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TEMPORAL LANDSLIDE SUSCEPTIBILITY ASSESSMENT USING LANDSLIDE DENSITY TECHNIQUE

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ABSTRACT

In this study, a temporal landslide assessment was carried out in a landslide prone areaalong the Ranau-Tambunan road in Sabah, Malaysia. The assessment was based on landslides interpreted from 1978 and 1994 aerial photographs and also from fieldworks which were done in 2009 and 2011. A total of 148 landslides were recorded from those four years with 24, 47, 56 and 21 landslides respectively for the year 1978, 1994, 2009 and 2011. Based on these landslides, a landslide density map was produced for each year which consist of three classes; low (1 landslide/km2); moderate (2-3 landslides/km2); and high (≥ 4 landslides/km2). Based on the combination of landslides occurred throughout the assessment years, 22 sections of the road were indicated to have high landslide density. Intersection with high lineament density zone shows that 16 of the high landslide density areas are located inside within the high lineament density zone. From both of these maps, a landslide susceptibility map was generated. Landslide records acquired from aerial photographs captured in 2005 was use to validate the map. The validation result shows that 83% of the total landslides in 2005 are within the high susceptibility zone and this value indicates that the accuracy of the susceptibility map is acceptable. The high susceptibility zone in the study area can be categorized as 'highly susceptible' with moderate hazard based on the International guideline on susceptibility and hazard zonation. In terms of landslide density, it is expected that 5.4 landslides can be observed for every km2 in the high susceptibility zone.

1. INTRODUCTION

Landslide researchers in the past have shown the importance of time-based landslide assessment [1-3]. By assessing landslides susceptibility based on different time frames, areas that are prone to landslide can be identified with higher confidence. Temporal landslide assessment is crucial especially in an area where landslide occurrences are often and can cause damages to infrastructure such as roads and fatality to human.

Therefore, this study aims to assess locations that are susceptible to landslide based on recorded landslide events in different time frames and to examine whether geological lineaments have controlled over the instability in the study area. Subsequently, a landslide susceptibility map from the combination of landslide density and geological lineament maps will be generated with different levels of susceptibility and hazard.

The study area selected is located along a 54 km stretch of road connecting two main districts, Ranau and Tambunan in the state of Sabah, Malaysia. This road is often damage by landslides that occurred along its slopes and embankments. The location of the study area is shown in Figure 1. The study areas have two substantial geological formation known as the Crocker and Trusmadi Formations. The Crocker Formation which is deposited in Late Eocene consists of four main lithological units: thick bedded sandstone; thinly bedded sandstone and siltstone; red and dark shale; and slumped deposits [4]. Trusmadi Formation on the other hand has four rock sequence with some have been metamorphosed [4]. These lithological units are argillaceous rocks, interbedded sequences (turbidites), cataclasites and massive sandstones. The lithological boundary of these formations in the study area is given in Figure 2.

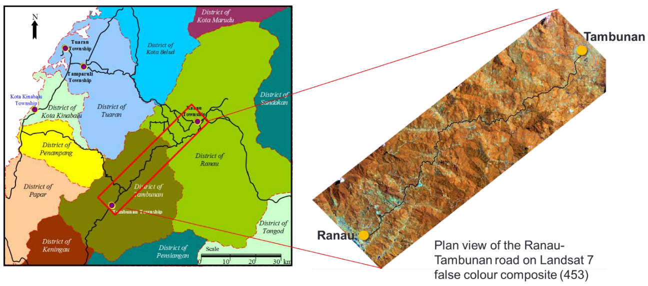

Figure 1: Location of the study area

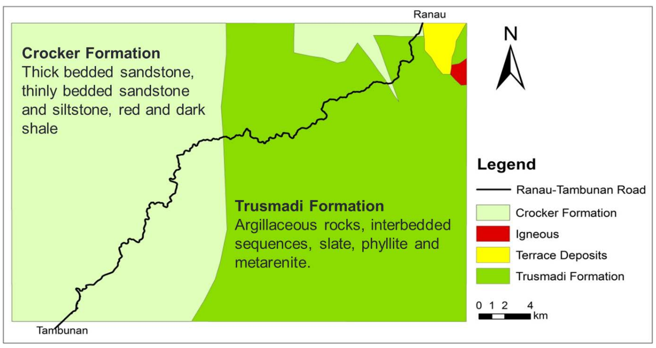

Figure 2: Lithology map of the study area with the Ranau-Tambunan road crossing both the Crocker and Trusmadi Formations

2. LANDSLIDES AND GEOLOGICAL STRUCTURE

Geological structure refers to the forms and shapes in rocks that were formed as a result of deformation processes [5]. Geological structures which exist in rocks are known as discontinuities. In engineering practice, a discontinuity is a fracture in rocks or a boundary in rocks or soil that signifies a change in rock mass [6,7]. According to a research paper, the importance of discontinuities is mostly in slope stability, underground excavations and foundations, and also because they influence the deformation and permeability of the ground [8].

The influence of discontinuities on landslide occurrences has been well studied in Malaysia [9-15]. Discontinuities as reported by these authors have either providing a sliding plane for failure or in certain cases, a weak zone exist in rock mass due to high density of fracture Landslide occurrences associated with lineaments have been demonstrated in several studies either as landslide proximity to lineaments or as the total length of lineaments with the number of landslides in a given area [16,17]. In this research, their association with landslide occurrences will be investigated based on regional analysis.

3. METHODOLOGY

The methodologies in this study are divided into four important parts. The first part is on creating a landslide inventory for the assessment years based on aerial photographs interpretation and fieldwork. This is followed by calculating lineament and landslide densities of the area. The third part is producing the landslide susceptibility map and validation of the map and the final part is classifying the landslide susceptibility map based on recommended susceptibility and hazard classification.

Landslide distributions were collected from two main sources. The first source is through the interpretation of aerial photographs from 1978, 1994, and 2005 which are in 1: 25,000 scales. The 1978 aerial photographs are in black and white and the 1994 photographs were obtained in color. A stereoscope was used to get a 3D view of the area from the aerial photographs and later all landslides interpreted from the photographs were digitized and processed using the ArcGIS 10.1 software. To make sure that landslide locations are correctly digitized, the aerial photographs were rectified first based on 1: 50,000 topographic maps. For this research, only the 1978 and 1994 landslides were used for the analysis and the 2005 dataset was used to validate the final susceptibility map. The second source of information is obtained through fieldwork. Two fieldworks were conducted to locate new landslides along the road, the first one was done in 2009 and the second fieldwork was carried out in 2011. The locations of these landslides were also digitized in a point format.

Geological lineaments were extracted from RADARSAT-1 standard mode satellite imagery of the study area. Lineament density map was produced by calculating the total length of lineaments in meter for every km2 of the study area (Figure 3.1). This was done by using the fishnet tool in ArcGIS 10.1 to create a set of 1 km x 1 km grid that later was overlaid with the lineament map. The lineament density map was classified using natural break method into three classes: low (< 350 m/km2), moderate (351-688 m/km2) and high (>688 m/km2).

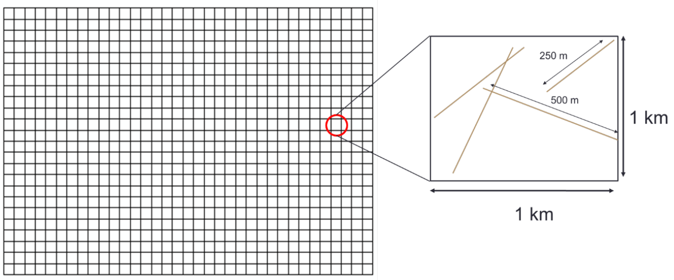

Figure 3: The fishnet tool is used to create a set of grids and the lineament density is calculated by counting the total length of lineaments in an every 1 km2 grid

The landslide density is also calculated based on similar concept that was applied on the lineament density map. The only different is that the landslide density is calculated based on the number of landslide in every 1 km x 1 km grid. To date, there is no standard landslide density classification to indicate high or low landslide density in an area. For that reason, this study uses three density classes to indicate the level of landslide density in an area. These classes are low (for 1 landslide/km2), moderate (2-3 landslides/km2) and high (≥ 4 landslides/km2).

The landslide susceptibility map is produced by combining both lineament and landslide density maps together. The overlapping areas indicated as high lineament density and high landslide density could be considered highly susceptible area for land sliding. Validation of this susceptibility map is carried out by calculating the numbers and percentage of landslides in the high susceptibility zone. Landslide data that are not part of the analysis were used to validate the map.

The level of susceptibility as indicated by the Australian Geomechanic Society (2007) is used to indicate the level of susceptibility based on the proportion of landslides that is in the high susceptibility class with the total landslides in the study area. The level of hazard was also calculated for the study area by calculating the number of landslides over the span of the assessment year in the high susceptibility zone. The levels of hazard and susceptibility based on the guidelines are given in Table 1.

Table 1: Descriptor on the degree of susceptibility and hazard used in this study [18]

Descriptor	Relative Susceptibility	Hazard
Very High	-	>10
High	>0.5	1-10
Moderate	0.1-0.5	0.1-1
Low	0.01-0.1	0.01-0.1
Very Low	0-0.01	<0.01

Note:
Susceptibility = proportion of the total landslide population in the study area Hazard = number or landslide / year / km

4. RESULT & DISCUSSION

4.1 Landslide density

The interpretation of aerial photographs resulted in 24 landslides in 1978 and 47 landslides in 1994. The landslides in 2009 and 2011 that were obtained from fieldworks showed high landslides occurrences in 2009 (56 landslides) but later declined sharply to only 21 landslides in 2011. The total landslides recorded for these four years are 148 landslides that spanned along the 55 km stretch Ranau-Tambunan road. The distribution of landslides based on each of the assessment years are presented in Figure 4.

The landslides were classified to examine their density in every 1 km2 of the study area (Figure 5). The classification was divided into three classes representing low landslide occurrence (1 landslide/km2), moderate occurrences (2-3 landslides/km2), and high occurrences (≥ 4 landslides/km2). Although the study area is dominantly characterized by low landslide occurrences all four assessment years, there are several sections of the roads that were classified as high landslide density area. The indicated high density sections of the road based on the distance from Ranau township to Tambunan is given in Table 2. Based on Table 2, the 2009 assessment year recorded the highest number of high landslide density locations with six locations, followed by three locations in 1994 and two locations in 1978 and 2009.

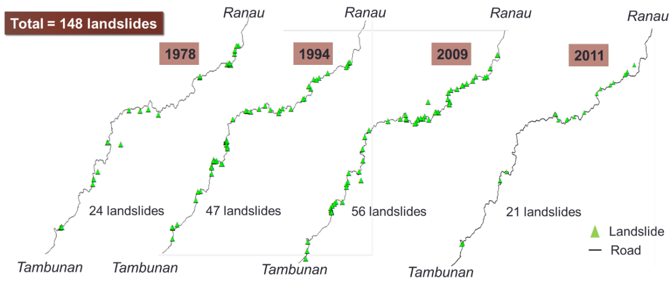

Figure 4: Landslide distribution along the Ranau-Tambunan road based on each of the assessment year

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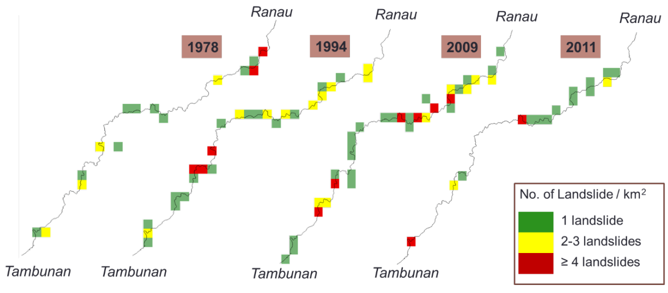

Figure 5: Landslide density classification for each assessment year

Table 2: Locations indicated as high landslide density for each assessment year

Year	1978	1994	2009	2011
Location (in km from Ranau town)	5, 8	35, 38, 39	16, 19, 22, 25, 41, 46	21, 45
Total locations	2	3	6	2

Although there were just few high landslide density zones in each of the assessment year, it can be observed that at least 1 landslide occurred in every 2-3 km of the road. In order to examine the landslide density as a total density for the four assessment years, landslides recorded in those four years were combined and analyzed together to produce the final landslide density map (Figure 6).

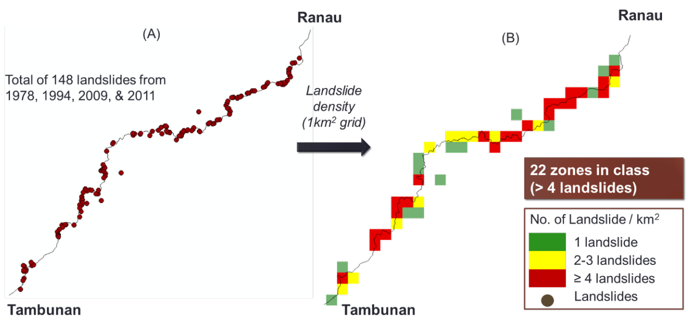

Figure 6: A final landslide density map was produced from combining landslides acquired from 1978, 1994, 2009, and 2011. (A) a map with landslide distributions from 1978, 1994,2009, and 2011 (B) A final landslide density map with 22 high landslide density zones computed from landslide events in the four assessment years

4.2 Lineament and Landslide Density

A lineament map that was produced from the interpretation of RADARSAT-1 satellite imagery was used to produce the lineament density map. This map is used to observe the association between landslide occurrences (landslide density) with the lineament density in the study area. The corrected lineament map that was transformed into a lineament density map is shown in Figure 7. The conversion on the lineament map from vector to density in a grid format is based on the total length of lineament in each of the 1 km2 fishnet grid. Subsequently, the lineament density map was classified into three density classes, namely: low (<350 m), moderate (351-622 m), and high (>688 m).

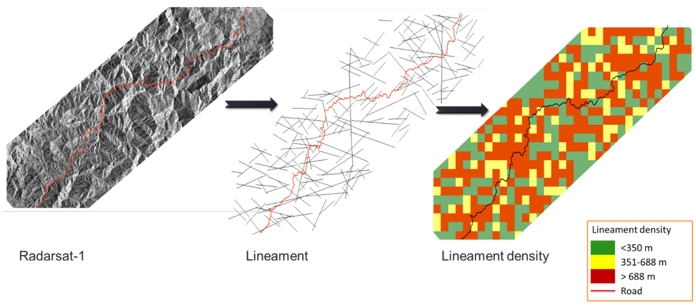

Figure 7: Landslide density map produced from geological lineaments interpreted from RADARSAT-1 satellite imagery

The high lineament density zone along the RTM road was extracted and overlaid on the 22 high landslide density zones (Figure 8). As a result of the overlay, 16 zones in the high lineament density are coincided with 16 zones in the high lineament density are coincided with 16 of the high

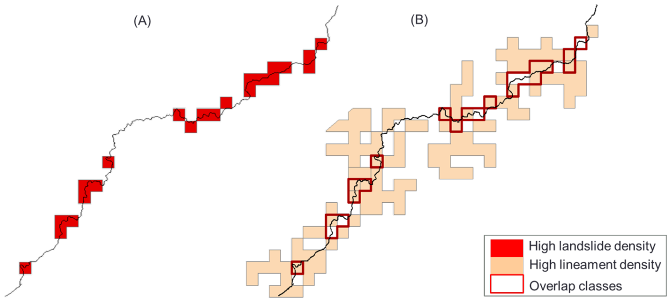

Figure 8: Overlaid of high landslide and high lineament densities zones

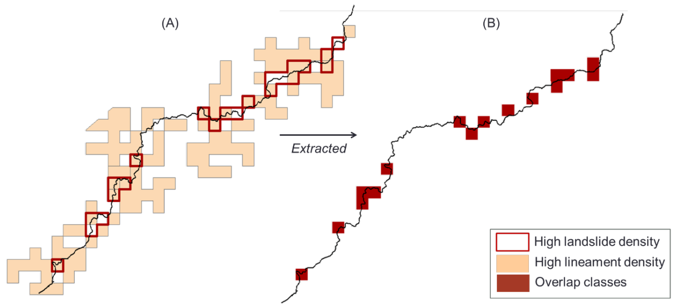

Figure 9: A total of 16 out of 22 high landslide densityzones coincide with the high lineament density zone (73% of the total high lineament density zones). (A) High lineament density overlaid on high landslide density zones (B) Overlaid classes of both high landslide and lineament densities zones extracted from (A)

4.3 Susceptibility and Hazard Quantification

The degree of susceptibility and hazard can be quantified and classified based on the method and proposed classes of susceptibility and hazard by AGS (Table 1) [18]. To proceed with the quantification process, the total landslide from the four assessment years were intersected with the 16 zones of high susceptibility classes shown in Figure 9. From the total 148 landslides acquired from the four assessment years, 87 landslides are within the 16 high susceptibility zones, which indicates that if the degree of susceptibility and hazard are calculated based on the guidelines by AGS (2007), the RTM road can be classified as highly susceptible (0.59) but moderate in terms of hazard (0.2). In terms of landslides that occurred in every 1 km2, it can be assumed that 5.4 landslides can be observed for every 1 km2, which is also can be indicated as high based on the classification of landslide density used in this study (Figure 5). Table 3 shows the degree of susceptibility, hazard and landslide density (per km2) that are based on the 87 landslides in the 16 high susceptibility zones along the RTM road.

Table 3: Description on the degree of susceptibility, hazard and landslide density of the study area

Degree	Quantification	Value	Degree
Susceptibility	87 landslides/148 total landslides	0.59	High
Hazard	87 landslides / 33 years / 16 km	0.2	Moderate
Landslide Density (per km^2)	87 landslides / 16 km^2	5.4 landslides/km^2	High

4.4 Validation

To validate the high susceptibility zones generated for the study area, 18 landslides in 2005 that occurred in close proximity to the road were used to validate the map. However, due to lack of aerial photographs, the landslides interpreted from the 2005 aerial dataset only covered around 50% of the road and only 18 landslides were recoded based on the availability of the aerial photographs. Nevertheless, the landslides from 2005 are adequate to validate the map. As a result, from the intersection between the high susceptibility zone and the 2005 landslides, 15 out of 18 landslides are located within the high susceptibility zones. This means that the susceptibility map accurately captures 83% of the overall landslides in 2005. This also demonstrates that the combined high lineament and landslide densities maps can be used to indicate locations that are highly susceptible to landslide in the future [19].

Figure 10 shows the distribution of landslides in 2005 along the RTM road.

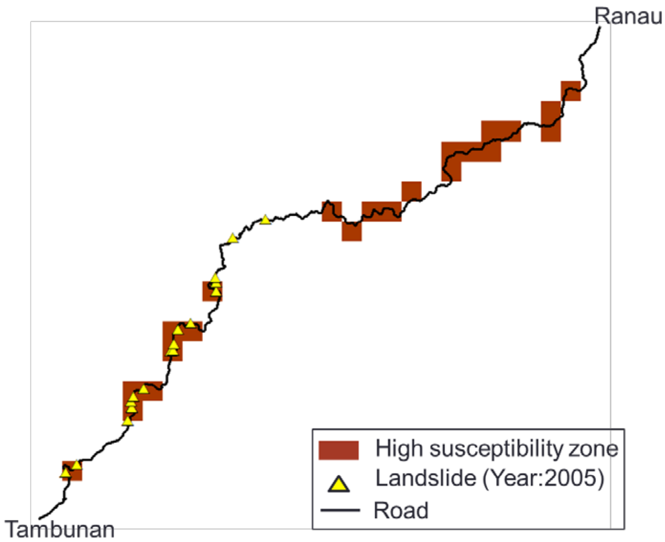

Figure 10: Landslide distribution that was acquired from aerial photographs in 2005 was used to validate the high susceptibility zone maprak

5. CONCLUSION

In this study, a simple and yet a useful technique using the landslide density method was used to carried out a temporal landslide assessment along the RTM road. Four assessment years with long duration between each year was used to assess the landslide density and landslide susceptibility of this road. From the analysis, it was shown that there is an association between the occurrences of high landslide density zones indicated by 4 landslides in a km2 with high lineaments area. Hence, most of landslides that occurred in this area were associated with the presence of high lineament density that may have caused the instability. A combination of the high landslide and high lineament densities maps resulted in a susceptibility map that has 83% acceptable accuracy. This map could be used to indicate areas that need better attention to minimize recurrence of landslides in the same area in the future.

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