Model of Physics Landslide for Disaster Mitigation in Sitinjau Laut Area Padang City Sumatera Barat

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Abstract. Sitinjau Laut area of Padang city is very prone to landslides because it has a very steep terrain (70° to 85°), improper land use and high rainfall. In the context of investigating potential landslides in this region, landslide potential analysis was carried out in five locations with a rating method for seven variables; slope, soil and rock structure, effective soil depth, rock weathering level, land use, vegetation density and rainfall. The total value of each location is, the first location has a total value of 26 with a category of severe landslide potential, the second location has a total value of 26 with a category of severe landslide potential, the third location has a total value of 24 with a category of severe landslide potential, the fourth location has a total value of 21 with a category of moderate landslide potential, the fifth location has a total value of 22 with a category of moderate landslide potential. It is hoped that this research can provide input to the Regional Government in the context of landslide mitigation in the region. So that the risks posed by landslides can be minimized for the future.

Keywords: Landslides, disaster mitigation, physical, region

1. Introduction

1.1 Geological Structure of Sumatra

Basically, the condition of the land in Indonesia is prone to landslides, especially along the west coast of Sumatra and along the southern coast of Java. This is a direct influence of the location of the two islands which are in the subduction zone of two continental plates that extend from the Andaman sea, the west coast of Sumatra to the south of the island of Java to the south of the Nusa Tenggara islands.

Subduction is formed due to the collision of the Eurasian plate and the Indo-Australian plate where the Indo-Australian plate from the south and west moves more actively.

Off the west coast of Sumatra these two plates which push each other up cause the ocean floor to rise to the surface of the sea that forms a group of non-volcanic islands that extend north to south: Simeulue Island, Nias Island, Siberut Island to Enggano Island and other small islands. In addition, the subduction of the Indo-Australian plate causes the magma under the stomach of the island of Sumatra to be trapped and presses the surface layer above it to form mountains and active volcanoes along the arat side of the island of Sumatra. This mountain range is known as the Bukit Barisan mountain range with its highest peak is Kerinci Mountain with an altitude of 3805 m above sea level.

The Bukit Barisan mountain range tends to narrow to the west side resulting in the formation of steep shorelines along the west coast of Sumatra, from Aceh to Bandar Lampung. Whereas on the east
coast a more gentle slope is found. The mountainous area and steep coastline along the west side are prone to landslides and land movements.

Figure 1. Tectonic conditions of the Indonesian archipelago

1.2 Padang Prone to Disasters Landslides

Padang City is one of the cities located on the west coast of Sumatra. The mainland topography of this city has a height of 0 m above sea level up to 1853 m above sea level. The highly varied topography and tectonic plate subduction zone makes the city of Padang vulnerable to landslides and ground movements. Based on data released by the National Disaster Management Agency (BNPB) in 2019 there have been 8 landslides in the city of Padang in the range of 2008 to 2018.

This research is focused on the area of the Sitinjau Laut, Lubuk Kilangan sub-district of the city of Padang because of the vast land area of the city of Padang with so many landslides. The Sitinjau Laut Area is then divided into five research locations with the coordinates of each location being as follows;

| Location | Coordinate                  |
|----------|-----------------------------|
| 1        | 0°56'57"S 100°30'10"E       |
| 2        | 0°56'56"S 100°30'12"E       |
| 3        | 0°56'56"S 100°30'17"E       |
| 4        | 0°57'08"S 100°30'20"E       |
| 5        | 0°57'06"S 100°30'26"E       |

In this research, a landslide potential test was conducted at each location and explained the occurrence of physical landslides so that it can be used as a reference in the process of education and disaster mitigation for the community as well as input for the Regional Government related to landslides in this region in particular and other regions in Indonesia in general.

2. Research Method

The research methodology used is a survey that includes observations, recording, and measurements in the field, as well as analysis of variables from each research sample area. The unit of analysis used is to scale each observed variable with a value of 1 to 5. The total value for each research sample area will be converted into the form of values referred to in table 9. Assuming the higher the total value of a sample area, the higher also the potential for landslides in the area.
2.1. Data Analysis
The analysis used in this research is descriptive qualitative with observation and survey data collection techniques conducted in the field. The value of each variable is as follows;

2.1.1. Slope
Slope slope refers to the classification made by M. Isa Darmawijaya (1990) in Rudiyanto (2010) as in table 2 below;

| Category  | Criteria     | Slope | Percentage slope (%) | Level |
|-----------|--------------|-------|----------------------|-------|
| Very good | flat         | 0 – 3 |                      | 1     |
| Good      | sloping      | 4 – 8 |                      | 2     |
| Moderate  | tilted       | 9 – 15|                      | 3     |
| Ugly      | rather steep | 16 – 30|                    | 4     |
| Very ugly | Steep       | > 30  |                      | 5     |

2.1.2. Soil Texture
In this research the classification of soil particle textures uses a system of verification according to the International Soil Science Society (ISSS). Classification of soil texture according to ISSS is as follows;

| Diameter (mm) | Fraction | Category      | Level |
|---------------|----------|---------------|-------|
| <0.002        | Clay     | Very good     | 1     |
| 0.002-0.02    | Dust     | Good          | 2     |
| 0.02-0.2      | Smooth sands | Moderate | 3     |
| 0.2-2         | Rough sands | Ugly         | 4     |
| >2            | Gravel   | Very ugly     | 5     |

2.1.3. Effective Soil Depth
Measurements are made from the ground surface on the cliff to the waterproof layer below the surface of the land. The level of effective soil depth can be seen in table 4 below;

| Category  | Soil depth | Level |
|-----------|------------|-------|
| Very shallow | < 50 cm   | 1     |
| Shallow   | 50 – 60 cm | 2     |
| Medim     | 60 – 90 cm | 3     |
| Deep      | 90 – 120 cm | 4     |
| Very deep | > 120 cm   | 5     |

2.1.4. Vegetation Density
Scaling up of vegetation density can be seen in table 5 below;

| Vegetation density (%) | Category | Level |
|------------------------|----------|-------|

> 75 Verythick 1
50 – 75 Thick 2
25 – 50 Moderate 3
10 – 25 Less 4
< 10 Openfield 5

2.1.5. Rock Weathering Rate
Rock weathering properties can be seen in table 6 below.

| Category               | Rock weathering                                                                 | Level |
|-----------------------|-------------------------------------------------------------------------------|-------|
| Fresh                 | There was no visible sign of weathering                                       | 1     |
| Weathered lightly     | Weathering only occurs in open discontinuities that cause discoloration, can   | 2     |
|                       | reach 1 cm from the surface of the discontinuity.                             |       |
| Moderately weathered  | Most color soil rocks have not been weathered (except sedimentary rocks),     | 3     |
|                       | discontinuity stained throughout weathering.                                 |       |
| Weathered heavy       | Weathering extends throughout the mass, rock material changes, easy to dig    | 4     |
|                       | with a geological hammer                                                     |       |
| Weathered perfectly   | All rocks change color and are weathered broad in appearance like soil.        | 5     |

2.1.6. Land Use
The use status can be seen in Table 7 below;

| No | Land use    | Level |
|----|-------------|-------|
| 1  | Forest      | 1     |
| 2  | Thicket     | 2     |
| 3  | Plantation  | 3     |
| 4  | Rice fields | 4     |
| 5  | Settlement  | 5     |

2.1.7. Rainfall
Rainfall values can be seen in table 8 below;

| Category  | Rainfall (mm) | Level |
|-----------|---------------|-------|
| Small     | < 2500        | 1     |
| Moderate  | 2500 – 3500   | 2     |
| Rather big| 3500 – 4500   | 3     |
| Big       | 4500 – 5500   | 4     |
| Very big  | > 5500        | 5     |
2.2. Landslide Potential Classification
Calculation of interval class for landslide potential in each research sample area is used the equation below;

\[ Ki = \frac{X_t - X_r}{K} \]  

(1)

\( Ki \) is the landslide class interval, \( X_t \) is the highest number of digits (5x7 = 35), \( X_r \) is the lowest number of digits (1x7 = 7), \( K \) is the number of landslide hazard classes. So the class interval \( (Ki) \) can be determined with;

\[ Ki = \frac{35 - 7}{5} = 5.6 \]  

(2)

After obtaining an interval class value of 5.6, the classification of landslide hazard levels can be grouped according to table 9 below.

**Table 9. Classification of Potential Levels of Landslides**

| No | Class | Class Interval | Landslide Hazard Level |
|----|-------|----------------|------------------------|
| 1  | I     | 7 – 12.6       | Very light             |
| 2  | II    | 12.7 – 18.2    | Light                  |
| 3  | III   | 18.3 – 23.8    | Moderate               |
| 4  | IV    | 23.9 – 29.4    | Severe                 |
| 5  | V     | 29.5 – 35      | Very severe            |

3. Results and Discussion
3.1. Result of Research
3.1.1. Slope
The slope level of each research location can be seen in table 10 below;

**Table 10. Value of slope**

| Research sites | Slope | Category | Level |
|----------------|-------|----------|-------|
|                | (°)   | (%)      | Criteria |       |
| 1              | 75    | 373.20   | Steep    | Very ugly | 5 |
| 2              | 70    | 274.74   | Steep    | Very ugly | 5 |
| 3              | 73    | 327.08   | Steep    | Very ugly | 5 |
| 4              | 80    | 567.12   | Steep    | Very ugly | 5 |
| 5              | 80    | 567.12   | Steep    | Very ugly | 5 |

3.1.2. Soil Texture
The soil texture level of each research location can be seen in table 11 below;

**Table 11. Value of soil texture**

| Research site | Type of soil | Category | Level |
|---------------|--------------|----------|-------|
| 1             | Rough sands  | Ugly     | 4     |
| 2             | Rough sands  | Ugly     | 4     |
| 3             | Rough sands  | Ugly     | 4     |
| 4             | Smooth sand  | Moderate | 3     |
| 5             | Clay         | Very good| 1     |
3.1.3. Effective Soil Depth

The level of effective soil depth from each research location can be seen in table 12 below:

**Table 12. Soil depth level**

| Research site | Soil depth (cm) | Category  | level |
|---------------|-----------------|-----------|-------|
| 1             | 250             | Very deep | 5     |
| 2             | 300             | Very deep | 5     |
| 3             | 100             | Deep      | 4     |
| 4             | 100             | Deep      | 4     |
| 5             | 50              | Shallow   | 2     |

3.1.4. Weathering Rate of Rock Slope

Weathering properties of the slope-forming rocks from each research location can be seen in table 13 below.

**Table 13. Level of weathering rocks making up the slope**

| Research site | Weathering rocks | Category | Level |
|---------------|------------------|----------|-------|
| 1             | Most color soil rocks have not been weathered (except sedimentary rocks), discontinuity stained throughout weathering. | Moderately weathered | 3     |
| 2             | Weathering extends throughout the mass, rock material changes, easy to dig with a geological hammer. | Weathered Heavy | 4     |
| 3             | Weathering only occurs in open discontinuities that cause discoloration, can reach 1 cm from the surface of the discontinuity. | Mild weathered | 2     |
| 4             | Most color soil rocks have not been weathered (except sedimentary rocks), discontinuity stained throughout weathering. | Moderately weathered | 3     |
| 5             | All rocks change color and are weathered broad in appearance like soil. | Weathered perfectly | 5     |

3.1.5. Land use

The land use level of each research location can be seen in table 14 below:

**Table 14. Land use level**

| Research site | Land use | Level |
|---------------|----------|-------|
| 1             | Thicket  | 2     |
| 2             | Thicket  | 2     |
| 3             | Thicket  | 2     |
| 4             | Thicket  | 2     |
| 5             | Thicket  | 2     |
3.1.6. Vegetation Density
The level of vegetation density from each research location can be seen in table 15 below:

| Research site | Vegetation Density (%) | Category | Level |
|---------------|------------------------|----------|-------|
| 1             | 20                     | Rare     | 4     |
| 2             | 70                     | Tight    | 3     |
| 3             | 20                     | Rare     | 4     |
| 4             | 60                     | Moderate | 2     |
| 5             | 23                     | Rare     | 4     |

3.1.7. Weather, Climate and Rainfall
Data of monthly average rainfall in the Padang City's SitinjauLaut area in the range of 2010 to 2016 can be seen in table 16 below:

| Moon     | Amount of Rainfall (mm) | Average |
|----------|-------------------------|---------|
|          | 2010   | 2011   | 2012   | 2013   | 2014   | 2015   | 2016   |        |
| January  | 264    | 156    | 216    | 262    | 291    | 160    | 264    | 230.42  |
| February | 426    | 240    | 420    | 442    | 200    | 216    | 338    | 300.28  |
| March    | 815    | 219    | 585    | 81     | 233    | 293    | 750    | 425.14  |
| April    | 233    | 327    | 247    | 456    | 487    | 385    | 481    | 373.71  |
| May      | 280    | 73     | 214    | 233    | 398    | 98     | 447    | 249     |
| June     | 346    | 420    | 244    | 257    | 224    | 457    | 627    | 367.85  |
| July     | 372    | 199    | 194    | 184    | 169    | 112    | 144    | 196.28  |
| Augustus | 308    | 113    | 211    | 469    | 326    | 422    | 366    | 316.42  |
| September| 539    | 266    | 235    | 379    | 324    | 353    | 374    | 352.85  |
| October  | 602    | 238    | 322    | 366    | 464    | 140    | 509    | 377.28  |
| November | 580    | 895    | 575    | 426    | 653    | 517    | 296    | 563.14  |
| December | 205    | 329    | 568    | 615    | 217    | 395    | 458    | 398.14  |
| total    | 4970   | 3475   | 4035   | 4170   | 4318   | 3844   | 5054   | 4266.57 |

Based on table 16 above, it can be concluded that the SitinjauLaut area is an area with high rainfall throughout the year. Thus the value of the average annual rainfall at each research location is seen in table 17 below.

| Research site | Average annual rainfall | Category | Level |
|---------------|-------------------------|----------|-------|
| 1             | 4.266,57 mm             | Rather big | 3     |
| 2             | 4.266,57 mm             | Rather big | 3     |
| 3             | 4.266,57 mm             | Rather big | 3     |
| 4             | 4.266,57 mm             | Rather big | 3     |
| 5             | 4.266,57 mm             | Rather big | 3     |
3.2. Discussion

3.2.1. First location

**Table 18.** Variable level at first location

| Indicator                      | Level | Category           |
|--------------------------------|-------|--------------------|
| Slope                          | 5     | Steep              |
| Soil texture                   | 4     | Rough sands        |
| Effective soil depth           | 5     | Very deep          |
| Rock weathering level          | 3     | Moderately weathered |
| Land use                       | 2     | Tensile / thicket  |
| Vegetation density             | 4     | Rarely             |
| Rainfall                       | 3     | Rather big         |
| **Total**                      | 26    | **Heavy**          |

At the first location the variable with the largest value is the slope and the effective depth of the land with a score of 5. While the variable with the lowest score is the land use variable with a score of 2. The total score at the first location is 26. So it can be concluded that the potential for landslides at the first location categorized as heavy.

3.2.2. Second location

**Table 19.** Variable level at second location

| Indicator                      | Level | Category              |
|--------------------------------|-------|-----------------------|
| Slope                          | 5     | Steep                 |
| Soil texture                   | 4     | Rough sands           |
| Effective soil depth           | 5     | Very deep             |
| Rock weathering level          | 4     | Weathered heavy       |
| Land use                       | 2     | Tensile / thicket     |
| Vegetation density             | 3     | Rarely                |
| Rainfall                       | 3     | Rather big            |
| **Total**                      | 26    | **Heavy**             |

At the second location the variable with the highest score is the slope and effective depth of land variable with a score of 5. While the variable with the lowest score is the land use variable with a score of 2. The total score at the second location is 26. So it can be concluded that the potential for landslides in the second category is categorized as heavy.

3.2.3. Third location

**Table 20.** Variable level at the third location

| Indicator                      | Level | Category            |
|--------------------------------|-------|---------------------|
| Slope                          | 5     | Steep               |
| Soil texture                   | 4     | Rough sands         |
| Effective soil depth           | 4     | Deep                |
| Rock weathering level          | 2     | Mild weathered      |
| Land use                       | 2     | Tensile / thicket   |
| Vegetation density             | 4     | Rarely              |
| Rainfall                       | 3     | Rather big          |
| **Total**                      | 24    | **Heavy**           |
At the third location the variable with the largest score is the slope variable with a score of 5. While the variable with the lowest score is the variable rock weathering and land use with a score of 2. The total score at the third location amounts to 24. So it can be concluded that the potential for landslides in the third category is categorized as heavy.

3.2.4. Fourth location

Table 21. Variable level at the fourth location

| Indikator               | Level | Category               |
|-------------------------|-------|------------------------|
| Slope                   | 5     | Steep                  |
| Soil texture            | 3     | Fine sand              |
| Effective soil depth    | 4     | Deep                   |
| Rock weathering level   | 3     | Moderately weathered   |
| Land use                | 2     | Tensile / thicket      |
| Vegetation density      | 2     | Heavy / tight          |
| Rainfall                | 3     | Rather big             |
| **Total**               | **21**| **Moderate**           |

At the fourth location the variable with the highest score is the slope variable with a score of 5. While the variable with the lowest score is the land use variable and vegetation density with a score of 2. The total score at the fourth location is 21. So it can be concluded that the potential landslides at the fourth location in the moderate category.

3.2.5. Fifth location

Table 22. Variable level at the fifth location

| Indikator               | Harkat | Kategori               |
|-------------------------|--------|------------------------|
| Slope                   | 5      | Steep                  |
| Soil texture            | 1      | Clay                   |
| Effective soil depth    | 2      | Shallow                |
| Rock weathering level   | 5      | Weathered perfectly    |
| Land use                | 2      | Tensile / thicket      |
| Vegetation density      | 4      | Rarely                 |
| Rainfall                | 3      | Rather big             |
| **Total**               | **22**| **Moderate**           |

At the fifth location the variable with the largest score is the slope variable and rock weathering level with a score of 5. While the variable with the lowest score is the land use variable with a score of 2. The total score at the fifth location amounts to 22. So it can be concluded that the potential for landslides in the fifth category is in the moderate category.

3.3. Analysis of the level of landslide hazard in the Sitinjau laut area

After summing the dignity of each variable for each research location, the classification of landslide potential for each research location can be determined. Where three locations, locations 1, 2 and 3, were identified as having landslide potential in the weight category, while the other two locations, locations 4 and 5, were identified as having moderate landslide potential.

3.4. Physical aspects of landslides

The surface of the soil / rock which is in two different places of height, then physically there will be forces that work to push so that the higher ground tends to move downward. In addition to the forces that push down, there are also forces that work against these forces. The driving force is produced from the weight of the soil material and other forces while the holding forces are the frictional force,
the cohesion force between soil particles, tree roots, buildings and others. The relationship between the driving force and the holding force is that if the driving force is stronger than the holding force there will be an avalanche and vice versa.

The basic forces acting on a natural slope can be schematically modeled as shown in Figure 2. For free body equilibrium, the amount of force in the normal direction of the sliding surface is equal to zero, so that:

\[ N - W \cdot \cos \alpha = 0 \rightarrow N = W \cdot \cos \alpha \]  \hspace{1cm} (3)

With \( N \) = normal force and \( W \) = gravity or the weight of the landslide mass above the slip plane. For the amount of force in the direction parallel to the slip plane is equal to zero, then,

\[ T - W \cdot \cos \alpha = 0 \rightarrow T = W \cdot \cos \alpha \]  \hspace{1cm} (4)

Where \( T \) is the thrust. If there is pore pressure on the slope, then;

\[ u = \gamma_w z_w \text{ (kN/m}^2) \]  \hspace{1cm} (5)

Where \( \gamma_w \) is the specific gravity of water, and \( z_w \) is the average depth of the slip surface under groundwater (m). Thus the effective normal stress (\( \sigma_f \), kN/m\(^2\)) in the crack / collapse plane is written as,

\[ \sigma_f = \sigma - u = \frac{N/b}{L} - u = \frac{(W/b) \cdot \cos \alpha}{l} - u \]  \hspace{1cm} (6)

With \( \sigma = (N/b) = (W/b) \cos \alpha \) is normal stress (kN/m\(^2\)), \( L \) = length of the slip plane (m) and \( \alpha = \) slope angle of the slip plane with the horizontal plane, \( W/b \) = weight of the landslide mass per skid width (kN / m).

Figure 2. Landslide model and sketch component style

Slope stability is strongly influenced by the shear strength of the soil to determine the ability of the soil to withstand stress without collapse. The shear strength of the soil can be written as follows:

\[ \tau_K = c - \sigma_f \tan \phi' = c - \left[ \frac{(W+V)}{b} \cdot \cos \alpha \right] \frac{L}{L} - u \tan \phi' \]  \hspace{1cm} (7)

With \( \tau_K \) = shear strength along the slip plane (kN/m\(^2\)), \( c = \) cohesion (kN/m\(^2\)), \( V = \) external weight above the slip plane (kN), \( V/b = \) external load per slip plane width (kN/m) and \( \phi' = \) inner shear angle (º). Equation 7 above is referred to as the Mohr-Coulomb collapse criterion. This collapse in the Mohr diagram is illustrated in Figure 3, where shear stress (\( \tau_T \)) can be described as a normal stress function (\( \sigma \)) with angles \( \theta \) varying.
Furthermore, if the shear stress is balanced along the slip plane \( L \), then it can be stated as:

\[
\tau_T = \frac{T/b}{L} = \frac{\left[ \frac{W+V}{b} \right] \sin \alpha}{L}
\]

(8)

So that the combination of equations (5) and (6), the slope safety factor \( (F_s) \) can be obtained as follows:

\[
F_s = \frac{\tau_k}{\tau_T} = \frac{c', L + \left[ \left( \frac{W+V}{b} \right) \cos \alpha - u \cdot L \right] \tan \theta'}{\left( \frac{W+V}{b} \right) \sin \alpha}
\]

(9)

Based on previous studies and comprehensive studies on slope collapse, then divided into 3 groups of ranges of safety factors \( F_s \) in terms of the intensity of the landslide, as shown in table 23 below:

| Safety factor value, \( (F_s) \) | Occurrence (landslide intensity) |
|----------------------------------|---------------------------------|
| \( F_s \leq 1,07 \)              | Landslides occur commonly / frequently (unstable slopes) |
| \( 1,07 < F_s \leq 1,25 \)      | Landslides have occurred (critical slope) |
| \( F_s > 1,25 \)                | Landslides are rare (slopes are relatively stable) |

4. Conclusion

This research has been able to identify the level of landslide vulnerability to five locations in the Sitinjau Laut area. The identification results are, the first location has a total value of 26 with a category of potential heavy landslides, the second location has a total value of 26 with a category of potential heavy landslides, the third location has a total value of 24 with a category of severe landslide potential, the fourth location has a total level of 21 with a category of medium landslide potential and the fifth location has a total level of 22 with a category of medium landslide potential. Prevention and mitigation of landslides in the region can use laws, concepts and physical principles so that the damage caused by landslides can be minimized. This effort certainly requires strong cooperation and coordination between related institutions and institutions so that this disaster prevention and mitigation effort can be carried out effectively and in a coordinated manner.
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