Landslide Density Based on Time Series Assessment in Kundasang, Sabah, Malaysia

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Abstract

Landslide density analysis based on a temporal landslide distribution over three different years was conducted in Kundasang, Sabah, Malaysia. The analysis involved landslides that occurred in 1984, 2009 and 2012. The objective of this study is to examine the relationship between the physical parameter and landslide density analysis based on temporal landslide distribution. This is the preliminary study for landslide hazard assessment. Landslides in these three assessment years were identified based on aerial photographs interpretation. The landslides detail has to be digitised as points and the point density was calculated using 1 km x 1 km grid on the landslide inventory map. From the analysis, there were 494 landslides distributed across the assessment years and by using the natural break classification, the landslide density map was classified into three classes of density, resulting low (1 landslide), moderate (2-3 landslides) and high (>4 landslides). Based on the landslide density analysis, there are 48 km^2 that were identified as highly susceptible to landslide. Out of the high landslide density area, 46km^2 were indicated as the most susceptible location for landslides due to the type of lithology that may lead to land sliding. This study indicates that the lithology played an important role as they can influence the geomorphologic process, and can induce landslides. As a conclusion, this study found that using the grid technique is an effective way to determine landslide density and detail investigation should be conducted to minimize the impact of landslide occurrences before any development could take place.

Keywords: *Hazard assessment, Landslide, landslide density, landslide susceptibility*

I. Introduction

Landslides are the primary natural geological hazards and are responsible in causing tremendous property damage with both direct and indirect costs every year [1]. In a simple definition, landslides are known as the rapid mass movement of rocks, soil, debris or earth down a slope by gravity pull. The materials may travel down the slope either by falling, toppling, sliding, spreading or flowing. Landslide plays an essential purpose in the evolution of landforms [2, 3].

The research effort of this work is directed towards determining the section area of high slope failure susceptibility in Kundasang, Sabah through landslide density analysis that uses landslide historical data. The objective of this study is to examine the relationship between the physical parameter and landslide density analysis based on temporal landslide distribution. This is the preliminary study for landslide hazard assessment.

II. Settings of the Area

The location of area being studied is in Kundasang, Sabah (Figure 1). This area is well-known for its hilly topographic terrain. This area was selected as the study area due to the landslide occurrences here.

The study area covers from the latitude 6°2'27.129"N and 5°54'36.652"N, and longitude of 116°38'35.095"E and 116°44'40.472"E. The total area coverage is 426km^2. Rapid development since the 90's has taken over this area and the development involves land clearing activities.

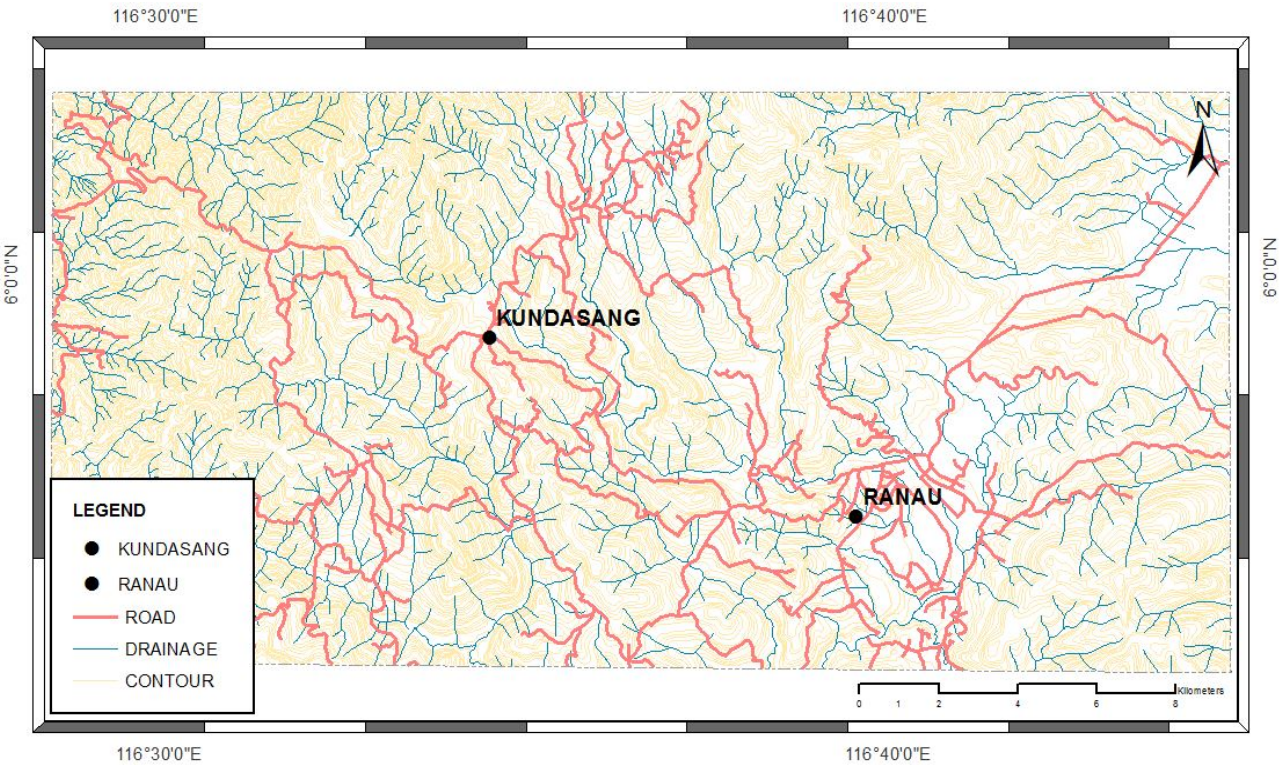

Figure 1. The study area located at Kundasang, Sabah, Malaysia.

The hilly terrain and ridges with an elevation of more than 1 500 meters a.s.l which happens to be a combination of steep to very steep slopes was a direct after-effect of violent tectonic activities in the past [4,5]. The steep and hummocky terrain, regional and unstable local geology, existence of old landslide areas, and intensively geomorphologic processes [5] in the study area, makes it an area prone to landslides. Due to these factors, any construction built on hilly terrain has higher tendency to landslide occurrences.

The geology of the study area include the Crocker Formation (Late Eocene to Early Miocence age), Trusmadi Formation (Paleocene to Eocene age), granite intrusion, as well as several recent Quaternary alluvial materials which are still being deposited [6]. In general, the Trusmadi Formation exhibits two main structural orientations NW-SE and NE-SW [7,6].

In areas within Kundasang, landslides could have been conceivably initiated by development, continuous heavy precipitation, and from earthquakes. By conducting scientific analysis of landslides, which starts with landslide inventories, landslide susceptibility areas could be identified and safer area for development can be delineated. GIS and remote sensing method make these tasks achieveable especially when mapping a large area.

III. Methodology

The methodology used in this study to produce the landslide density map consists three stages; (stage 1) landslide data collection – is the process to identify the landslides from the aerial photographs, (stage 2) density calculation – is the process of converting and classifying the landslide inventory map into a landslide density map and (stage 3) correlation with physical parameter – is the analysis to examine the influence of physical parameter (lithology) with high landslide density class. The past landslide events were acquired by aerial photograph interpretation. The landslide data were collected from 1984, 2009 and 2012 aerial photographs. All the landslides were digitised in a point format in GIS environment for the density calculation.

1. Landslide Data Collection

A total of 178 aerial photographs were used to map landslides with the scale of 1:25 000 throughout three assessment years, starting from 1984, 2009 and 2012. The interpretation of aerial photographs were mostly done in the Kundasang's towns area. The aerial photographs in 1984 are in black and white, while the 2009 and 2012 aerial photographs are available in colour. In order to identify landslides in the aerial photograph, stereo viewing were used. To minimize errors in landslides identification, only landslides with visible scars observed in the photographs were extracted.

2. Density calculation

The landslide density technique calculates the point of landslide in a specified grid. In this study, the density calculation used fishnet method provided in ArcGIS software with 1 km^2 of search grid. The 1 km^2 grid area is used to standardize it with the topography map grid which is also 1 km^2. This grid was overlapped with the landslide inventory map to calculate the total points of landslides in each grid. The total points of landslides in each grid represent the density of landslide in the grid. The landslide density was later classified into low (1 landslide), moderate (2-3 landslides) and high (>4 landslides) density classes using natural breaks technique in ArcGIS 10.4 software. This density technique is a modification of the technique applied by Eyles et al. [8] and enhance by Simon et al. [9].

3. Correlation with physical parameter

The landslide density map was overlapped with the lithological map as lithological map is one of the important physical parameter that contribut to landsliding. The percentage of the landslide density was calculated in each classes.

IV. Result & Discussion

A sum of 494 landslides was identified; 92 of them had occured in 1984, 284 occurences in 2009 and another 118 landslides in 2012. Table 1 summarizes the landslide inventory with the number, type and occurences for each assessment year.

Table 1. Landslide inventory

Year	Total landslides	Type of landslide		
		Flow	*Slide*	*Complex*
1984	92	35	52	5
2009	284	98	182	4
2012	118	49	63	6

Lithology is very important, as they are the top factors that are able to influence the type and intensity of geomorphologic processes, which can induce landslides [10]. The lithotypes in the study area have been distinguished into five types. On the basis of both the occurring lithotypes and the relative abundance of each lithotype within the study area, the detected lithological have been named, respectively, "Flysch type sandstone, shale, siltstone with rare tuff, limestone, breccia and agglomerate" (F), "Shale and phyllite with some siltstone and sandstone" (SP), "Terrace sand, gravel and coral" (TS), "Basic to ultrabasic intrusive: gabbro, dolerite, serpentinite, peridotite, dunite and pyroxenite" (BUI), "Coastal and riverine alluvium mainly clay, silt and sand" (CR) and "Acid to intermediate intrusive: adamellite and granodiorite" (AII). Figure 2 shows the lithological units distribution in the study area.

Figure 2. The lithological units distribution in the study area.

The "Flysch type sandstone, shale, siltstone with rare tuff, limestone, breccia and agglomerate" is the most widespread one in the study area, as it crops out in 43% of the study area. The "Shale and phyllite with some siltstone and sandstone", generally Paleogene in age, crops out in the 31% of the study area. The "Terrace sand, gravel and coral", Pleistocene in age, crops out in the 14% of the study area and the rest of the lithotypes have small portion of area.

Figure 3 shows the landslide density map in the study area and Table 2 shows the classification of the landslide density. Based on the landslide density analysis, there are 48 km^2 that were identified as highly susceptible to landslide. Out of the high landslide density area, 46km^2 are more pronounced in the "Flysch type sandstone, shale, siltstone with rare tuff, limestone, breccia and agglomerate" (F). The correlation of landslide density with lithology is shown in Figure 4.

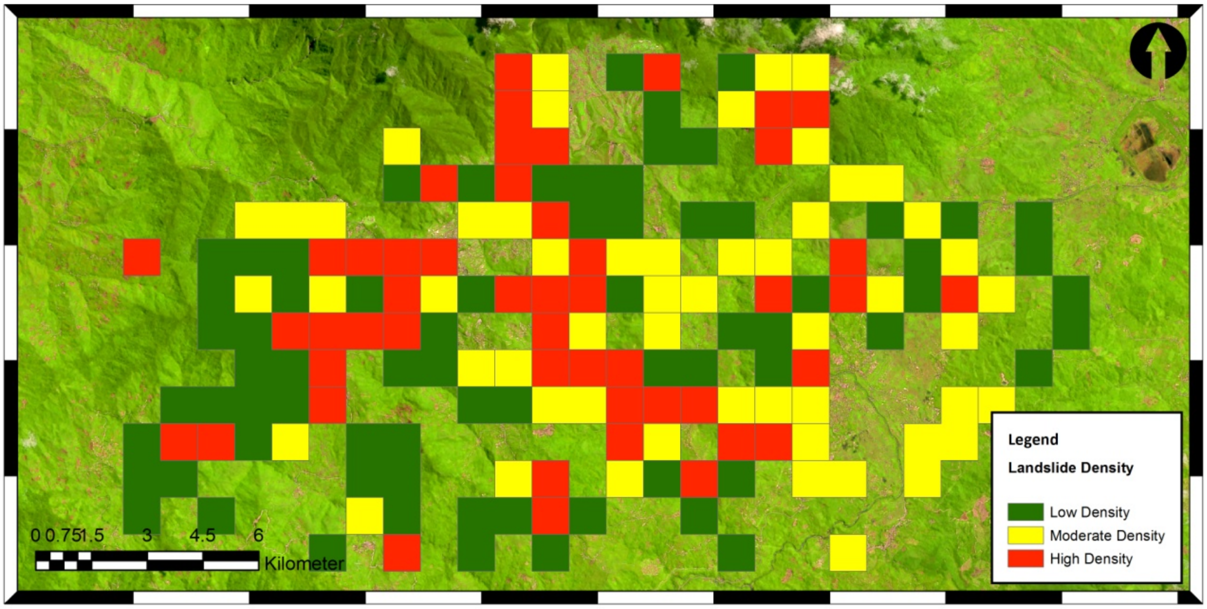

Figure 3. The landslide density map of the study area.

Table 2. Landslide density

Density	Area (km^2)
Low (<1 Landslide)	75
Moderate (2-3 Landslides)	54
High (>4 Landslides)	48

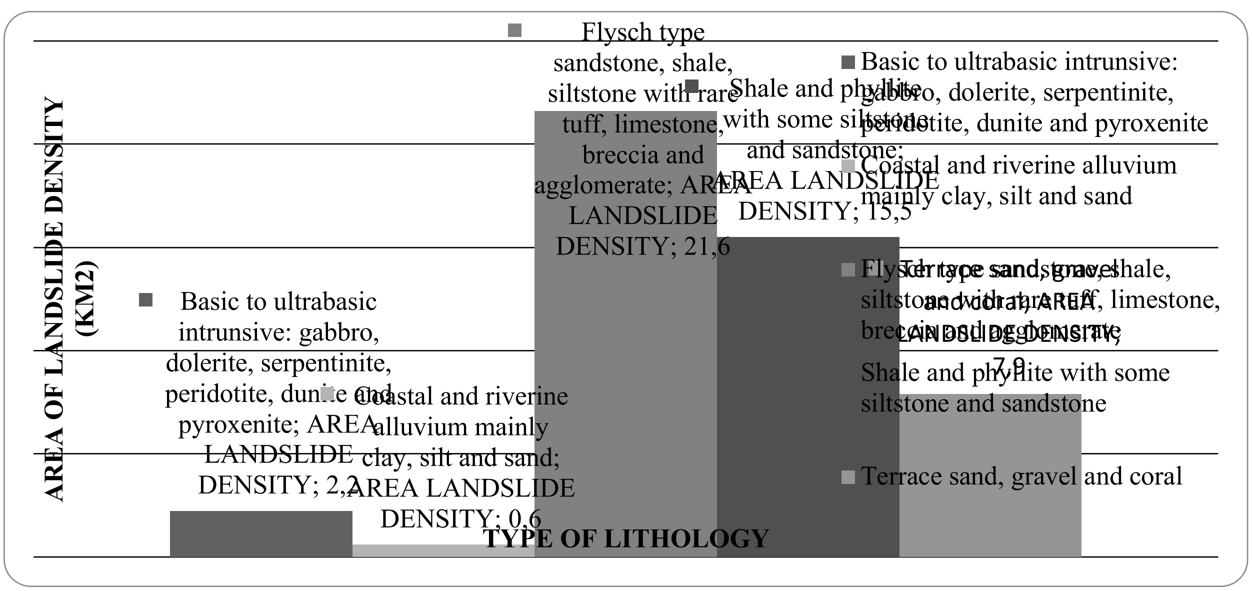

Figure 4. The correlation of the landslide density and the lithology in the study area.

From the result, it can be seen that, there are three lithotype categories with relatively high number of landslide, namely as “Flysch type sandstone, shale, siltstone with rare tuff, limestone, breccia and agglomerate” (F), “Shale and phyllite with some siltstone and sandstone” (SP), and “Terrace sand, gravel and coral” (TS), with the former being the highest.

The high susceptibility to landslides shown by the geological materials in both datasets was in agreement with the opinion that interbedded rock types (especially with shale) and shale are the most susceptible to landslides [9]. The interbedded rock type such as the interlayer consists of competent sandstone and shale will have different degree of degradation especially when this rock type is exposed to weathering. Shale will experience a faster degree of degradation, compared to sandstone, and therefore, will weaken the rock structure and making sandstone easier to slide down. Shale is formed of mainly very fine (clay size) materials, which resulted in low strength and vulnerable to weathering [9]. These are the main causes that make it highly susceptible to landsliding. Sandstone, on the other hand, is commonly less susceptible to landslides [9].

V. Conclusion

This study shows the simple technique to calculate the landslide density analysis. The 1km^2 grid can be used as a guideline for landslide density comparison and can be systematically done by calculating the each point in each grid. As for the analysis, the result in this study indicates that lithology plays an important role in inducing landslides in the study area.

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