Spatial distribution of landslide vulnerability level in Langkat Regency, North Sumatra Province, Indonesia

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Abstract. Forest and land degradation tend increase and can trigger an increased risk of disaster. The landslide is a deadly disaster that frequently occurs in Indonesia, particularly in Langkat Regency. The study objective was to analyze the spatial distribution of landslide vulnerability levels in Langkat Regency, North Sumatera Province. The spatial distribution of landslide vulnerability level was used the Storie Index method with four variables, including rainfall, slope, soil type, and land cover type. The results of this study were the landslide vulnerability level and the area of spatial distribution with high – very high vulnerability levels. The spatial distribution of landslide vulnerability level in Langkat Regency is mostly at a moderate level with the area reaching nearly 32%, while the area of the high – very high vulnerability level is 19.77% of the total area of Langkat Regency. The widest area that occupied the high – very high landslide vulnerability level in Langkat Regency includes three districts, including Bahorok, Batang Serangan, and Sei Bingai. Areas that are very vulnerable to landslides are generally precipitous with a land cover of plantation and agricultural areas. Most of the high landslide vulnerability areas are included in the Gunung Leuser National Park area. Various parties need to pay serious attention to landslide areas with high – very high vulnerability levels to reduce disaster risk.

1. Introduction
In the last five years, the number and frequency of disasters in Indonesia tend experience increasing occurrences. The Indonesian National Board for Disaster Management (BNPB) stated that the number of disasters in Indonesia in 2018 was 2572 events [1]. Hydro-meteorological disasters such as floods, landslides, and hurricanes were the most frequent disasters in the period 2013-2017 [2].

The incidence of landslides in Indonesia is increasing with the distribution of the disaster area getting more dispersed. In 2014-2017, landslides were among the disasters that caused the most fatalities. The number of victims who died due to landslides was 135 people in 2015-2017, 188 people in 2015, and 156 people in 2016 [3].

The North Sumatera region has an area with a very wide steep topography. This natural condition has the potential for landslide hazards. A report by [4] stated that one of the high risk level of landslide disaster in North Sumatera is Langkat Regency. The locations that are vulnerable to landslides are generally on critical land[5]. A study by [6] found that climate change is predicted to increase the risk of landslides in North Sumatera.

The area of Langkat Regency is 6,263 km² or 626,329 ha, consisting of 23 districts which are divided into 240 villages and 37 sub-districts. The risk of landslides in Langkat Regency causes losses either socially, ecologically, economically, and environmentally. Socially, the landslide disaster in
Langkat Regency has a high social risk where 1,919 people are affected. Physically and economically, landslides in this area can be risky and cause losses between IDR 200 – IDR 400 million. Meanwhile, environmentally, there is an area of 112,382.6 ha of land in Langkat Regency which is categorized as a high-level landslide risk area [7]. According to study by [8], some factors such as geology, hydrology, hydrogeology, topography and morphology, climate, and weathering are effective on slope instability and cause landslides.

Given the rapid development of development with a high potential for landslides in Langkat Regency, it is need to conduct research related to disaster risk reduction program. Several studies related to landslide disaster mitigation in North Sumatera and surrounding areas such as studies by [9], [10], [11], still focus on biophysical characteristics. The factors of community activities that result in the loss of function of forest areas in protection functioning from landslides has not been broadly studied. Therefore, it is necessary to continuously update disaster vulnerability studies so that various parties can carry out disaster mitigation. The study objective was to analyze the distribution of landslide vulnerability levels in Langkat Regency, North Sumatera Province.

2. Materials and Methods

2.1. Research Sites

This study was carried out in Langkat Regency, North Sumatera Province (Figure 1). The study was carried out from May to July 2021. A previous study has analyzed the distribution of the vulnerability level to forest and land fires in North Sumatera [11]. This study can be used to evaluate areas that are vulnerable to fires due to changes in land cover that have the potential to have a landslide hazard.

Geographically, Langkat Regency is located at 3° 14’– 4° 13’ of North Latitude, 97°52’ – 98° 45’ of East Longitude and 4 – 105 m above sea level. The area of Langkat Regency is ± 6,263.29 km² (626,329 ha) which consists of 23 sub-districts, 240 villages, and 37 definitive sub-districts. Based on administrative boundaries, Langkat Regency is bordered by Aceh Tamiang Regency and the Malacca Strait in the north, by Karo Regency in the south, by Aceh Tenggara / Tanah Alas Regency in the west, and by Deli Serdang Regency in the east [12].

![Figure 1. Research Sites](image-url)
2.2. Data Analysis

The materials in this study were the 2019 land cover map from Indonesia Central Forest Region I (BPKH) Medan, a slope map from DEMNAS from National Geospatial Information Agency, a soil type map from the Landssystem Map, and a rainfall map from the Center for Hydrometeorology and Remote Sensing (http://chrs.web.uci.edu). The field data collection tools used the Global Positioning System (GPS), cameras, tally sheets, and stationery. The data analysis and maps used spreadsheet software, and ArcGis 10.8.

The determination of vulnerability level of landslides was through the Storie Index method. This method was first introduced by [13] and then developed in studies by [14] and by [15]. The determination of areas that are vulnerable to landslides used the Geographic Information System with the Storie Index method, which is the multiplication of each parameter. The next analysis will later produce the value of the total score range for the potential for landslides. Furthermore, the value of the total score range for the potential for landslides is converted at several levels of landslide vulnerability. The Storie Index method [13] is presented in formula 1. The detail characteristics of each variable of landslide vulnerability are presented in detail in Table 1. The total score range of landslide potential is classified into 5 vulnerability classes, including: Very High, High, Moderate, Low, and Very Low using the natural break classification.

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

(1)

Notes
L = Landslide potential
A = Slope
B = Rainfall
C = Land cover
D = Soil type

| Sj | Variable  | Criteria                                      | Score |
|----|-----------|-----------------------------------------------|-------|
| 1  | Rainfall  | Rainfall > 3700 mm/year                       | 8     |
|    |           | Rainfall of 3400 - 3700 mm/year               | 7     |
|    |           | Rainfall of 3100 - 3400 mm/year               | 6     |
|    |           | Rainfall of 2800 - 3100 mm/year               | 5     |
|    |           | Rainfall of 2500 - 2800 mm/year               | 4     |
|    |           | Rainfall of 2200 - 2500 mm/year               | 3     |
|    |           | Rainfall of 1900 - 2200 mm/year               | 2     |
|    |           | Rainfall < 1900 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     |
|    |           | Grassland, 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     |
In this study, a field survey was conducted by taking sample points of landslide vulnerability locations. The results of the field survey were then used to test the accuracy between the map and the overall field survey points based on the landslide vulnerability level. The accuracy test method used was based on [16], which was the ratio of the number of pixels in the i column to the number of pixels in the i-th row with the number of pixels in the sample.

$$\text{Overall Accuracy} = \frac{\sum_{i=1}^{n} X_{ii}}{n} \times 100\%$$

Where:
- $X_{ii}$: Diagonal value of the i-th row and i-th column contingency matrix
- $X_{+i}$: Number of pixels in i-th column
- $X_{i+}$: Number of pixels in i-th row
- $N$: Number of pixels in the example

The ground check results were adjusted to the landslide vulnerability map category. Locations with a certain level of landslide vulnerability obtained from the survey were 96 points. The sampling points were determined randomly at each level of landslide vulnerability and expected to be evenly distributed throughout the study area, particularly the Langkat area affected by the landslide.

3. Results and Discussion

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

The North Sumatera region consists of mountainous, hilly, and lowland areas. The mountainous and hilly areas with slopes of more than 30% are located in the middle of the Gunung Leuser National Park area. Meanwhile, the lowland area occupies the area on the east and west coast near the coast of the Malacca Strait. Slope conditions in Langkat Regency vary from flat to very steep (Table 2). Based on demonstrate Table 2, the Langkat Regency area is dominated by areas with steep – precipitous slopes with a percentage of 59.83%.

| No. | Slope Criteria | Slope (%) | Score | Area (ha) | Area (%) |
|-----|----------------|-----------|-------|-----------|----------|
| 1   | Flat           | 0-3       | 1     | 60,352.12226 | 9.99     |
| 2   | Sloping        | 4-15      | 2     | 77,250.99224 | 12.79    |
| 3   | Medium         | 16-30     | 3     | 53,073.32974 | 8.79     |
| 4   | Steep          | 31-45     | 4     | 35,215.53505 | 5.83     |
| 5   | Very Steep     | 46-75     | 5     | 79,434.55639 | 13.15    |
| 6   | Precipitous    | >75       | 6     | 298,420.4032 | 49.42    |
|     | Total          |           |       | 603,746.93   | 100      |

Source: DEMNAS Analysis, 2019

Most of the areas with very steep – precipitous slopes are located on the border of Langkat Regency with the surrounding regencies, including Binjai, Deli Serdang, Medan, and Aceh Province (Figure 2). According to the field survey, the border areas between regencies are generally characterized by medium – very steep slopes where landslides are often found. One of the locations with very steep – precipitous slopes is located in the Gunung Leuser National Park area which
includes Batang Serangan and Sei Bingai Districts which are high mountainous areas. A study by [17] stated that moderate landslide vulnerability areas are characterized by moderately steep slopes, while areas with high landslide vulnerability are characterized by steep slopes (> 30%). The slope has an indirect effect on the instability of the soil surface.

Figure 2. Slope Map (Source: DEMNAS)

The soil types in Langkat Regency mostly are covered by Inceptisol and Entisol with coverage areas 49.87% and 36.32% of respectively (Table 3). The Inceptisol and the Entisol groups are oxides. Most of the land in Langkat Regency is classified as land that is vulnerable to landslides. This soil type is spread across the border of Langkat Regency with other regencies, including Karo, Seli Serdang, and Binjai (Figure 3). Lands that are vulnerable to landslides are generally in the medium – very steep slope classes.

| No. | Soil Type  | Score | Area (ha) | Area (%) |
|-----|------------|-------|-----------|----------|
| 1   | Histosol   | 1     | 84,829.82 | 13.80    |
| 2   | Entisol    | 2     | 223,192.18 | 36.32    |
| 3   | Inceptisol | 3     | 306,438.165 | 49.87    |
|     |            |       | 614,460.1707 | 100      |

Source: Analysis, 2021

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 [19].

![Figure 3. Soil Type Map (Source: Center for Soil and Agro-climate Research)](image)

The land use scores are related on the level of vegetation desnity and the level of roots. The rarer the vegetation and the weaker the roots, the higher the landslide levels. Areas that have good vegetated land cover have no evidence of landslide activity or no signs of ground collapse [20]. Land use in Langkat Regency is still dominated by dense forests and plantations (Table 4 and Figure 5).

| No. | Land use                                      | Score | Area (ha)  | Area (%) |
|-----|----------------------------------------------|-------|------------|----------|
| 1   | Dense forest                                 | 1     | 212,177.2  | 34.38    |
| 2   | Plantation (Trees)                           | 2     | 164,926.5  | 26.72    |
| 3   | Mixed Plantation and Perennial Crops         | 3     | 23,718.39  | 3.843    |
| 4   | Grass Land, Shrub, Agricultural Land (Paddy, Corn) | 4  | 161,061.4  | 26.10    |
| 5   | Without Vegetation                           | 5     | 55,187.98  | 8.94     |
|     | **Total Area**                               |       | **617,071.5** | **100** |

Source: Analysis, 2021

The condition of land use that have less or without vegetation such as grassland, shrubs, and agricultural land might be due to a large number of conversion activities of plantation and forest land into agricultural areas. Most of the area that has been converted becomes abandoned land. Forests that are cleared for agriculture with less vegetation cover can increase landslide vulnerability in Langkat.
Regency. Land use in the form of dense forest in Langkat Regency is partly located in the Gunung Leuser National Park area, including Bahorok, Besitang, and Batang Serangan Districts.

The rainy season in Langkat Regency lasts from September to February and the dry season lasts from March to August. The scoring of rainfall is based on the size of the average annual rainfall. The relatively high average rainfall may result in a higher level of landslide vulnerability. The rainfall in Langkat Regency ranges from 2937 – 3364 mm/year and has a score of 2 on the classified climate parameters as shown in Table 5 and Figure 5. Rainfall in Langkat is quite high, generally in the Bahorok and Sei Bingai areas.

Table 5. Score, area, and percentage of rainfall classes in Langkat Regency

| No. | Rainfall (mm/year) | Score | Area (ha)    | Area (%)  |
|-----|--------------------|-------|--------------|-----------|
| 1   | 2500-2800          | 4     | 120,719.51   | 19.68     |
| 2   | 2800-3100          | 5     | 187,299.22   | 30.53     |
| 3   | 3100-3400          | 6     | 88,961.09    | 14.50     |
| 4   | 3400-3700          | 7     | 167,056.15   | 27.23     |
| 5   | >3700              | 8     | 49,358.97    | 8.046     |
|     | **Total**          |       | **613,394.6981** | **100**   |

Source: Analysis, 2021
Climatological conditions in North Sumatera Province are influenced by wind and rainfall conditions. The air temperature in the North Sumatera region ranges from 18–32 °C. Areas that have high rainfall are Bahorok, Kutambaru, Salapiamn, and Sei Bingai. This area is a mountainous area that has a high altitude and it often rains in mountainous areas.

### 3.2. Distribution of Landslide Vulnerability Levels

Most of the Langkat Regency areas are still in a condition of very low - moderate level of landslide vulnerability. Areas with a high - very high level of landslide vulnerability occupy an area of 19.77% of the total area of Langkat Regency as represent in Table 6.

#### Table 6. Score Range and Area of Landslide Vulnerability

| No. | Notes    | Score Range | Area (ha) | P Area (%) |
|-----|----------|-------------|-----------|------------|
| 1   | Very Low | 0.005-0.05  | 154,574.34| 25.94      |
| 2   | Low      | 0.051-0.108 | 127,491.26| 21.39      |
| 3   | Moderate | 0.108-0.2   | 195,991.85| 32.89      |
| 4   | High     | 0.201-0.336 | 101,677.26| 17.06      |
| 5   | Very High| 0.38-0.73   | 16,097.67 | 2.71       |
|     | Total Area|            | 595,832.40| 100        |

Source: Analysis, 2021

The spatial distribution of landslides with high – very high levels is spread in the western and eastern parts of the Langkat Regency. This area has a steep – precipitous topography. Areas with a high – very high level of landslide vulnerability are found in all districts in Langkat Regency (Figure 5).
Figure 6. Landslide Vulnerability Levels Map in Langkat Regency (Analysis, 2021)

The three districts that have the largest area of a high – very high level of vulnerability are Bahorok, Sei Bingai, dan Salapian. These three districts mostly have steep – very steep slopes. Bahorok District is located in upstream of the Bukit Barisan Mountains area with a mostly steep slope area, while Kuala also has a steep - very steep area characteristic. In addition to the steep slope, land use in the area is also influential. Areas that have landslide vulnerability are generally in shrubland, grasslands, and agricultural areas.

A study by [21] stated that landslides occur mainly 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 landslides on a large scale.

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

| No. | District      | Landslide Vulnerability Level | Area (Ha) | Area (ha) |
|-----|---------------|-------------------------------|-----------|-----------|
| 1   | Bahorok       | High - Very High              | 27,743.51 | 24.68     |
| 2   | Batang Serangan | High - Very High             | 4,027.91  | 3.58      |
| 3   | Besitang      | High - Very High              | 989.74    | 0.88      |
| 4   | Kuala         | High - Very High              | 15,022.26 | 13.36     |
| 5   | Kutambaru     | High - Very High              | 14,917.84 | 13.27     |
| 6   | Salapian      | High - Very High              | 20,461.16 | 18.20     |
| 7   | Sei Bingai    | High - Very High              | 25,440.83 | 22.63     |
| 8   | Sarapit       | High - Very High              | 3,808.84  | 3.39      |

| Total|               |                               | 112,412.1 | 100.00    |

Source: Analysis, 2019
According to field surveys and interviews in March 2021, there was a landslide followed by a flash flood that damaged buildings and hundreds of hectares of agricultural land in three villages in Bahorok District, particularly in Timbang Lawan Village and Timbang Jaya Village. Timbang Lawan Village has an area with a high – very high level of landslide vulnerability with a quite large area. Land conversion is an activity that has the potential to increase the landslide vulnerability level. 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 landslide hazard potential is higher on land with very steep slopes.

The Sei Bingai has large area of high level of landslide vulnerability. There are several villages there that are vulnerable to landslides, generally located in less dense land cover with sparse vegetation. This makes the soil unable to withstand the surface which makes the area vulnerable to landslides [22].

The accuracy of the landslide vulnerability level is determined through the ground check results in the field were matched with the landslide vulnerability level map. The ground check was carried out by visiting landslide survey sites based on the level of landslide vulnerability. The distribution of field survey points is presented in Figure 7.

Figure 7. The distribution of field survey points

The results of the field survey obtained the accuracy test values that can be seen in Table 8. The overall accuracy test obtained was 88%. It can be seen in Table 8.
Table 8. The accuracy of the landslide vulnerability level with ground checkpoints in the field

| Category   | Very Low | Low | Moderate | HIgh | Very High | Total |
|------------|----------|-----|----------|------|-----------|-------|
| Very Low   | 13       | 3   | 3        |      |           | 16    |
| Low        | 12       | 7   | 5        | 3    | 12        | 15    |
| Moderate   |          | 2   | 7        | 5    | 3         | 17    |
| High       | 1        | 34  | 1        | 37   | 12        | 36    |
| Very High  |          | 12  |          |      | 12        | 24    |
| Grand Total| 14       | 13  | 16       | 8    | 45        | 96    |

Overall = 88%

The field survey was adjusted to the level of landslide vulnerability, which is for 5 classes, including very low, low, moderate, high, and very high classes which were adjusted to the location of the field. There were point locations that did not match the vulnerability category in the field. There were cases showing high landslide vulnerability conditions which should be very high. The field conditions found were a change in forest use into plantations and agricultural areas due to encroachment activities by the community. The community took forest products in the form of wood in the Batang Serangan and Bahorok Districts. Based on the field survey that had been carried out, the condition of the Bahorok area showed a hilly area that was part of the Gunung Leuser National Park area.

The high accuracy results in this study might be due to several possibilities, in which there were differences between the interpretation of the sample on the map with the actual conditions in the field. The difference occurred because the map used was the result of recording in 2019, while the study was conducted in 2021. It is possible that field conditions have changed. Even though interviews with the surrounding community have been carried out, but the information is not necessarily accurate because there is a different time span. According to [26] the accuracy test of the classification results was carried out to test the level of accuracy of the usage map generated from the digital classification process with test samples from the results of field activities. The aim was to check the accuracy between the sample used as a training area and the sample used for accuracy testing.

The roots of seasonal plants are generally fibrous and shallow, so they are not optimal in preventing erosion. Study by [23] and [24] stated that 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.

According to [25] mitigation to avoid landslides is an important step in reducing the impact of landslides which are not even completely free from hazards and risks as occurred in Nepal because many villages are located in or adjacent to previous landslides. Landslides are a common phenomenon of geomorphic evolution on mountain hillsides and thus, it is very crucial to living with the risks and evaluate various mitigation techniques with success and failure.

This study can help decision-makers to improve the existing information to predict the occurrence of landslides in the future. The spatial distribution of landslide vulnerability levels can be developed into an early warning system and long-term mitigation program [24]. Landslide disaster management can be successful only when detailed knowledge is obtained about land characteristics, land use changes, and regional spatial planning policies. A landslide vulnerability level map is required to be the basis for any landslide disaster mitigation strategy. According to [25] landslide vulnerability maps 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 function of protection and disaster prevention.
4. Conclusion
The spatial distribution of landslide vulnerability level is mostly at a moderate level with the percentage of the area reaching almost 32% of the area of Langkat Regency. Areas with high - very high levels of landslide vulnerability reached 19.77%. Areas that occupy a high - very high level of landslide vulnerability with the largest area are in three districts, including Bahorok, Seilepan, and Sei Bingai. The map accuracy rate has an overall accuracy value of 88% or high. The area of less vegetation coverage can increase the level of landslide vulnerability. Various parties need to carry out restoration and protection. This is very important to restore the key functions of the forest, including the function of protection and disaster prevention.

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