Spatial distribution of landslide vulnerability level in Dairi District, North Sumatera Province, Indonesia

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Abstract. Forest damage has had a real impact in increasing the level of disaster risk, especially landslides. The real impact of landslides, especially in the Dairi District, North Sumatera Province, is physical, social, economic, and environmental losses that are felt directly by the community near the disaster location. This study was conducted to determine the spatial distribution of landslide-prone areas in the Dairi District. The determination of the distribution of landslide-vulnerability level areas used spatial modeling with the Storie Index method with several variables, which were rainfall, slope, soil type, and land cover type. The distribution of landslide-prone areas was mostly at very low-low levels with the percentage of the area reaching almost 60% of the area of the Dairi District. The areas that occupy high-very high landslide-vulnerable levels with the largest area were in three sub-districts, which were Tanah Pinem, Sumbul, and Parbuluan. The landslide areas were generally located on shrubs and grassland and on steep slopes. Various parties need to improve unmanaged land to productive land by land rehabilitation and agroforestry system.

1. Introduction
Indonesia has experienced natural disasters whose frequency has tended to increase in the last five years. The National Disaster Management Agency (BNPB) states that in 2018, the number of disasters in Indonesia was 2,572 [1]. The frequency of disasters in Indonesia tends to increase from year to year. Floods, landslides, and whirlwinds dominated disasters in Indonesia in the period of 2013-2017 [2]. In 2014-2017, the disaster which caused the most fatalities was landslides. There were 135 fatalities reported as a result of landslides in 2015-2017, 188 fatalities in 2015, and 156 fatalities in 2016. Landslides were the deadliest disasters in that period [3].

North Sumatera Province is one of the disaster-prone areas, including landslides. The steep topography that dominates several districts in North Sumatera is a natural condition that has the landslide potentials. According to BNPB [4], one of the areas with a high level of risk of landslides in North Sumatera is the Dairi District. In addition, other landslide-prone areas are located in the districts of Lake Toba Catchment Area, South Tapanuli, Mandailing Natal and Padang Lawas. Generally, the landslide-prone locations are on critical land, which is also a forest and land fire disaster-prone land [5]. A study by [6] stated that climate change is predicted to increase the risk of landslides in North Sumatera, especially in September.

The risk of landslides in the Dairi District causes social, physical, economic, and environmental losses. Socially, landslides in the Dairi District have a high social risk, with 31,454 people affected. Physically and economically, landslides in this area can be risky and cause losses between Rp. 200 -
Rp. 400 million. As for the environment, there is 52,292 ha of land in the Dairi District categorized as a high-level landslide risk area [4]. Considering the landslide, which is increasing in frequency and risk in the Dairi District, it is necessary to conduct a study related to reduction efforts of disaster risk. Several studies related to landslide mitigation in North Sumatera and its surrounding areas such as a study by [7-9] still focus on biophysical aspects. The aspect of the relationship of land cover changes due to community activities resulting in loss of area functions in landslide protection services has not been much studied. Development planning often ignores aspects of land capacity in carrying out its ecological functions. Therefore, regional scale studies that are continuously updated are needed, so that various parties can anticipate disaster earlier. The objective of this study was to analyze the distribution of landslide-vulnerability levels in the Dairi District of North Sumatera Province.

2. Materials and Method

2.1 Study Area

This study was conducted in the Dairi District, North Sumatera Province (Figure 1). This study was carried out for one year, starting from the fiscal year of 2019. The previous study that has been carried out examines the vulnerability map model of forest and land fire vulnerability models in North Sumatera (Thoha and Ahmad, 2018). The continuation of this study is to evaluate the fire-prone areas due to human activities based on field survey that have the potential for landslides.

![Figure 1. Study area](image_url)

2.2 Data Analysis

The materials that would be used in this study was a land cover map of 2017, slope map, soil type map, and rainfall map. The tools for field data collection were, among others, Global Positioning System (GPS), camera, tally sheets, and stationery. The data analysis tools that would be used were spreadsheet software and ArcGis 10.5.

To find out the dynamics of changes in land cover, land cover map data was needed from the Forest Region Consolidation Agency of Region I, Medan. The determination of community activities in each type of land cover was carried out by observations and interviews.

The determination of landslide-prone areas used the Storie Index method, which was first introduced by [10] and developed by [11]. The determination of landslide-prone areas used GIS with the Storie Index method, which was the multiplication of each parameter. The results of the analysis would produce a range of Storie Index values. Furthermore, the range of Storie Index values was
converted at several landslide-prone levels. The Storie Index analysis [10] is presented in formula 1. The characteristics of each of the landslide-prone variables are presented in detail in Table 1.

\[ L = A \times B^{10} \times C^{10} \times D^{10} \]  

(1)

Where:
L = Landslide potential
A = Slope
B = Rainfall
C = Land Cover
D = Soil type

The determination of landslide-prone areas used GIS tools with the Storie Index method to obtain a total score. This score range was converted at several levels according to requirement, landslide-prone levels were classified into five classes or levels, which were: Very High, High, Medium, Low, and Very Low using the natural break method.

| Sj | Variable | Criteria | Score |
|----|----------|----------|-------|
| 1  | Rainfall | - Rainfall of >33700 mm a year | 8     |
|    |          | - Rainfall of 3400 - 3700 mm a year | 7     |
|    |          | - Rainfall of 3100 - 3400 mm a year | 6     |
|    |          | - Rainfall of 2800 - 3100 mm a year | 5     |
|    |          | - Rainfall of 2500 - 2800 mm a year | 4     |
|    |          | - Rainfall of 2200 - 2500 mm a year | 3     |
|    |          | - Rainfall of 1900 - 2200 mm a year | 2     |
|    |          | - Rainfall of <1900 mm year | 1     |
| 2  | Slope    | - Steep to very steep, slope of >75% | 6     |
|    |          | - Very steep to steep, slope of 46 - 75% | 5     |
|    |          | - Steep up to very steep, slope of 31 - 45% | 4     |
|    |          | - Rather steep, hilly, slope of 16 - 30% | 3     |
|    |          | - Sloping, wavy, bumpy, slope of 4 - 15% | 2     |
|    |          | - Flat, slope of 0 - 3% | 1     |
| 3  | Land Cover | - Without vegetation | 5     |
|    |          | - Grass, bush, rice field vegetation (paddy, corn) | 4     |
|    |          | - Mixed gardens, garden plants | 3     |
|    |          | - Plantation (trees) | 2     |
|    |          | - Dense forest | 1     |
| 4  | Soil     | - Oxisol | 7     |
|    |          | - Ultisol | 6     |
|    |          | - Alfisol | 5     |
|    |          | - Mollisol | 4     |
|    |          | - Enseptisol | 3     |
|    |          | - Entisol | 2     |
|    |          | - Histosol | 1     |

Source: Arifin et al. (2009)

3. Results and Discussion
Slope conditions in the Dairi District varied from flat to very steep (Table 2). The results of the spatial analysis of the landslide slope show that the Dairi District area was dominated by areas with flat –
sloping slope levels with a percentage of 59.83%. This shows that parts of the Dairi District were relatively safe from landslides.

| No. | Slope Criteria | Score | Area (Ha)     | Percentage (%) |
|-----|----------------|-------|---------------|----------------|
| 1.  | 0 - 8% flat    | 1     | 72657.08      | 35.66          |
| 2.  | 8 - 16% sloping| 2     | 49237.53      | 24.17          |
| 3.  | 16 - 25% rather steep | 3   | 3754.85       | 18.43          |
| 4.  | 25 - 36% steep | 4     | 30273.20      | 14.86          |
| 5.  | 36 - 73% very steep | 5   | 14017.09      | 6.88           |
|     | Total          |       | 203730.35     | 100            |

Table 2. Score, Area and Percentage of Slope Class in the Dairi District

Source: Analysis of DEMNAS Geospatial Information Agency, 2019

Areas that had steep - very steep slopes were mostly on the border of the Dairi District with the surrounding districts, including Karo, Samosir, Pakpak Bharat and Southeast Aceh (Figure 2). Based on the results of the field survey, the border area between districts was generally marked by a rather steep - very steep slopes where landslides often occurred. One of the locations with rather steep – steep slope levels was in the Catchment Area (DTA) of Lake Toba covering Silahisabung Sub-district and Sumbul. A study by [12] mentioned that the medium landslide-prone area was marked by rather steep slope, while the high landslide-prone area was marked by a steep slope (> 30%).

![Figure 2. Slope Map(Source: DEMNAS 2019)](image)

The dominant soil types in the Dairi District were enseptisol and oxisol soils, with a percentage of 39.76% and 25.08% (Table 3). In general, the oxisol group and the enseptisol group were oxides. Most of the land in the Dairi District was classified as lands that are not prone to landslides. The types of lands that were prone to landslides were spread across the border of the Dairi District with other districts including Karo, West Pakpak, and Samosir (Figure 3). These landslide-prone lands were generally in the rather steep - very steep slope classes.
Table 3. Scores, area and percentage of soil type classes in the Dairi District

| No. | Soil Type | Score | Area (Ha)   | Percentage |
|-----|-----------|-------|-------------|------------|
| 1.  | Entisol   | 2     | 37846,05    | 18.59      |
| 2.  | Enseptisol| 3     | 80899,40    | 39.76      |
| 3.  | Ultisol   | 6     | 33735,20    | 16.57      |
| 4.  | Oxisol    | 7     | 51021,79    | 25.08      |
|     | Total     |       | 203502,44   | 100        |

Source: Analysis by authors, 2019

Oxisol is a type of soil which is easy to plow using heavy machines, a day after heavy rain and it is difficult to break aggregate. Lots of oxisol soils are easily compacted and eroded [13]. This shows that oxisol management is very difficult to process and is prone to landslides due to erosion.

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Table 4. Scores, area and percentage of land cover classes in the Dairi District

| No. | Land Use                | Score | Area (Ha)   | Percentage (%) |
|-----|-------------------------|-------|-------------|----------------|
| 1.  | Dense forest            | 1     | 50646,15    | 25.84          |
| 2.  | Plantation              | 2     | 7129,43     | 3.64           |
| 3.  | Grass, bush, rice field vegetation | 4 | 134097,44  | 68.42          |
| 4.  | Without vegetation      | 5     | 4121,47     | 2.10           |
|     | Total                   |       | 17,654      | 100            |

Source: Analysis, 2019
The spatial distribution of land use in the Dairi District shows that grass, bush, and rice field vegetation were spread in almost all regions (Figure 4). A small part of the Dairi District region was land without vegetation, which was spread across the border of Karo District and some were in the Catchment Area of Lake Toba. The results of the field survey showed that land without vegetation in the field was a meadow expanse growing on the land with steep - very steep slopes.

![Figure 4. Land Use Map(Source: BPKH of North Sumatera)](image)

Scoring for rainfall was based on the average value of the annual rainfall. The relatively large average rainfall could result in higher landslide-prone levels. Rainfall in the Dairi District was about 2517 mm/year and had a score of 4 on the climate parameter (Table 5 and Figure 5). The rainfall data obtained from the BPS of Dairi District was only one data, this was due to the limited information on rainfall data provided by the Dairi District Government.

**Table 5. Scores, area and percentage of rainfall classes in the Dairi District**

| No. | Rainfall     | Score | Area (Ha)    | Percentage (%) |
|-----|--------------|-------|--------------|----------------|
| 1.  | 2517 mm/year | 4     | 203735.31    | 100            |
|     | Total        |       | 203735.31    | 100            |

Source: BPS of Dairi District, 2019
The result of Storie Index analysis obtained a range value of the total score which was classified into five classes or landslide-prone levels, which were: Very High, High, Medium, Low, and Very Low. That was 58.37% of the total area of the Dairi District. The areas with the highest percentage were at low vulnerable levels of 34.14% and high vulnerable levels of 26.48%. The areas with high - very high landslide-prone levels occupied an area of 38.79% of the total area (Table 5).

| No. | Vulnerability level | Score Range       | Area (Ha)    | Percentage (%) |
|-----|---------------------|-------------------|--------------|----------------|
| 1.  | Very high           | 0.360001 – 0.700000 | 1817,489     | 12.49          |
| 2.  | High                | 0.216001 – 0.360000 | 3853,03      | 26.48          |
| 3.  | Medium              | 0.128001 – 0.216000 | 334,81       | 2.30           |
| 4.  | Low                 | 0.072001 – 0.128000 | 4966,97      | 34.14          |
| 5.  | Very low            | 0.016000 – 0.072000 | 3577,59      | 24.59          |
|     | **Total**           |                   | **14549,89** | **100**        |

Source: analysis by authors, 2019

Spatially, it could be seen that the distribution of landslides with high levels was widely spread in almost all districts in the Dairi District (Figure 6). The areas that were categorized as high - very high landslide-prone were evenly distributed in the western, central, north, south and east of the Dairi District.
The areas with high - very high landslide-prone levels were found in all districts in the Dairi District (Table 6). The three sub-districts which had the widest area of high - very high landslide-prone levels were Tanah Pinem, Sumbul, and Parbuluan. Most areas of these three sub-districts had steep - very steep slopes. Sumbul sub-district was located in the upstream of the Catchment Area of Lake Toba where the area was mostly steep. The Pinem and Parbuluan Land also had steep - very steep area characteristics. In addition to the steep slopes, land use in the area also affected. Generally, the landslide-prone areas were on the land of bush, meadow, and agricultural areas.

In Taiwan, landslides are disasters that often occur, especially during extreme events such as earthquakes and typhoons, which cause the slopes to become unstable. The cycle of land degradation and high uncertainty with the characteristics of repeated landslides have led to the formation of large numbers of landslides [14].

| No. | Vulnerability level | Sub-district       | Area (Ha) | Percentage (%) |
|-----|---------------------|--------------------|-----------|---------------|
| 1.  | High - Very High    | Berampu            | 72.14     | 0.49          |
| 2.  | High - Very High    | Sidikalang         | 93.69     | 0.64          |
| 3.  | High - Very High    | Tanah Pinem        | 399.46    | 2.75          |
| 4.  | High - Very High    | Siempat Nempu Hilir| 78.46     | 0.54          |
| 5.  | High - Very High    | Silimapungga - Pungga| 110.33  | 0.76          |
| 6.  | High - Very High    | Pegagan Hilir      | 128.25    | 0.88          |
| 7.  | High - Very High    | Gunung Sitember    | 82.49     | 0.57          |
| 8.  | High - Very High    | Tigalingga         | 108.57    | 0.75          |
| 9.  | High - Very High    | Siempat Nempu      | 41.05     | 0.28          |
| 10. | High - Very High    | Sitinjo            | 67.65     | 0.46          |
| 11. | High - Very High    | Sumbul             | 356.51    | 2.45          |
| 12. | High - Very High    | Parbuluan          | 267.61    | 1.84          |
| 13. | High - Very High    | Silahisabungan     | 166.96    | 1.15          |
| 14. | High - Very High    | Siempat Nempu Hulu | 82.56     | 0.57          |
| 15. | High - Very High    | Lae Parira         | 96.54     | 0.66          |

Total 2152.30 14.79

Source: analysis by authors, 2019
Based on the surveys and interviews in December 2018, there was a landslide followed by flash floods that caused six people died and hundreds of hectares of agricultural land damaged in three villages in the Silimapungga-pungga Sub-district. Even though the Silimapungga Sub-district had a high – very high level of landslide-prone areas which was quite broad, most of the area had steep slopes, and there was the activity of converting forest land into Gambir (Uncaria gambir) plantations. Meanwhile, in the Tanah Pinem Sub-district, there was a land conversion from the forest and the Candlenut (Aleurites moluccanus) plantations into the corn (Zea mays) field. Conversion of land into activities had the potential to increase the level of vulnerability of an area. Substitution of types of plants from woody plants with strong taproot holding the soil into seasonal plants with rooted fibers could trigger landslides in the future. The potential for landslides was higher on land with very steep slopes.

Seasonal plant roots were generally stringy and shallow, so that they were less than optimal in preventing erosion. According to the study by [15] and [16], plants with deep fibrous roots could reduce the possibility of landslides and soil movements. Roots with many deep roots and fibrous roots could increase soil traction.

Landslide-prone maps could be assumed to be used as a basis for analyzing future landslide events. Bachri [12] found that landslides usually occur periodically located in certain conditions such as geological conditions, slopes, and soils, which are categorized as inseparable factors. Landslides that had occurred in the past could occur in the future under similar conditions and areas.

This study can help decision-makers to improve reference information in predicting future landslides. Spatial distribution of landslide-prone areas can be developed into early warning systems, making rapid disaster response procedures, evacuation protocols, and long-term mitigation solutions (Fu et al. 2016). Landslide disaster management can succeed only when the detailed knowledge is obtained about the expected frequency, character, and magnitude of the mass movement in an area. Landslide-prone maps are needed to be the basis in any landslide mitigation strategy. According to [17], a landslide-prone map must provide adequate and understandable information for the planners and decision-makers. Land management is needed to improve critical land that have high level landslide vulnerability for examples by implementation agroforestry system and land rehabilitation.

4. Conclusion
The distribution of landslide-prone areas is mostly at very low - low levels with the percentage of the area reaching almost 60% of the area of the Dairi District. The areas that occupy high - very high landslide-prone levels with the largest area are in three sub-districts, which are Tanah Pinem, Sumbul, and Parbuluan. Large area of unmanaged land can increase landslide-vulnerability level. Various parties need to improve unmanaged land to productive land by land rehabilitation and agroforestry system.

5. References
[1] [BNPB] Badan Penanggulangan Bencana Nasional. 2017a. 2.341 Kejadian Bencana, 377 Tewas dan 3,5 Juta Jiwa Mengungsi dan Menderita Akibat Bencana Tahun 2017. URL :https://www.bnpb.go.id/2341-kejadian-bencana-377-tewas-dan-35-juta-jiwa-mengungsi-dan-menderita-akibat-bencana-tahun-2017 [accessed 7 Februari 2018]
[2] [BNPB] Badan Penanggulangan Bencana Nasional. 2017b. Tren Bencana 2013-2017. URL : https://bnpb.go.id/trend-bencana-2013-2017 [accessed 7 Februari 2018]
[3] [BNPB] Badan Penanggulangan Bencana Nasional. 2018. Infografis Kejadian Bencana (Desember 2018). URL :https://bnpb.go.id/uploads/24/info-bencana-desember-2018.pdf [accessed 7 Februari 2018]
[4] [BNPB] Badan Penanggulangan Bencana Nasional. 2016. Risiko Bencana Indonesia. Direktur Pengurangan Risiko Bencana (Jakarta-BNPB)
[5] Thoha AS dan Ahmad AG. 2018. Modeling of Forest and Land Fires Vulnerability Level in North Sumatera Province, Indonesia. EnvironmentAsia 11(3): 1-14

[6] Setiawan B, Hadi TW, Abdurrahman O. Impact of climate change on the risk of landslide in Indonesia and the proposed adaptation activities 2010 Proceeding on Geotechnical and Geosynthetics Engineering: Challenges and Opportunities in Climate Change 7 to 9 December 2010 Bangkok, Thailand

[7] Kurniawan L. 2008. Kajian penilaian bahaya tanah longsor Provinsi Sumatera Utara. Jurnal Sains dan Teknologi Indonesia 10(2): 90-98

[8] Rahmat L, Suib, Nurman A. 2018. Aplikasi SIG untuk Pemetaan Tingkat Ancaman Longsor di Kecamatan Sibolangit, Kabupaten Deli Serdang, Sumatera Utara. Majalah Geografi Indonesia 32(1): 1-13

[9] Rachman, S dan Pramudito,H. 2018. Study of Landslide Disaster in Aceh Tamiang Area of Nanggroe Aceh Darussalam Province Indonesia. 2018. Proceeding on FIG Congress 2018 Embracing our smart world where the continents connect: enhancing the geospatial maturity of societies Istanbul, Turkey, May 6–11, 2018

[10] Sitorus S. 1995. Evaluasi Sumber Daya Lahan (Bandung-Tarsito)

[11] Arifin S, Carolina I, Winarsro C. 2006. Implementasi penginderaan jauh dan SIG untuk inventarisasi daerah rawan bencana longsor (Propinsi Lampung). Jurnal Penginderaan Jauh 3(1): 77-86

[12] Bachri S dan Rajendra PS. 2010. Landslide hazard assessment using analytic hierarchy processing (AHP) and geographic information system in Kaligesing mountain area of Central Java Province Indonesia. 5th Annual International Workshop & Expo on Sumatra Tsunami Disaster & Recovery 2010. Malang :107-112.

[13] Sanchez PA. 1992. Sifat dan Pengelolaan Tanah Tropika, ed. Johara TJ. Institut Teknologi Bandung. Bandung, pp. 103-106

[14] Fu K, Bor-Shiuin L, Kent T, Chun-Kai C and Hsing-Chuan H. 2016 Evaluation of Environmental Factors in Landslide Prone Areas of Central Taiwan using Spatial Analysis of Landslide Inventory Maps . Nat. Hazards Earth Syst. Sci. Discuss. 1-54. URL : http://Natural.Hazards.and.Earth.System.Sciences. [accessed 07 August 2019].

[15] Riyanto, HD 2016 Rekayasa Vegetatif untuk Mengurangi Risiko Longsor. Balai Penelitian dan Pengembangan Teknologi Pengelolaan Daerah Aliran Sungai. Kementerian Lingkungan Hidup dan Kehutanan.

[16] Wulan TR 2017. Pemetaan Cepat Kawasan Terdampak Bencana Longsor dan Banjir di Kabupaten Bangli Provinsi Bali. Jurnal Majalah Geografi Indonesia 3(2): 44-50.

[17] Pareta K dan Upasana P 2012 Landslide Modeling and Susceptibility Mapping of Giri River Watershed, Himachal Pradesh (India). International Journal of Science and Technology. 1(2): 91-104

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