Vulnerability analysis of landslide at Sibolangit using Geographic Information System (GIS) based on population density and slope gradient

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Abstract. Sibolangit is one of districts in Deli Serdang that has wavy and hilly relief and has high gradient of slope. This condition causes Sibolangit is vulnerable towards natural landslide. One of the causes of landslide is population density and slope gradient/ Based on BPS data in 2018, the population growth/year from 2016 to 2016 is 2.42% and in 2015 to 2016 is 2.37%. It shows that the growth in Sibolangit increases where the population density affects the changes of land use. People living on a land with high gradient is most likely to be one of the causes of slide. This research is to determine the vulnerability level in Sibolangit based on population density and gradient. The analysis is done using Geographic System Information. Parameter used is gradient, population density, working factor, number of children, number of the elderly, and number of women to map the vulnerability. Risk Map with citizenship as parameter has three classes such as low, high and very high.

1. Introduction
Landslide is one of the natural disaster that happens in Indonesia and generally often occurs in a mountainous area and in rainy season. Total incidents of the highest landslide in Indonesia is in an area with steep topography and has rainfall of 2000mm/year [1]. Area Sibolangit is a highland with height of 400-700 msl with 30 villages. Highlands in Sibolangit has rough topography with hilly relief with gradient in between 600-900 [2]. Based on the slope gradient mapping obtained from SRTM data (Shuttle Radar Topography Mission), it shows that 5 villages has score of 6 with slope gradient <8% s/d 30%, 6 villages has score of 10 with slope gradient 15-40%, 17 villages has score of 15 with gradient of <8% s/d >45%. This means that 57% of villages in Sibolangit and contour of >45%. Sibolangit consist of few vulnerable area that occurs soil movement. Based on Prediction Potential Soil Movement to occur in March in Province of North Sumatera (Geology), Sibolangit is a natural disaster area including potential zone soil movement with medium – high. It means that area has medium to high potential for soil movement to occur. [3]

One of the causes of slide to occur is the population density and gradient of the land. The activity of citizens for using the land and natura resources around the locals can be the cause of the unstable slope. The impact of the slide can be death and materials, damages of facilities that affect the economical growth in the area. To reduce this, a mitigation has been suggested. One of the mitigations is by mapping
the area which is vulnerable to the slide, where this mapping is a means to prepare and do any efforts to prevent the slide. [1]

Application of GIS technology can help the mitigation for natural disaster by identifying the location and analyze the issue that is related to the impact of the landslide. Mitigation to reduce the impact of landslide is by making a model for GIS, such as by analyzing few maps as a variable to determine the area that is vulnerable towards danger and risk of landslide. Moreover, satellite can be useful indirectly in determining the landslide potential, describing the surface of an area, and geological structure.[2][3]

![Figure 1. Administration map of Sibolangit District.](image)

Numbers of population living in an area with contour of more than 45% can also be the cause of the vulnerability in that particular area towards landslide. One of the samples is Bandar Baru Village has 347.95 people/km2 with a gradient of >45%. Table 1 shows the gradient with population of each village in Sibolangit. The higher the gradient of the slope, the faster the surface flow will be so erosion occurs.

![Table 1. Classification of slope gradient and population density in Sibolangit.](table)

| Village       | Slope Gradient (%) | Density (people/km²) | Village       | Slope Gradient (%) | Density (people/km²) |
|---------------|-------------------|----------------------|---------------|-------------------|----------------------|
| Bandar Baru   | <8 s/d >45        | 347.92               | Tambunen      | <8 s/d 45        | 99.02                |
| Sikeben       | <8 s/d >45        | 95.29                | Puang Aja     | <8 s/d >45       | 103.66               |
| Martelu       | <8 s/d >45        | 85.78                | Betimus Mbaru | <8 s/d >45       | 102.39               |
| Bukum         | <8 s/d >45        | 66.93                | Rumah Sumbul  | <8 s/d 30        | 132.80               |
| Negeri Gugung | <8 s/d >45        | 46.62                | Rumah         | <8 s/d >45       | 116.27               |
| Cinta Rakyat  | <8 s/d >45        | 91.00                | Sala Bulan    | <8 s/d 45        | 62.00                |
| Ketangkuhen   | <8 s/d >45        | 88.73                | Bengkuring    | <8 s/d 45        | 44.03                |
2. Research methodology

Research methodology done by using scoring and overlay. Secondary data obtained by scoring system where scoring done to give weight to each parameter. Then it is continued by doing overlay to determine the vulnerability level of landslide in Sibolangit. Parameter analyzed covers the slope gradient, population density, population jobs, numbers of women, numbers of kids, and numbers of elderly. Population density in an area and its slope gradient will be mapped then the area with most vulnerable level of slide will show. Based on BNPB (Disaster Management Agency) Regulation (2012), population density is weighted of 60% for vulnerability factor, gender, poverty, disability and age ratio is weighted of 10%. Arsjad (2012), considers that population density is the most potential factor to give a significant impact. Location that is densely populated tends to have more property. The following table 2 shows the score of population density.

| Location         | Population Density | Slope Gradient |
|------------------|--------------------|----------------|
| Suka Maju        | <8 s/d >45         | 136.52         |
| Buluh Awar       | <8 s/d >45         | 153.60         |
| Batu Layang      | <8 s/d >45         | 90.00          |
| Rumah PilPil     | <8 s/d >45         | 231.27         |
| Suka Makmur      | <8 s/d >45         | 423.81         |
| Durin Serugun    | <8 s/d >45         | 59.26          |
| Ujug Deleng      | <8 s/d 45          | 21.51          |
| Tanjung Beringin | <8 s/d 45          | 47.20          |

Figure 2. Map of slope gradient in Sibolangit.
**Table 2.** Scoring of vulnerability parameter (Regulation of BNPB 2012).

| Parameter               | Weight | Low (1)  | Medium (2) | High (3)          |
|-------------------------|--------|----------|------------|-------------------|
| Population Density     | 4      | < 500 people/km² | 500 – 1000 people/km² | > 1000 people/km² |
| Job                     | 2      | PNS/TNI/POLRI | Businessman/Farmer/Staff | Labor/porters/etc |
| Numbers of children    | 2      | < 33 %     | 33% - 66%  | > 66%             |
| Numbers of Elderly     | 1      | < 33 %     | 33% - 66%  | > 66%             |
| Numbers of Women       | 1      | < 33 %     | 33% - 66%  | > 66%             |

3. **Result**

3.1. **Mapping for vulnerability of landslide**

Numbers of population living in an area with slope above 45% affects the vulnerability level of landslide. Numbers of population is affecting the land use that can change the function caused by the economical and infrastructure needs of an area.

3.1.1. **Factor of population density.**

Based on BPS data Deli Serdang, population density in Sibolangit is in between 21.5 – 582.5 people/km². For clearer explanation, it is shown in Table 3 and Figure 3.

**Table 3.** Scoring of population density in each village of Sibolangit District.

| Village           | Density (people/km²) | Score | Village        | Density (people/km²) | Score |
|-------------------|----------------------|-------|----------------|----------------------|-------|
| Bandar Baru       | 347.92               | 1     | Tambunen       | 99.02                | 1     |
| Sikeben           | 95.29                | 1     | Puang Aja      | 103.66               | 1     |
| Martelu           | 85.78                | 1     | Betimus Mbaru  | 102.39               | 1     |
| Bukum             | 66.93                | 1     | Rumah Sumbul   | 132.80               | 1     |
| Negeri Gugung     | 46.62                | 1     | Rumah Sumbul   | 132.80               | 1     |
| Cinta Rakyat      | 91.00                | 1     | Sala Bulan     | 62.00                | 1     |
| Ketangkuhen       | 88.73                | 1     | Bengkuru       | 44.03                | 1     |
| Suka Maju         | 136.52               | 1     | Kuala          | 49.33                | 1     |
| Buluh Awar        | 153.60               | 1     | Batu Mbelin    | 252.33               | 1     |
| Batu Layang       | 90.00                | 1     | Sibolangit     | 219.29               | 1     |
| Rumah Pili Pil     | 231.27               | 1     | Sembah         | 582.50               | 2     |
| Suka Makmur       | 423.81               | 1     | Buah Nabar     | 75.45                | 1     |
| Durin Serugun     | 59.26                | 1     | Bingkawan      | 212.89               | 1     |
| Ujug Deleng       | 21.51                | 1     | Sayum Sabah    | 93.03                | 1     |
| Tanjung Beringin  | 47.20                | 1     | Rambung Baru   | 248.84               | 1     |
3.1.2. Jobs of population. Based on BPS data Deli Serdang, jobs of the citizens in Sibolangit District is dominated by businessman and farming sector, followed by PNS/TNI/POLRI and labor/etc. For clearer explanation, it is shown in Table 4 and Figure 4.

Table 4. Scoring of population job in each village of Sibolangit District.

| Village          | Score | Village          | Score |
|------------------|-------|------------------|-------|
| Bandar Baru      | 6     | Tambunen         | 3     |
| Sikeben          | 6     | Puang Aja        | 3     |
| Martelu          | 6     | Betimus Mbaru    | 6     |
| Bukum            | 6     | Rumah Sumbul     | 6     |
| Negeri Gugung    | 3     | Rumah Kinangkung | 3     |
| Cinta Rakyat     | 3     | Sala Bulan       | 3     |
| Ketangkuhen      | 6     | Bengkuring       | 6     |
| Suka Maju        | 6     | Kuala            | 6     |
| Buluh Awar       | 6     | BatuMbelin       | 6     |
| Batu Layang      | 6     | Sibolangit       | 6     |
| Rumah PilPil     | 6     | Sembah'e         | 6     |
| Suka Makmur      | 3     | Buah Nabar       | 6     |
| Durin Serugun    | 6     | Bingkawan        | 6     |
| Ujug Deleng      | 1     | Sayum Sabah      | 6     |
| Tanjung Beringin | 3     | Rambung Baru     | 6     |
3.1.3. Numbers of elderly, women and children.

Based on BPS data Deli Serdang, numbers of elderly, women and children in Sibolangit District is in between 1.74 – 10.56%/village. Scoring can be seen in Table 5 and Figure 5, Figure 6, and Figure 7.

Table 5. Scoring of numbers of elderly, children and women.

| Village       | %elderly | %Women | %Children | Scoring | Village       | %Numbers of elderly (%) | %women | %Children | Scoring |
|---------------|----------|--------|-----------|---------|---------------|-------------------------|--------|-----------|---------|
| Bandar Baru   | 3.44     | 47.89  | 29.05     | 1       | Tambunen      | 27.13                   | 47.92  | 27.13     | 1       |
| Sikeben       | 6.44     | 51.23  | 26.54     | 1       | Puang Aja     | 27.17                   | 50.52  | 27.17     | 1       |
| Martelu       | 7.16     | 49.74  | 27.72     | 1       | Betimus Mbaru | 33.34                   | 51.60  | 33.34     | 1       |
| Bukum         | 8.39     | 50.75  | 27.01     | 1       | Rumah Sumbul  | 24.69                   | 53.01  | 24.69     | 1       |
| Negeri Gugung | 5.08     | 50.33  | 29.14     | 1       | Rumah         | 25.68                   | 51.61  | 25.68     | 1       |
| Cinta Rakyat  | 7.14     | 52.01  | 26.74     | 1       | Sala Bulan    | 31.96                   | 52.19  | 31.96     | 1       |
| Ketanakahan   | 9.51     | 61.69  | 28.44     | 1       | Bengkurung    | 26.81                   | 49.53  | 26.81     | 1       |
| Suka Maju     | 9.77     | 51.08  | 26.24     | 1       | Kuala         | 30.00                   | 49.55  | 30.00     | 1       |
| Buluh Awar    | 8.00     | 51.82  | 27.34     | 1       | BatuMbelin   | 29.72                   | 50.19  | 29.72     | 1       |
| Batu Layang   | 4.19     | 50.59  | 29.91     | 1       | Sibolangit    | 24.89                   | 51.39  | 24.89     | 1       |
| Rumah PilPil  | 5.30     | 51.72  | 28.46     | 1       | Sembaha       | 26.92                   | 51.01  | 26.92     | 1       |
| Suka Makmur   | 5.24     | 49.97  | 29.53     | 1       | Buah Nabar    | 27.95                   | 48.92  | 27.95     | 1       |
| Durin Serugun | 3.48     | 47.16  | 29.26     | 1       | Bingkawan     | 29.02                   | 52.50  | 29.02     | 1       |
| Ujug Deleng   | 5.26     | 50.52  | 35.05     | 1       | Sayum Sabah   | 28.43                   | 51.18  | 28.43     | 1       |
| Tanjung       | 1.74     | 46.19  | 25.42     | 1       | Rambung Baru  | 30.79                   | 51.27  | 30.79     | 1       |
Figure 5. Maps of elderly population in Sibolangit District.

Figure 6. Maps of women population in Sibolangit District.
Based on Table 3, it is shown that the village with biggest population density is in Sembah with population of 1631 people and area of 5.5 km$^2$. Therefore the population density is 582.5 people/km$^2$. Village with least population density is in Ujug Deleng with population of 194 people and area of 9.02 km$^2$ with density of 21.5 people/km$^2$. Scoring based on regulation of BNPB states that 29 villages in Sibolangit district has less density than 500 people/km$^2$, so it is scored by 1 (one). One other village such as Sembah has density in between 500 – 1000 people/km$^2$, so that is scored by 2 (two) as stated in scoring regulation for population density.

3.1.4. Vulnerability analysis.

Prediction of landslide vulnerability is taken place by using the estimated model from the research by BNPB (2004). Based on that model, parameter used covers the population density, population jobs, numbers of elderly, women and children. All parameters are classified based on scoring then weighted based on each contribution and then overlay is taken place. Parameter of rainfall gets 30%, rock types 20%, soil type 10%, gradient 0.2%, land use 0.2% with following formula:

Cumulative score = (0.4x factor of population density) + (0.2x factor of population jobs) + (0.2x factor of numbers of women) + (0.1x Factor of elderly) + (0.1x Factor of children)

Based on the total score analysis, classification is obtained from four classes of vulnerability with score interval obtained from this following equation:

\[
\text{Interval} = \frac{(\text{Highest Score} - \text{Lowest Score})}{(\text{Total Class Interval})}
\]

\[
\text{Interval} = \frac{(2.5 - 1.3)}{4} = 0.3
\]

Based on analysis, cumulative score and class interval, vulnerability level of landslide in Sibolangit District can be seen in Table 6 and Figure 8.
Table 6. Cumulative scoring and vulnerability level of landslide in Sibolangit District.

| Village          | Cumulative Score | Vulnerability Level | Village          | Cumulative Score | Vulnerability Level |
|------------------|------------------|---------------------|------------------|------------------|---------------------|
| Bandar Baru      | 2.1              | High                | Tambunen         | 1.5              | Low                 |
| Sikeben          | 2.1              | High                | Puang Aja        | 1.5              | Low                 |
| Martelu          | 2.1              | High                | Betimus Mbaru    | 2.3              | Very high           |
| Bukum            | 2.1              | High                | Rumah Sumbal     | 2.1              | High                |
| Negeri Gugung   | 1.5              | Low                 | Rumah Kinangkung | 1.5              | Low                 |
| Cinta Rakyat     | 1.5              | Low                 | Sala Bulan       | 1.5              | Low                 |
| Ketangkuhen      | 2.1              | High                | Bengkurung       | 2.1              | High                |
| Suka Maju        | 2.1              | High                | Kuala            | 2.1              | High                |
| Buluh Awar       | 2.1              | High                | BatuMbelin       | 2.1              | High                |
| Batu Layang      | 2.1              | High                | Sibolangit       | 2.1              | High                |
| Rumah PilPil     | 2.1              | High                | Sembahce         | 2.5              | Very high           |
| Suka Makmur      | 2.5              | Very high           | Buah Nabar       | 2.1              | High                |
| Durin Serugun    | 1.5              | Low                 | Bingkawan        | 2.1              | High                |
| Ujug Deleng      | 1.3              | Low                 | Sayum Sabah      | 2.1              | High                |
| Tanjung          | 1.5              | Low                 | Rambung Baru     | 2.1              | High                |

Figure 8. Maps of vulnerability for landslide in Sibolangit District.
According to Figure 8, it is shown that area with highest vulnerability level in Suka Makmur Village, Betimus Mbaru, and Sembahe Village with interval of vulnerability level of 2.21 – 2.50.

4. Conclusion
The use of GIS for mapping the landslide risk with determination and classification of population and slope gradient. Area with biggest population number is at gradient above 45% with potential towards changes of land use that will affect the bearing capacity and water absorption. Maps of risk and parameter of population has three classes such as low (56.75 km²), high (102.57 km²), and very high (14.10 km²). Based on the result, it is concluded that population density and slope gradient are one of the causes of landslide to occur. Whereas the area with high vulnerability is Makmur Village with score 2.5, gradient <8 to >45%. Batimus Village with score of 2.3 and gradient of <8 to >45% and Sembahe Village with score 2.5 and gradient of <8 to 45%.

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