability level used spatial modeling with the Storie Index method with four variables, including rainfall, slope, soil type, and land cover type. The spatial distribution of landslide vulnerability level was mostly at a very low – low level with a percentage of 57.6% of the area of Labuhanbatu Utara Regency. Areas that occupied high – very high of landslide vulnerability level with the largest area were in three districts, including Na IX-X, Aek Natas, and Kualuh Selatan. Landslide prone areas are generally located on plantation and agricultural land use and also distribute on steep slopes. Various parties need to reorganize community activities in areas of high – very high landslide vulnerability to reduce disaster risk.

1. Introduction

In the last five years, Indonesia has experienced an increase in the frequency of natural disasters. The Indonesian National Board for Disaster Management (BNPB) stated that the number of disasters occurrence in Indonesia in 2018 was 2572 events [1]. The disasters frequency in Indonesia tends to increase from year to year. The Floods, landslides, and hurricanes dominated disasters in Indonesia in the last five years [2].

The disaster that caused the most fatalities was landslides among 2014-2017. It was recorded that the number of victims who died due to landslides was 135 people in 2015-2017, 188 people in 2015, and 156 people in 2016. Landslide became the deadliest disaster in this period [3].

North Sumatera Region is one of the areas that are vulnerable to disasters, including landslides. The steep slope that dominates some regencies is a natural condition that holds the potential for landslide vulnerability level. Study by [4], one of the areas with a high level of landslide risk in North Sumatera is Labuhanbatu Utara Regency. Besides, other areas that are vulnerable to landslides are located in the regencies in the Lake Toba Catchment Areas, South Tapanuli, Mandailing Natal, and Padang Lawas. The locations that are vulnerable to landslides are generally on critical land which is also vulnerable to forest and land fires [5]. According to Setiawan and Abdurrahman [6], climate change is predicted to increase the risk of landslides in North Sumatera, especially in September.
The landslides disaster in Labuhanbatu Utara Regency causes losses either socially, physically, economically, and environmentally. Socially, the landslide disaster in Labuhanbatu Utara Regency has a high social risk where 7,393 people are affected [7]. Economically, landslides in this area can cause losses of between IDR 200 – IDR 400 million. Meanwhile, environmentally, there is an area of 102,945.011 ha of land in Labuhanbatu Utara Regency which is categorized as a high-level landslide risk area [3].

Several factors such as geology, hydrology, hydrogeology, topography and morphology, climate, and weathering are effective on slope instability and cause landslides [8]. According to Sarkar et al. [9], the Geographic Information System (GIS) has acquired significant importance for spatial data analysis. It has proven to be a highly useful tool for landslide studies. In recent years, GIS has been used globally for spatial data analysis of landslide hazard zoning mapping. Landslide vulnerability maps provide a critical evaluation of the class of factors present in areas of the Earth’s surface where GIS can be of great utility. GIS tools offer a useful tool for analyzing processes that occur on the Earth’s surface including analyzing potential disasters [10].

Given the increasing frequency and risk of landslides in the Labuhanbatu Utara Regency, it is necessary to carry out the research related to disaster mitigation. Several studies related to landslide disaster mitigation in North Sumatera and surrounding areas such as studies by [11-13] still focus on biophysical factors. Development planning often ignores the aspect of land capacity in carrying out its ecological functions. Therefore, it is necessary to continuously update studies at the regional levels so that various parties can formulate a mitigation update. The objective of this study was to analyze the distribution of landslide vulnerability levels in the Labuhanbatu Utara Regency of North Sumatra Province.

2. Materials and Methods

2.1. Study area

This study was carried out in Labuhanbatu Utara Regency, North Sumatra Province (Figure 1). The study was conducted August - December 2020. The last study that has been examined the modeling of vulnerability for forest and land fires in North Sumatera [6]. The study try to evaluate areas that are vulnerable to fires due to changes in land cover that have potential to have a landslide hazard.

Figure 1. Study area
Labuhanbatu Utara is located at the coordinates of 1°58’00”-2°50’00” N, 99°25’00”-100°05’00” E. Administratively, it has these regional boundaries: in the north, it is bordered by Asahan Regency and the Malacca Strait; in the south, it is bordered by Labuhanbatu Regency, Lawas Utara Regency, and Tapanuli Selatan; in the west, it is bordered by Tapanuli Utara Regency and Toba Samosir Regency; and in the east, it is bordered by Labuhanbatu [14].

2.2. Data Analysis
We used the 2019 land cover map, the slope map, the soil type map, and rainfall map. The field data collection used various tools including the Global Positioning System (GPS), cameras, tally sheets, and stationery. The data processing tools used were spreadsheet software and ArcGIS 10.5.

The determination of landslides vulnerable area was using the Storie Index method which was first introduced by [15] and developed by [13,16]. The determination of landslide area prone using spatial analysis using multiplication of each parameter. Value of landslide potential as formula 1 will produce the value of the Storie Index range. Furthermore, the value of the storie index range is converted at several levels of landslide vulnerability. The Storie Index analysis is presented in formula 1. The scores of each variable of landslide vulnerability are presented in Table 1.

\[ L = A \times \frac{B}{10} \times \frac{C}{10} \times \frac{D}{10} \]  \hspace{1cm} (1)

Notes
- \( L \) = Landslide potential, \( A \) = Slope, \( B \) = Rainfall, \( C \) = Land cover, \( D \) = Soil type

The determination of areas that are vulnerable to landslides used a GIS tool with the Storie Index method to get a total score. The landslide vulnerability level is classified into 5 classes or levels, including: Very High, High, Moderate, Low, and Very Low using the natural break classification method.

**Table 1. Characteristics of Parameters for Determining Landslide Vulnerability [15]**

| Sj | Variable       | Criteria                                      | Score |
|----|----------------|-----------------------------------------------|-------|
| 1  | Rainfall       | - Rainfall > 3,700 mm year                    | 8     |
|    |                | - Rainfall of 3,400 – 3,700 mm/year           | 7     |
|    |                | - Rainfall of 3,100 – 3,400 mm/year           | 6     |
|    |                | - Rainfall of 2,800 – 3,100 mm/year           | 5     |
|    |                | - Rainfall of 2,500 – 2,800 mm/year           | 4     |
|    |                | - Rainfall of 2,200 – 2,500 mm/year           | 3     |
|    |                | - Rainfall of 1,900 – 2,200 mm/year           | 2     |
|    |                | - Rainfall < 1,900 mm/year                    | 1     |
| 2  | Slope          | - Precipitous to very precipitous, slope > 75%| 6     |
|    |                | - Very steep to precipitous, slope of 46 - 75%| 5     |
|    |                | - Steep to very steep, slope of 31 - 45%      | 4     |
|    |                | - Medium, hilly, slope of 16 - 30%            | 3     |
|    |                | - Sloping, choppy, bumpy, slope of 4 - 15%    | 2     |
|    |                | - Flat, slope of 0 - 3%                       | 1     |
| 3  | Land Cover     | - Without vegetation                          | 5     |
|    |                | - Grass land, shrub, agricultural land (paddy, corn) | 4     |
|    |                | - Mixed plantation, perennial crops           | 3     |
|    |                | - Plantation (trees)                          | 2     |
|    |                | - Dense forest                                | 1     |
| 4  | Soil           | - Oxisol                                      | 7     |
|    |                | - Ultisol                                     | 6     |
|    |                | - Alfisol                                     | 5     |
|    |                | - Mollisol                                    | 4     |
The results of mapping the landslide vulnerability levels were then used as the basis for conducting field surveys. This field survey aimed to determine the condition of land cover and community activities in areas with high – very high landslide vulnerability levels.

3. Results and Discussion

3.1. The score and area of parameters that make up the landslide vulnerability level

The conditions of slope in Labuhanbatu Utara Regency vary from flat to precipitous (Table 2). The area of the Labuhanbatu Utara Regency are dominated by an area with a sloping slope with a percentage of 37.59%. The results of the calculation of the area per slope class show that more than 42% or almost half of the Labuhanbatu Utara Regency area has steep - precipitous slopes. This means that the area has a high potential for landslide vulnerability.

| No. | Slope   | Slope Range (%) | Score | Area (Ha)    | Percentage (%) |
|-----|---------|-----------------|-------|--------------|----------------|
| 1   | Flat    | 0-3             | 1     | 30,038.41    | 8.13           |
| 2   | Sloping | 4-15            | 2     | 138,885.47   | 37.59          |
| 3   | Medium  | 16-30           | 3     | 35,263.65    | 9.54           |
| 4   | Steep   | 30-45           | 4     | 18,246.61    | 4.93           |
| 5   | Very Steep | 45-75     | 5     | 22,062.77    | 5.97           |
| 6   | Precipitous | >75        | 6     | 124,970.47   | 33.82          |
|     | Total Area |             |       | 369,467.37   | 100            |

Source: DEMNAS Analysis, 2019

Most of the areas with steep - precipitous slopes are located on the border of Labuhanbatu Utara Regency with the surrounding regencies, including Toba Samosir, Asahan, and Labuhanbatu (Figure 2). Based on field surveys, the border areas between regencies are generally have a medium - very steep slope where landslide sites are often found. One of the locations with steep – very steep slopes includes Aek Natas and Na IX-X Districts. The study by [17] stated that moderate landslide vulnerability areas are characterized by medium slopes, while areas with high landslide vulnerability are characterized by steep slopes (> 30%).
The soil types in Labuhanbatu Utara Regency are dominated by Inceptisol and Entisol with a percentage of 24.23% and 24.19% (Table 3). Generally, the Inceptisol group and the Entisol group are oxides. Most of the land in Labuhanbatu Utara Regency is classified as land that is not vulnerable to landslides area. Types of soil that are vulnerable to landslides are scattered on the border of Labuhanbatu Utara Regency with other regencies, including Tapanuli Utara and Toba Samosir (Figure 3). Lands that are vulnerable to landslides are generally in the class of steep-precipitous slopes.

Table 3. Score, area, and percentage of soil type classes in Labuhanbatu Utara Regency

| No. | Soil type | Score | Area   | Percentage (%) |
|-----|-----------|-------|--------|----------------|
| 1   | Entisol   | 2     | 89,712.4 | 24.23          |
| 2   | Histosol  | 1     | 70,421  | 19.02          |
| 3   | Inceptisol| 3     | 89,548.5 | 24.19          |
| 4   | Oxisol    | 7     | 71,169  | 19.22          |
| 5   | Ultisol   | 6     | 49,311.2 | 13.32          |

|   | Area       | 370,162 | 100   |

Source: Analysis, 2019

According to [18], Inceptisol soil is young soil, but more developed than Entisol. This shows immature soils with a weaker profile development than mature soils and still resembles the properties of the parent material. Several factors that influence the formation of inceptisols are very resistant parent material, found in steep positions or valleys with slopes, young geomorphological surfaces so that soil formation has not continued. This type of soil is found at a depth of 20-50 cm below the soil surface.
Figure 3. Soil Type Map (Source: Center for Soil and Agroclimate Research)

The land use score was based on the density level of vegetation and the level of roots. The land that have good vegetated cover have no evidence of landslide activity [19]. Land use in Labuhanbatu Utara Regency is dominated by plantation (Table 4). The land use with less or no vegetation cover is considered to be due to a large number of conversion activities of plantation and forest land into agricultural areas and some into abandoned land. The forests area that are converted to agriculture and open areas can increase the vulnerability of landslides in the Labuhanbatu Utara Regency.

Table 4. Score, area, and percentage of land use classes in Labuhanbatu Utara Regency

| No. | Land Use                                         | Area (Ha) | Percentage |
|-----|-------------------------------------------------|-----------|------------|
| 1   | Dense forest                                    | 44,395.57 | 11.98      |
| 2   | Plantation (Trees)                              | 218,996.38| 59.11      |
| 3   | Mixed Plantation and Perennial Crops            | 3,241.05  | 0.87       |
| 4   | Grass Land, Shrub, Agricultural Land (Paddy, Corn)| 94,886.36 | 25.61      |
| 5   | Without Vegetation                              | 8,990.28  | 2.43       |
|     | Total Area                                      | 370,509.64| 100.00     |

Source: Analysis, 2019

The spatial distribution of land use in Labuhanbatu Utara Regency shows that plantations are spread around 59.11% in almost all areas (Figure 4). A small part of the Labuhanbatu Utara Regency area has grass land, shrub, and agricultural land scattered on the border of Toba Samosir Regency. The field survey data showed that grass land (reeds), shrub, and agricultural land in the field are in areas with steep - very steep slopes.
The rainfall score is based on the size of the average annual rainfall. The relatively high average rainfall may result in a higher level of landslide vulnerability. Rainfall in Labuhanbatu Utara Regency ranges from 3,400-3,700 mm/year and has a score of 2 on climate parameters (Table 5 and Figure 5). The rainfall data were obtained from the CHRS of Labuhanbatu Utara. Most of the high rainfall intensity resulted in frequent landslides. Rainwater that fell would penetrate the soil and cause the soil pores to crack [20].

**Table 5.** Score, area, and percentage of rainfall classes in Labuhanbatu Utara Regency

| No. | Rainfall (mm) | Score | Area (Ha)  | Area Percentage |
|-----|---------------|-------|------------|-----------------|
| 1   | 3400-3700     | 7     | 19,667.14  | 5.21            |
| 2   | >3700         | 8     | 358,057.72 | 94.79           |
|     | Total Luas    |       | 377,724.86 | 100             |

Source: Analysis, 2019
3.2. **Analysis of Landslide Vulnerability Level of Area**

The score was obtained a total score range that was classified into 5 classes or levels of landslide vulnerability, including: very high, high, moderate, low, and very Low, with a total area of 352,482.42 of Labuhanbatu Utara Regency (Figure 6). The area with the highest percentage is at a very low vulnerability level at 37.07% and low at 19.93%. Areas with a high - very high vulnerability level are 17.6% and 11.6%. (Table 6)

| No. | Vulnerability Level | Score Range   | Area (Ha)     | Percentage (%) |
|-----|---------------------|---------------|---------------|----------------|
| 1   | Very Low            | 0.0160 – 0.072| 130,689.66    | 37.1           |
| 2   | Low                 | 0.072 – 0.128 | 70,271.64     | 19.9           |
| 3   | Moderate            | 0.128 – 0.216 | 48,576.11     | 13.8           |
| 4   | High                | 0.216 – 0.36  | 62,191.11     | 17.6           |
| 5   | Very High           | 0.360-0.7     | 40,753.90     | 11.6           |
|     | **Total Area**      |               | **352,482.42**| **100.0**      |

Source: Analysis, 2019
Figure 6. Map of Landslide Vulnerability Levels in Labuhanbatu Utara Regency (Analysis, 2019)

Vulnerability level distribution of landslides with high–very high levels is widely spread in several districts in Labuhanbatu Utara Regency. Areas that fall into the criteria for high – very high vulnerability level are evenly distributed in the western and southern regions of Labuhanbatu Utara Regency. Areas with a high – very high level of vulnerability level are found in several districts in Labuhanbatu Utara Regency (Table 7). The three districts that have the largest area of high – very high vulnerability are Na IX-X, Aek Natas, and Kualuh Selatan. These three districts mostly have steep – very steep slopes.

Table 7. Distribution of districts with a high – very high landslide vulnerability level

| No. | District            | Category          | Area (Ha) | Percentage |
|-----|---------------------|-------------------|-----------|------------|
| 1   | Aekkuo              | High - Very High  | 1,540.499 | 1.49       |
| 2   | Aek Natas           | High - Very High  | 32,616.810| 31.68      |
| 3   | Kualuh Hulu         | High - Very High  | 7,631.168 | 7.41       |
| 4   | Kualuh Selatan      | High - Very High  | 13,350.925| 12.96      |
| 5   | Marbau              | High - Very High  | 5,110.684 | 4.96       |
| 6   | Na Sembilan Sepuluh | High - Very High  | 42,694.925| 41.47      |
|     | Total               |                   | 102,945.011| 100        |

Source: Analysis, 2019

Based on filed surveys and deep interviews in December 2019, there were a landslide occurrence then followed by a flash flood in January 2020. This incident resulted in five people missing, 9 houses washed away, and large areas of agricultural land damaged in three villages in Na IX-X District. In this district, most of the area has steep slopes and there are conversion activities of forest into palm oil plantations. Meanwhile, in Aek Natas District, land conversion from forest to palm oil plantations occurred. These districts in the past found forest and land fires almost every year. Study by [21] showed that burned land mostly spread out Na IX-X,Kualuh Selatan and Aek Natas district. After forest and land fires occurrence, these area were found landslide and flashflood disaster.
Land conversion is an activity that can increase the vulnerability level of an area. The change of plant species from woody plants with strong taproots holding the soil to fibrous-rooted seasonal plants can trigger landslides in the future. The roots of seasonal plants are generally fibrous and shallow, so they are not effective in preventing erosion. The study by [22] and [23], plants with deep fibrous roots can reduce the possibility of landslides and soil movement. Roots with deep roots and lots of fibrous roots can increase the grip of the soil.

The potential for landslide hazard is higher on land with very steep slopes. Heavy rainfall causes landslides to occur. Besides the steep slope, land use in the area is also influential. Areas that are vulnerable to landslides are in mixed plantations, grass land, shrub, and agricultural land [24].

Study in Taiwan, landslides are a frequent disaster especially during extreme events such as earthquakes and typhoons that result in unstable slopes. Cycles of land degradation and high uncertainty with repeated landslide characteristics have led to the formation of large numbers of landslides [20].

The landslide vulnerability map can be assumed to be used as a basis for analyzing future landslide events. The results of study can help decision-makers to improve references in predicting the risk of landslides in the future. The spatial distribution of landslide vulnerability levels can be developed into an early warning system and mitigation solutions [25]. Based on study by [26], the map of landslide vulnerability should provide planners and decision-makers with adequate and understandable information. Moreover, it is important for various parties to restore lands, particularly those that have been degraded by fire, encroachment, illegal logging, and cultivation. This is to restore the important function of the forest, including the disaster protection and prevention functions

4. Conclusion
The spatial distribution of landslide vulnerability level is mostly at a very low - low level with the percentage of the area reaching almost 57% of the area of Labuhanbatu Utara Regency. Areas that occupy a high - very high level of landslide vulnerability with the largest area are in three districts, including Na IX-X, Aek Natas, and Kualuh Selatan. Areas with a high - very high level of landslide vulnerability are on steep - precipitous slopes, unstable soils, and land cover of grass lands, shrubs, and dry agricultural land. Mitigation of landslides in Labuhanbatu Utara Regency needs to be prioritized to restore the condition of land cover that lacks vegetation in areas with steep - precipitous slopes.

Acknowledgment
This study was funded by the TALENTA Fund of Universitas Sumatera Utara for the Fiscal Year of 2020 with a Contract Number of 4142/UN5.1.R/PPM/2020. We would also like to thank the Regional Disaster Management Agency of Labuhanbatu Utara Regency, North Sumatera Province and the field team who provided support during the data collection. We also give our highest appreciation to the editor and reviewers team who have provided their corrections and comments.

References
[1] [BNPB] Badan Penanggulangan Bencana Nasional 2018 *Infografis Kejadian Bencana* (Desember 2018) Available in: https://bnpb.go.id/uploads/24/info-bencana-desember-2018.pdf [accessed 7 Februari 2018]
[2] [BNPB] Badan Penanggulangan Bencana Nasional 2017a *2.341 Kejadian Bencana, 377 Tewas dan 3,5 Juta Jiwa Mengungsi dan Menderita Akibat Bencana Tahun 2017* Available in: https://www.bnpb.go.id/2341-kejadian-bencana-377-tewas-dan-3-5-juta-jiwa-mengungsi-dan-menderita-akibat-bencana-tahun-2017 [accessed 7 Februari 2018]
[3] [BNPB] Badan Penanggulangan Bencana Nasional. 2017b *Tren Bencana 2013-2017* Available in: https://bnpb.go.id/trend-bencana-2013-2017 [accessed 7 Februari 2018]
[4] [BNPB] Badan Penanggulangan Bencana Nasional 2016 *Risiko Bencana Indonesia* (Jakarta: Direktur Pengurangan Risiko Bencana BNPB)
[5] Thoha A S and Ahmad A G 2018 *Environment Asia* 11 1
[6] Setiawan B, Hadi T W, Abdurrahman O 2010 *Proceeding on Geotechnical and Geosynthetics*
Engineering: Challenges and Opportunities in Climate Change (Thailand)

[7] [BNPB] Badan Penanggulangan Bencana Nasional 2015 Kajian Risiko Bencana 2016 (Jakarta: Direktur Pengurangan Risiko Bencana BNPB)

[8] Annisa J, Sutikno S and Rinaldi 2015 JOM FT Teknik 2 30

[9] Sarkar S, Kanungo D P, Patra A K and Kumar P 2008 Journal of Mountain Science 5 52

[10] Kuldeep P and Upasana P 2012 International Journal of Science and Technology 1 91

[11] Kurniawan L 2008 Jurnal Sains dan Teknologi Indonesia 10 90

[12] Rahmat L, Suib and Nurman A 2018 Majalah Geografi Indonesia 32 1

[13] Thoha A S, Sundari D, Patana P and Sulistiyono N 2020 Journal of Physic: Conference Series 1542 012011

[14] Bappeda 2014 Review RPJM Kabupaten Labuhanbatu Utara (2014-2018) Available in: https://sippa.ciptakarya.pu.go.id

[15] Sitorus S 1995 Evaluasi Sumber Daya Lahan (Bandung: Tarsito)

[16] Arifin S, Carolina I and Winarsso C 2006 Jurnal Penginderaan Jauh 3 77

[17] Bachri S and Rajendra P S 2010 5th Annual International Workshop & Expo on Sumatra Tsunami Disaster & Recovery 2010 (Malang) 107

[18] Hartono R 2016 Jurnal Pendidikan Geografi 21 30

[19] Sanchez P A 1992 Sifat dan Pengelolaan Tanah Tropika ed. Johara T J (Bandung: Institut Teknologi Bandung) 103

[20] Kui-Lin F, Bor-Shiun L, Kent T, Chun-Kai C and Hsing-Chuan H 2016 Nat. Hazards Earth Syst. Sci. Discuss. 1 Available in: http://Natural.Hazards.and.Earth.System.Sciences. [07 Agustus 2019].

[21] Thoha A S, Sofyan M a and Ahmad A G 2020 Earth and Environmental Science 454 012081

[22] Riyanto H D 2016 Rekayasa Vegetatif untuk Mengurangi Risiko Longsor (Jakarta: Balai Penelitian dan Pengembangan Teknologi Pengelolaan Daerah Aliran Sungai, Kementerian Lingkungan Hidup dan Kehutanan)

[23] Wulan T R 2017 Jurnal Majalah Geografi Indonesia 3 44

[24] Jiménez-Perálvarez J D, Irigaray C, El Hamdouni R and Chacón J 2009 Natural hazards 50 571

[25] Solaimani., Mousavi S Z and Kavian A 2013 Arab J Geoscience 6 2557

[26] Thapa P 2015 Journal of Nepal Geological Society 49 17