Place exposure pattern toward landslide disaster due to heavy rainfall in Probolinggo District, East Java

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Abstract. Landslide is the third largest disaster occurred in Indonesia, including in Probolinggo District. Analyzing the place exposure patterns toward landslide disaster due to heavy rainfall, which triggering the landslide in Probolinggo District is the purpose of this study. Daily rainfall data in 1990–2015 were used to obtain the frequency of heavy rainfall regions (> 50 mm/day, > 100 mm/three days and > 150 mm/five days) using the interpolation method based on Thiessen Polygon. The potential landslide region was obtained by using SINMAP models, which was verified by the landslide location data from 2015 to 2016. Descriptive spatial analysis using the overlay technique showed that 50.30 % (85,358 Ha) area in Probolinggo District has the potential of the landslide, especially in Sub District Krucil, Andisol Soil region, the slopes of 15–40 % region, and the rainfall of 1500–2000 mm/year region. The place exposure patterns toward landslide disaster due to heavy rainfall in Probolinggo district is in the region which has the higher potential of landslides, and heavy rainfall frequency, the level of place exposure to landslides disaster due to heavy rainfall will be higher.

Keywords: Exposure pattern, landslide disaster, heavy rainfall, Probolinggo district

1. Introduction
Landslide disaster is a disaster which occurred in Indonesia since ancient times and has been occurred frequently in the last decades. Nature disaster is the disaster which due to event or series event which caused by natural phenomenon such as geological factors, climatological factors, and extra-terrestrial factors that could result in environmental damage, loss of material, as well as victims of human [1]. According to Arsyad [2], factors that led to the landslide disaster was slope, rainfall, and soil conditions. In general, landslides often occur in areas that have a slope of more than 25 %. Landslide disaster also often occurs in areas that have duration of 2–7 rainy days in a row [3].

Probolinggo district is located at 7°40’– 8°10’ LS and 112°50’–113°30’ BT with an area of 1,696.10 km² which immediately adjacent to the Madura Strait in the north, Pasuruan district in the west, Jember district and Lumajang district in the south, and Situbondo district in the east. Administratively, Probolinggo has 24 districts consisting of 325 villages and five urban villages. Topography of Probolinggo district consisting of coast to the mountains caused the existence of height variation ranging from 0 meters above sea level to the highest point in the form of Mount Argopuro which is 3,088 meters above sea level (figure 1), and the existence of variation slopes ranging from 0 % to > 40 % (figure 1). Topographic variations in Probolinggo make existence territories in
Probolinggo, which has the potential to landslides disaster. From the aspect of soil conditions, Probolinggo district consists of Andisol soil, Alfisol soil, Inceptisol soil, and Entisol soil with domination Andisol soil (figure 1). Climatological conditions of Probolinggo district viewed by average rainfall a year have a diversity ranging from $< 1500$ mm/year up to $> 2500$ mm/year with the spread increasingly to the (figure 1). The rainfall variation makes existence areas which have the potential to landslide disaster in Probolinggo.

The incidence of landslide disaster would be even greater if there are triggers that cause landslides, one of which is heavy rainfall [3]. Heavy rainfall that occurred is one of the effects of deviations or global climate change that cannot be separated from the influence of El Nino Southern Oscillation (ENSO) phenomenon which is a global phenomenon in the Pacific Ocean. The anomalous conditions such as heating or cooling of the sea water temperature are well above or under normal conditions that affect variations in rainfall and increase the frequency of heavy rainfall in a given region [4, 5]. Global climate change causes the exposure of the region to landslides due to heavy rainfall in Probolinggo district. Exposures are external biophysical factors that increase vulnerability [6]. One of the strategic steps that can reduce the risk of landslide disaster is to map the territory of its potential area to landslide disaster in Probolinggo district in order to determine the areas that have the potential to landslide disaster.

In determining potential areas of landslide disaster, Geographic Information Systems (GIS), which is model Stability Index Mapping (SINMAP), is often utilized in this kind of study. SINMAP Model is a model used to calculate the stability index value of the soil by combining elements of hydrology, slope, and soil conditions [7]. In addition, it should also map the exposure places to landslide disaster due to heavy rainfall. Thus, this study aims to know which region is more potential for the occurrence
of landslides due to heavy rainfall, which is a trigger factor of landslide disaster in Probolinggo, that is expected to assist the government in taking the right decisions to cope with landslides. Also, it can be a source of information in designing appropriate mitigation program for the future.

2. Method
This study was conducted to analyze place exposure pattern to landslide hazard because of heavy rainfall in Probolinggo Regency, East Java. The variables that were studied in this research were the physical aspects and the landslide point. There are several physical aspects such as slopes, daily rainfall, and soil types. Those three variables were processed using a SINMAP model to generate potential areas of landslides. Aspects of daily rainfall were also assessed by the frequency of heavy rainfall which consists of rainfall > 50mm/day, rainfall > 100 mm/three days, and rainfall > 150 mm/five days. The third variable is used to generate a frequency region of heavy rainfall, which triggers factors trigger of landslides disaster. Furthermore, the landslide point data used to validate the place exposure pattern to landslide hazard because of heavy rainfall in Probolinggo Regency. The flowchart of this research is depicted in figure 2.

2.1. Data collecting
In achieving the goal of this study, it takes some secondary data from several agencies. Secondary data was needed is the daily rainfall years 1990–2015 are sourced from the Agency of Public Works and Water Management Probolinggo district, soil type data sourced from the Research Institute for Soil, elevation contour data sourced from Geospatial Information Agency, and the landslide location data sourced from Regional Disaster Management Agencies of Probolinggo district. Landslide location data were also obtained through field survey in October 2016 as many as 21 locations by way of a coordinate measuring landslide point, field observations, and interviews with the local peoples.

2.2. Data processing and analysis
In this study, data processed in tabular and spatial. Tabular data processing was done by calculating the mean frequency of heavy rainfall during 26 years. Heavy rainfall was calculated rainfall > 50 mm/day, rainfall > 100 mm/three days, and rainfall > 150 mm/five days using software Ms. Excel. Once calculated, the data mean annual frequency of heavy rainfall were classified into three classes, namely low, medium, and high. Spatial data processing was done by using SINMAP (Stability Index Mapping) Model to map the potential area of landslide with Data Digital Elevation Figure 2.

Figure 2. Research flow chart
Model (DEM) as the main reference, and data types of soil with many indicators such as the value of soil cohesion, the value of friction angle and the value of index moisture of soil, as well as data on average daily rainfall as supporting data. SINMAP Modeling carried out using Arc.View 3.3 software, followed by manufacturing of heavy rainfall frequency maps with Thiessen polygon method using Arc.GIS 10.1 software, and making maps of the place exposure pattern to landslide disaster due to heavy rainfall with overlay and scoring techniques using Arc. GIS 10.1 software.

2.3. Data analysis
Analysis that used to achieve the goals of this research was using descriptive spatial analysis to analyze the distribution of potential landslides region in Probolinggo and analyze place exposure pattern to landslide hazard because of heavy rainfall in Probolinggo Regency. After that, validation test was using the landslide data in 2015-2016 to look at the percentage of the landslide disaster at a map of potential landslides and map of exposure area toward landslide disaster due to heavy rainfall. So it can be analyzed the accuracy of SINMAP model and the results of the place exposure toward landslide disaster due to heavy rainfall in Probolinggo that have been made.

3. Results and discussion

3.1. Distribution of landslide potential area in Probolinggo district
The results of SINMAP model generated the soil saturation level area of research and the stability index area of the soil area. Both values then used to determine potential areas of landslides in Probolinggo District. Potential areas of landslides in Probolinggo District is shown in figure 3. Generally, the potential landslide area in Probolinggo district was well-distributed in the south region. If studied based on its area, the area of potential landslides in Probolinggo is shown in table 1.

Based on figure 3 dan table 1, 49.70 % area in Probolinggo district was located in the non-potential area of landslide and generally distributed in the north of Probolinggo district, while 50.30 % area in Probolinggo district is the potential area of landslides, which divided into three different groups; 10.41 % low potential area, 21.29 % middle potential area, and 19.60 % high potential area. Specifically, based on the sub-district, soil type area, slope area, and rainfall area, the distribution of landslides potential area in Probolinggo is as can be seen in figure 4.

Based on subdistrict, there are 13 subdistricts with low potential areas of the landslide, 12 subdistricts with medium potential areas of landslide and 10 subdistricts with high potential areas

![Figure 3. (a) Landslide potential area in Probolinggo district and (b) landslide location.](image-url)
of the landslide. The potential areas of landslides in Probolinggo majority are located in Krucil subdistrict, in the southern of Probolinggo district, with an area of 23,066.33 hectares or 26.9 % of the area of potential landslides in Probolinggo district.

Based on the soil type, generally, potential landslide area in Probolinggo district spreads in any soil type. Potential areas of landslides in Probolinggo district majority spread on Andisol soil area which amounted to 40,824.1 hectares or 47.8 % of the landslides potential area in Probolinggo District. Based on its slopes, generally, landslides potential area in Probolinggo majority spreads across the slopes of 15–40 % which is an area of 29,001.73 hectares or 34 % of the total area of potential landslides in Probolinggo. If examined by region rainfall, generally, landslides potential area spread over an area of rainfall 1,500–2,000 mm/year in the amount of 37,130.57 or 43.5% of the area of potential landslides in Probolinggo.

| Table 1. Landslide potential area in Probolinggo district (Ha). |
|-----------------------------------------------|
| Level of landslide potential | Hectares | Percentage | Location of landslide |
| -------------------------------- | -------- | --------- | ---------------------- |
| Not Potential                   | 84,302  | 49.70    | 5 %                   |
| Low Potential                   | 17,663  | 10.41    | 14 %                  |
| Medium Potential                | 36,105  | 21.29    | 28 %                  |
| High Potential                  | 31,541  | 19.60    | 53 %                  |
| Total                           | 169,610 | 100.00   | 100 %                 |

Figure 4. Area of landslide potential in Probolinggo district based on subdistrict, slope area, soil type area and rainfall area (Ha).
Figure 5. The area of heavy rainfall in Probolinggo district

Based on the data from Regional Disaster Management Agencies of Probolinggo district, there were 21 landslide locations from many levels which distributed in many subdistricts in Probolinggo District (table 1). The distribution of landslide location based on the potential area of landslide and subdistrict is shown in figure 3. Based on the validation test using landslide location, 95 % of landslides in Probolinggo District are located at the potential area of a landslide by SINMAP Model. Fifty two percent landslides located in the high potential area, 29 % located in the medium potential area and 14 % located in the low potential area. Therefore, it can be concluded that SINMAP (Stability Index Mapping) model which used in this study had good accuracy because it can predict potential areas of landslides accurate.

3.2. Frequency of heavy rainfall in Probolinggo

Heavy rainfall, in this study, is divided into three indicators, which are the frequency of rainfall > 50 mm/day, frequency of rainfall > 100 mm/three days, and rainfall > 150 mm/five days. Based on the overlay process of three heavy rainfall indicators, we then obtained the frequency region of heavy rainfall in Probolinggo (figure 5). Based on figure 5, the frequency of heavy rainfall in Probolinggo District dominated by a medium level of heavy rainfall region with the area is 75,700 hectares, or 44.63 % of the total area of Probolinggo and generally spread in the southern of Probolinggo District.

3.3. Place exposure pattern to landslide hazard due to heavy rainfall in Probolinggo Regency

Figure 6 shows the place exposure toward landslide disaster due to heavy rainfall in Probolinggo District. Based on figure 6, the place exposure toward landslide disaster due to heavy rainfall at low levels has an area of 103,205.24 hectares or 61 % of the area of Probolinggo and generally spread in the southern. The place exposure toward landslide disaster due to heavy rainfall at medium levels has an area of 34,513.71 hectares or 20 % of the total area of Probolinggo. The place exposure toward landslide disaster due to heavy rainfall at high levels has an area of 31,891.05 hectares or 19 % of the total area of Probolinggo.
Based on the subdistrict, in Probolinggo there are 24 subdistricts that have place exposure toward landslide disaster due to heavy rainfall with a low level and dominated in Gading subdistrict, 12 subdistricts have a medium level that dominated in Krucil subdistrict, and nine subdistricts have a high level that dominated in Krucil subdistrict. If examined by potential landslides area, 83% of the low level of place exposure was in not potential landslide area, 70% of medium level of place exposure are in medium potential landslide area, 80% of the high level of place exposure was in the high potential landslide area. Therefore, it can be concluded that the pattern of place place exposure pattern to landslide hazard because of heavy rainfall in Probolinggo Regency is following the potential landslide area and frequency of rainfall area where the higher potential landslides area supported by the higher frequency of heavy rainfall area, the level of place exposure toward landslides due to heavy rainfall will be higher as well. Based on data from Regional Disaster Management Agencies of Probolinggo district, there are 21 landslide locations which distributed in the place exposure pattern to landslide hazard because of heavy rainfall in Probolinggo Regency. Based on this study, the distribution of landslides location in Probolinggo District can be seen in table 2.

Based on the level of place exposure in this study area, there are 15 landslides at a high level of exposure consist of nine locations in the high potential landslides area and six locations in the medium potential landslides area. Six landslides locations with a medium level of potential landslides area have a high level of place exposure caused by there are trigger factors such as heavy rainfall that make the area becomes more exposed to a landslide. Furthermore, five landslides occurred at medium place exposure levels were at two locations occurred in a high level of potential landslides area tree locations in the low potential landslides area. The next one landslide location occurred at a low level of place exposure that does not have landslide potential.

![Figure 6. (a) Place exposure pattern toward landslide disaster due to rainfall and (b) landslide location.](image)

| Level of landslide potential | Level of place exposure toward landslide disaster due to heavy rainfall |
|-----------------------------|-------------------------------------------------------------|
| Not Potential               | Low 0 Medium 0 High 0                                      |
| Low Potential               | 0 3 0                                                       |
| Medium Potential            | 0 0 6                                                       |
| High Potential              | 0 2 9                                                       |
4. Conclusion
Landslide potential area in Probolinggo District has an area to 85.358 Hectares or 50.30 % from the total area of Probolinggo District such as 21.29 % area has the medium potential of landslide, 19.60 % area has a high potential of landslide and 10.41% area has the low potential of the landslide. Landslide potential areas in Probolinggo District distributed in Southern and are dominated at Krucil Subdistrict with Andisol soil area, 15–40 % of slope area, and 1500–2000 mm/year of rainfall area. Based on the distribution of landslide location, 81 % location of landslide occurred in the high and medium level of landslide potential. Therefore, SINMAP model in this area can predict the potential landslide area as well. Place exposure toward landslide disaster due to heavy rainfall in Probolinggo district with low level has an area to 62.21 %, with medium level has an area to 19.64 %, and with high level has an area to 18.15 % from total area in Probolinggo District. Place exposure pattern to landslide hazard because of heavy rainfall in Probolinggo Regency is following the landslide potential area and heavy rainfall area. If the landslide potential area and heavy rainfall area level is higher, the level of place exposure toward landslide disaster due to heavy rainfall is higher too. Based on the distribution of landslide location, if the level of place exposure toward landslide disaster due to heavy rainfall is higher, the area has more landslide location.

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