Spatial pattern of landslide potential area by SMORPH, INDEX STORIE and SINMAP method in Pelabuhanratu and surrounding area, Indonesia

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Abstract. Landslide is a frequent disaster in Indonesia that is affected by several factors. Cisolok, Cikakak, Pelabuhanratu, and Simpenan are Sub-district that has physical characteristics which can increase the potential of landslides in the area. Therefore, mitigation efforts by potential landslide mapping are needed in the research area. In this research landslide potential map was made by using 3 methods: SMORPH (slope morphology), Index Storie, and SINMAP (stability index mapping). This study is aimed to know the differentiation of spatial pattern of the landslide potential areas by SMORPH, SINMAP, and Index Storie methods. Spatial analysis was implemented by overlay technique between landslide potential area with landslide location. The results reveal that the research area was dominated by high potential based on the SMORPH method, low by SINMAP, and moderate by Index Storie. The result also reveal that 33% of the total research area has different potential and 7% has the same potential in the results of all three methods. Where areas with high potential in all three methods was distributed in the northern of the study area. The SMORPH method has 19,951 Ha of high potential area and there are 34 landslides in it, SINMAP 2,568 Ha with 32 landslides, and Index Storie has 4,684 Ha with 21 landslide. The result also explain that in addition to the side of slope gradient factor, landuse change factor has a very big affecting for the occurrence of landslide in the research area. Mapping of landslide potential areas in this research is may practically be applied for the regional planning and development of infrastructures in the area.

Keywords: Landslide, landslide potential, SINMAP, SMORPH, INDEX STORIE.
The research area has physical characteristics that can increase landslide potential. According to [11], an area with the steep slope condition has higher potency of landslide than the flat area. Based on the topographic condition, this research area has 121.5 km² (22.2%) areas with the steep slope condition (more than 65%). Moreover, seen from the lithology condition, this area dominated by volcanic bedrock, and according to [5], landslides tend to be connected with certain types of bedrock associations and outcrops of volcanic rocks. The research area also has high rainfall (2844 mm/year), where high rainfall is a trigger factor of landslides [12].

The physical characteristic of the research area (Figure 1) caused the area to be frequently affected by landslide. In the period from 2010 – 2016, there were 87 landslides recorded in this research area, endangering people's lives. Therefore, mitigation efforts by potential landslide mapping are needed in the research area. In the last 5 years, several published studies have been carried out about landslide mapping in different parts of Indonesia using SINMAP, SMORPH, and Index Storie methods ([7]; [13]; [14]; [15]; [16]) This study aims to know the differentiation of the landslide potential areas formed based on the three methods, considering the three methods not created specifically for tropical regions such as Indonesia.

![Figure 1. Physical Characteristic of research area](image)

2. Methodology
In the past studies, Shallow landslide modeling falls into three categories: empirical, statistical, and physically based models [1]. Among these, physically based models are preferred because of their accuracy and ability to forecast the spatial and temporal occurrence of landslides [1]. In this research, 3 methods or models are used in assessing the landslide potential: SMORPH, SINMAP, and Index Storie. This research began with collecting data and then processing (assessing the landslide potential) with 3 methods and finally analyzing data. Figure 1 is the conceptual framework of this research.
2.1 Data Collection
In achieving the goal of this research, secondary data are used in assessing the landslide potential. Secondary data that used are determined based on the method that used in this research. Secondary data was needed are the daily rainfall, soil type data, digital elevation model (DEM) from Alaska Satellite Facility, and the landslide location data. DEM data are used, because they constitute the most commonly used and readily available source of topographic data on GIS systems. Alos Palsar DEM was used in this research, because it has more detail resolution (12.5 m) than SRTM or ASTER GDEM that usually are used assessing the landslide potential. In this research, landslide location data were also obtained through field survey by way of plotting the coordinate of landslide point, field observations and interviews with the local peoples.

2.2 Models of Assessing The Landslide Potential
In this research 3 methods or models are used in assessing the landslide potential: SMORPH, SINMAP, and Index Storie. Where three both of it has a new classification of landslide potential (i.e not potential, low potential, moderate potential, high potential) to see the comparation of each potential landslide area.

2.2.1 SMORPH
The SMORPH method is a method developed by [17]. This computational model analyzes, on the basis of slope gradient and form, the susceptibility of terrain to landslide processes [17]. The topographic and geomorphic condition (slope gradient and slope form) which used in this method are obtained from raster data. This method using the raster data as the main variable because the formations displayed through the raster data has described the hydrological process and the nature of the soil. To obtain the form slope, raster data was classified using the following curvature value classification (table 2)
Table 1. Classification of Form Slope

| Form Slope | Curvature value |
|------------|-----------------|
| Concave    | < -0.1          |
| Planar     | -0.1 – 0.01     |
| Convex     | > 0.01          |

Source: [13]

In this method, the slope-morphology (SMORPH) matrix is formed by the union of slope gradient and form. The classification of landslide potential can be read at table 3 below.

Table 2. SMORPH Classification of Landslide Potential

| Slope Form | Slope Gradient (%) |
|------------|-------------------|
|            | 0-2               |
|            | 2-15              |
|            | 15-25             |
|            | 25-45             |
|            | 45-65             |
|            | > 65              |
| Convex     | Non Potential     |
| Planar     | Non Potential     |
| Concave    | Non Potential     |
|            | Low Potential     |
|            | Low Potential     |
|            | Low Potential     |
|            | Low Potential     |
|            | Moderate Potential|
|            | Moderate Potential|
|            | High Potential    |
|            | Low Potential     |
|            | Low Potential     |
|            | Low Potential     |
|            | Moderate Potential|
|            | Low Potential     |
|            | Low Potential     |
|            | Moderate Potential|
|            | High Potential    |
|            | High Potential    |
|            | High Potential    |
|            | High Potential    |

Source: [13]

2.2.2 SINMAP

SINMAP is a landslide susceptibility model based on the “infinite slope” equation [18]. This method is one of the predicted methods of landslides potential that not only take into account slope factors. The approach takes full account of topographic control through shallow subsurface water flow in landslide generation [19].

combines topographic, hydrographic, and soil variables to predict potential landslide zones with sparse information [19]. This method assessing the landslide potential from the stability index value. When the stability index value of an area has higher value, the area has lower landslide potential. The classification of stability index value can be read at table 4 below.

Table 3. SINMAP Classification of Landslide Potential

| Clasification | Stability Index Value (SI) | New Clasification |
|---------------|----------------------------|-------------------|
| Stable        | SI > 1.5                   |                   |
| Moderately Stable | 1.5 > SI > 1.25       | Non Potential     |
| Quasy Stable  | 1.25 > SI > 1             |                   |
| Lower Threshold | 1 > SI > 0.5               | Low Potential     |
| Upper Threshold | 0.5 > SI > 0.001       | Moderate Potential|
| Defended      | SI < 0.001                 | High Potential    |

Source: [18]

2.2.3 Index Storie

This method is a method developed by Storie in 1978. In this method soil type, rainfall, landuse, and slope gradient are used to assessing the potential landslide. Variables that used in this method are processed by this following equation [20]:

\[ L = A \times B/10 \times C/10 \times D/10 \]

L = Landslide Potential  A = Landuse
B = Slope Gradient       C = Soil Type
D = Rainfall             

The Index Storie’s landslide potential classification can be read at Table 6 below.
| Landuse | Soil Type | Slope Gradient | Rainfall | Final Score | Score of Class | Classification |
|---------|-----------|----------------|----------|-------------|----------------|----------------|
| 1       | 1         | 1              | 1        | 0.001       | < 0.001        | Non Potential  |
| 2       | 2         | 2              | 2        | 0.016       | 0.001 – 0.016  | Low Potential  |
| 3       | 3         | 3              | 3        | 0.081       | 0.016 – 0.081  | Moderate Potential |
| 4       | 4         | 4              | 4        | 0.256       | 0.081 – 0.256  | High Potential  |
| 5       | 4         | 5              | 4        | 0.4         | > 0.256        | High Potential  |

Source: Modified from [16]

3. Result

Based on the three landslide potential map, research area was divided into four landslide potential classification (figure 4.). The classification contained in the research area are not potential, low potential, moderate potential, and high potential. Based on Index Storie’s map, research area was dominated by moderate landslide potential, with an area of 33.453 Ha or 60.78% from all of the research area. Based on the ratio of each potential level area (Figure 5.), the index storie area has wider low and moderate landslide potential area than the others method. Furthermore, by using the Index Storie method research area has 16.856 Ha low potential area, 4.684 Ha of high potential area, and 45 Ha not potential area, which is the lowest area in the research area according to Index Storie method. Where, the high potential area was tend to be distributed in an area with various kind of landuse, especially settlement.

Based on landslide potential map by SINMAP method, the research area was dominated by the low potential area, with an area of 21.879 Ha or 39.75% from all of the research area. The result also reveal that SINMAP has wider non potential area than the others method (Figure 5.) with 19.578 Ha 35.57% from all of the research area. Other than that by SINMAP method, the study area has 11.013 Ha moderate potential area, and 2.568 Ha of high potential area, which is the lowest area in SINMAP landslide potential area.

The analysis reveal that there are 3.856 Ha areas with the same landslide potential level and 18.528 Ha areas with different landslide potential levels by the three methods. The areas with the same landslide potential tends to lie in an area with a steep to a very steep incline that is widely distributed in the northern part of the study area. The same potential area was dominated by moderate and low potential area where the area was distributed from northern to south of research area. There are 138 Ha high potential and 5 Ha non potential area. That area...
tends to be distributed in Pelabuhanratu sub-district with low rainfall (<2000 mm/tahun) and forest landuse.

There are 14 landslide occurrences in same landslide potential area and 15 landslide occurrences in different landslide potential area. The landslide in the same potential area lie in high and moderate potential, where is widely distributed in the northern part of the study area. The analysis of landslide in the different potential area reveal that SINMAP has better prediction in southern area. Where those area have homogeneous landuse (dominated by shrubs and plantation). The results are influenced by the variables that used by SINMAP itself. SINMAP is method that used to determine the amount of wood volume and estimate the location of forest rejuvenation to reduce the landslide potential by using a specific catchment area where the area is not large [18]. Based on some previous researchs [1]; [6]; [19], SINMAP was tends to be used for not extensive area. More over, the accuracy of SINMAP’s result would be preferable to be used in areas with homogeneous landuse. Based on research conducted by McCullough, et al., (2015) SINMAP was used to detecting landslide potential in the City of Pittsburgh, PA. only on scale 1:12,000.

Figure 4. Comparation Landslide Potential Area at each level

SMORPH method also divided the research area into four landslide potential classification as index storie and SINMAP method (figure 4.a). Even though having the same classification, the result by using SMORPH method was dominated by high potential area, with an area of 19,951 Ha or 36.25% from all of the research area. The study area has 18,474 Ha moderate potential area, 10,014 Ha of low potential area, and 6,599 Ha non potential area, which is the lowest area in the research area according to SMORPH method. Despite having a high potential area larger than the other two methods, SMORPH can only detecting shallow landslide which the deep average less than 10 m [17]. Figure 6. is showing the number of landslide events in the landslide potential area of SINMAP, SMORPH, and Index Storie methods.

Based on Figure 6, the Index Storie Method has a higher number of occurrences in high and medium potential areas. Based on the methodology of the Index Storie method itself, the Index Storie method using more variables than the other two methods. The high number of landslide occurrence in high and moderate potential level is also influenced by the area of moderate potential that dominates the Index Storie map (figure 5). The same result is also shown in SMORPH, landslide occurrence is mostly distributed in high area because high potential area has the biggest area on landslide potential map by SMORPH. Different results are shown by the SINMAP method where the number of landslide occurrence is mostly distributed in high potential although the area has the smallest area in landslide potential map by SINMAP method. The results indicate that landslides that occur in research area are more influenced by slopes. Soil type with high humidity actually causes the load of the slope increases and trigger
the occurrence of landslides. Therefore, most landslide occurrences are distributed in the northern part with a sloping and hilly terrain.

Figure 5. Total landslide location in Landslide Potential Area

|           | Non-Potential | Low Potential | Moderate Potential | High Potential |
|-----------|---------------|---------------|--------------------|---------------|
| SINMAP    | 8             | 9             | 40                 | 32            |
| SMORPH    | 8             | 12            | 33                 | 36            |
| Index Storie | 2           | 9             | 57                 | 21            |

4. Conclusion

Potential landslide area of Pelabuhanratu Sub-district and its surroundings area based on SINMAP, SMORPH and Index Storie methods are divided into four potential classes, that are high potential area, medium, low, and non potential. There are 3,856 Ha of research area is an area with the same potential level based on the three methods. Where 138 ha of them are areas with high potential levels tend to be distributed in the northern part of the study area with the slope of the slope to very steep as well as the form of hilly terrain. More than 50% of landslide location in the research area was distributed in the high and medium potential areas of the three methods. Based on the analysis between landslide potential areas and landslide location, SINMAP method is the method that most closely or in accordance with the landslide location in Kecamatan Pelabuhanratu and surrounding areas. The result also explain that in addition to the beside of slope gradient factor, landuse change factor has a very big affecting for the occurrence of landslide in the research area.
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