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Lineaments And Their Association With Landslide Occurrences Along The Ranau-Tambunan Road, Sabah

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ABSTRACT

The purpose of this study is to assess the influence of lineaments on landslide occurrences based on the concept of lineament density. The Ranau-Tambunan districts with a 54 km road stretch from Ranau to Tambunan, crossing the Crocker and Trusmadi Formations is selected as the study area. In total, the study area is 844.7 km^2. Both formations have similar area with Crocker at 405.5 km^2 and Trusmadi at 425.6 km^2 The rest are either igneous and alluvium (13.6 km^2). The lineaments were identified using a 5x5 weighted kernel filter on a

RADARSAT-1 standard mode image. The lineament density was calculated using a 1 km x 1 km grid on the lineament map and the density for each 1 km^2 grid is represented by the total length of lineaments in a grid. A total of 334 lineaments were identified with the lineament density map classified into three classes of density, resulting low (<318-m), moderate (319-775-m), and high (>775-m) using the natural break classification. The lineament density is more pronounced in the Crocker compared to the Trusmadi Formation. The influence of lineament on landslide occurrences was examined by overlapping the lineament density map with 75 landslides observed from fieldwork to determine the number of landslides in each density class. Out of the 75 landslides, 29 landslides occurred in the Crocker Formation and the other 46 landslides in the Trusmadi Formation. From the overlapped, a total of 47 landslides (63%) were captured into the high density class with 19 and 28 landslides in the Crocker and Trusmadi Formations respectively. These results indicate over half of the landslide occurrences are induced by the presence of lineaments with the highest percentage of landslides occurring in the Crocker Formation. As a conclusion, this study found that using the grid technique is an effective way to determine lineament density and quantify its influence on landslide occurrences.

KEYWORDS: Lineament density, lineament, landslides, RADARSAT.

INTRODUCTION

Several studies has shown the importance of incorporating geological lineaments in landslide studies especially in rock formation that has experience shearing activities in mountainous regions (Tongkul, 2007; Lee and Lee, 2006). However, there is no standard approach or guideline to quantify the degree of lineament that may cause landslide. It is undeniable that landslides occurred not only due to one factor but quantifying the density of lineament to induce landslides will indicate the importance of that factor towards landsliding.

A simple approach is used in this study to quantify the degree of lineament influence towards landsliding. The concept of density is applied as opposed to buffer zone that is often used in many studies (Pachauri *et al*., 1998; Lee, 2005; Lee and Lee, 2006). The density concept has been introduced by Eyles et al. (1978) where they examine the density of road and the number of landslide occurrences using a grid technique. Therefore, the objectives of this study are

a) to create a lineament map of the study area
b) to quantify the lineament density of the study area
c) to examine the influence of lineament on landslide occurrences in the study area

GEOLOGY

The geology of the study area is composed of sedimentary rock of the argillaceous Trusmadi Formation (Palaeocene to Eocene age), the arenaceous Crocker Formation (Late Eocene age) and Quaternary Alluvium Deposits (Jacobson, 1970). While the study area is dominated by these formations, alluvium deposits and igneous rock do occurred in some parts of the study area. Figure 1 shows the rock formations of the study area based on the geological map by the Yin (1985) and the Ranau-Tambunan road crossing both the Trusmadi and Crocker Formations.

Jacobson (1970) divided the Trusmadi Formation rock sequence into four main lithological units; argillaceous rocks, interbedded sequences (turbidites), cataclasites and massive sandstones. Trusmadi Formation is characterized by the present of dark coloured argillaceous rocks, siltstone and thin-bedded turbidite in a well-stratified sequence. Some of the Trusmadi Formation rocks have been metamorphosed to low grade of the green-schist facies; the sediments have become slate, phyllite and metarenite. The shale is dark grey when fresh but changes to light grey and brownish when weathered. The Trusmadi formation generally shows two major structural orientations NW-SE and NE-SW (Tongkul, 2007).

The Crocker Formation can be divided into four main lithological units; namely thick bedded sandstone, thinly bedded sandstone and siltstone, red and dark shale and slumped deposits (Jacobson, 1970). The sandstone of the Crocker Formation is normally fine to very fine-grained and highly fractured while the shale layers are sheared (Roslee *et al.*, 2006). The shale unit is generally composed of red and grey types. The grey variety is occasionally calcareous. The sandstone composition is dominated by quartz with subordinate amounts of feldspars and chloritized, illitized or silicified lithic fragments. Calcareous fractions are rare. Thin shale or siltstone beds between 3 to 40 cm thicknesses occurr between the thick sandstone beds. The argillaceous beds are frequently sites of shearing while the sandstone beds are sites of fracturing or jointing (Roslee *et al.* 2011).

The alluvium is restricted to the low land. It mainly represent unconsolidated alluvial sediments on river terraces composed of unsorted to well-sorted, sand, silt and clay of varying proportions which were derived from the upstream bed rocks. They occur in irregular lenses varying in form and thickness. The alluvium may also consist of a very thin layer of organic matter. The alluvium sediment is soft, compressible and may be prone to settlement (Roslee *et al.* 2006; 2011). The igneous rock that consist of granitic and ultrabasic rocks are found closer to the Ranau district. The lithology map of the study area is shown in Figure 1.

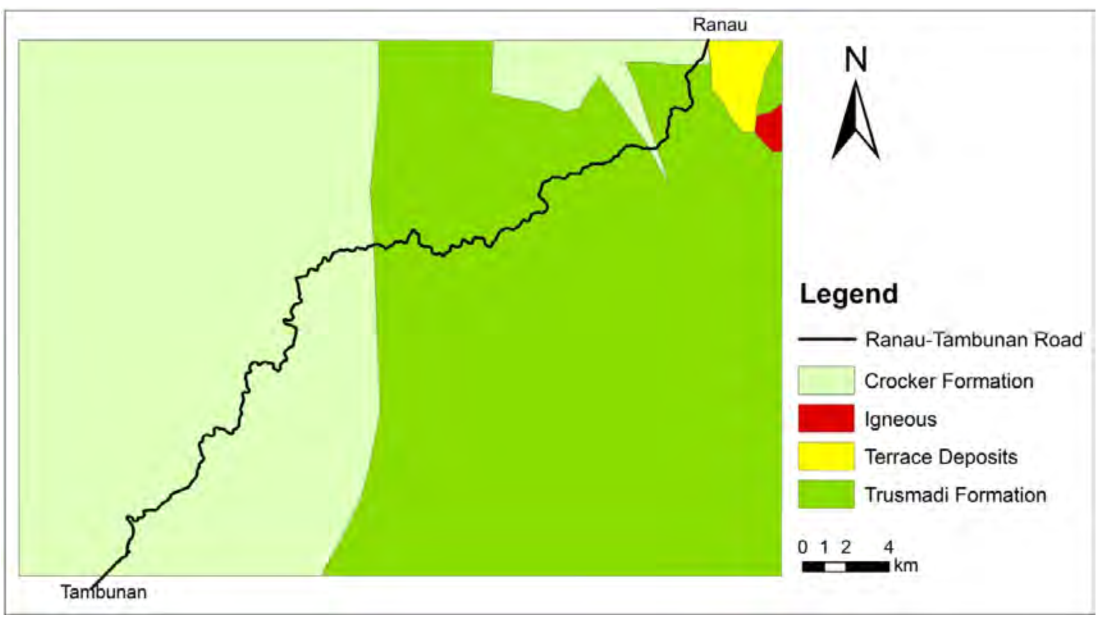

Figure 1: Lithology map of the study area with the Ranau-Tambunan road crossing both the Crocker and Trusmadi Formations (modified from Yin, 1985)

Geological Lineaments & Landslides

Geological structures which exist in rocks are known as discontinuities. In engineering practice, a discontinuity is a rupture in rocks or a boundary in rock or soil that indicates a change in the rockmass (Hencher, 1989). Examples of discontinuities in rocks are foliations, beddings, faults, folds, fractures and joints. A high volume of fractures and joints in a rock slope may create a fracture zone and indirectly lower the stability of rock slopes by reducing the overall rock mass strength (Saha *et al*., 2002; Ferdaus and Chow, 2004; Roslee *et al*., 2007; Ramli *et al*., 2010).

Besides high volume of lineaments, several elements that are present between lineaments such as sensitive infill materials may also weaken the strength of rockmass. Infill materials and water found in the discontinuities also play a major role in determining the shear strength of the discontinuity. Low shear strength of infill materials will increase the likelihood of rock blocks sliding (Amin & Yau, 2004). Water flowing through a network of discontinuities will dissolve some unstable minerals, and over time, decrease the rock strength (Kwong *et al*., 2004). Apart from infill materials and flowing water, slope ripening, which refers to the aging of a slope will also increase instability due to opening up of the slope's joint system (Crozier, 1984). As the slope ages, the joint system in the slope will widen and the action of 'cleft water' in the joint due to rainfall will destabilize the slope.

Lineament density and distance to lineaments are two factors often used for GIS based landslide analysis. Several studies have found that lineaments directly influence landslide occurrences either by distance between the lineament and landslides or by concentration of lineaments in a particular area, which also known as lineament density (e.g. Atkinson and Massari ,1998; Pachauri *et al*., 1998; Suzen and Doyuran, 2004; Lee, 2005; Lee and Lee, 2006). These studies however, did not specify how the buffer zone and lineament density were determined. In his review, Ramli *et al*. (2010) acknowledged that lineament analysis in landslide studies, especially in specifying lineament buffer distance or zone varies across studies and is most probably due to the different conditions of the study area.

METHODOLOGY

The concept of lineament density is different from the concept of lineament buffer zone, where the latter technique measures the distance between the lineament and landslide occurrences. The lineament density technique measures the length of lineament in a specified grid. For instance, in this study, a set of grid containing squares with an area of 1 km^2 each was constructed and overlayed on the lineament map. The 1 km^2 grid area is used to standardize it with the topography map grid which is also 1 km^2.

The regional lineament of the study area was identified by applying a non-directional filter on a Radarsat-1 standard mode image. This image underwent three speckle suppression stages with the coefficient of variation of 0.264258, 0.219524, and 0.168426. These coefficient values are needed to remove harsh noise in the radar image. The Lee-Sigma filter in the ERDAS 9.3 software was used to filter out the noise in the image. After the speckle suppression process, a 5x5 non-directional edge enhancement method known as weighted line which is also available in the ERDAS 9.3 software was used to enhance edges in the radar image. The weighted line edge detection method has four non-directional filters. These filters enhance lineaments that are negative as darker objects making it easy to identify than the positive lineaments . This study interested in negative lineaments because they represent geological structures such as fault, joints, and cracks.

After the lineaments were digitized, a correction process is carried out to ascertain the lineaments are geological lineaments. The correction process involved comparing the lineament map with road map and ridges line in aerial photograph and Landsat image. The overlapping lineaments were also examined to ensure sure that no single lineament was digitized twice. The correction method suggested by Akhir (2003) was also applied.

Next, a 1 km x 1 km grid was created using the fishnet tool in ArcGIS 9.3 software. This grid which is initially in polyline format was converted to a polygon format and later was overlapped with the lineament map to calculate the total length of lineaments in each grid. The total length of lineaments in each grid represent the density of lineament in the grid (Figure 2). The lineament density is transformed to a continuous surface by converting the grid file to raster format. This density technique is a modification of the technique applied by Eyles et al. (1978) where they used a set of grid (400 m x 250 m) to measure the total length of road in each grid and turning it into road density. The lineament density was later classified into low, moderate, and high density classes using the natural breaks technique and subsequently, the map was overlapped with the landslide locations obtained from the field to determine the percentage of landslides in each density class. The summary of the methodology employed in this study is shown in Figure 3.

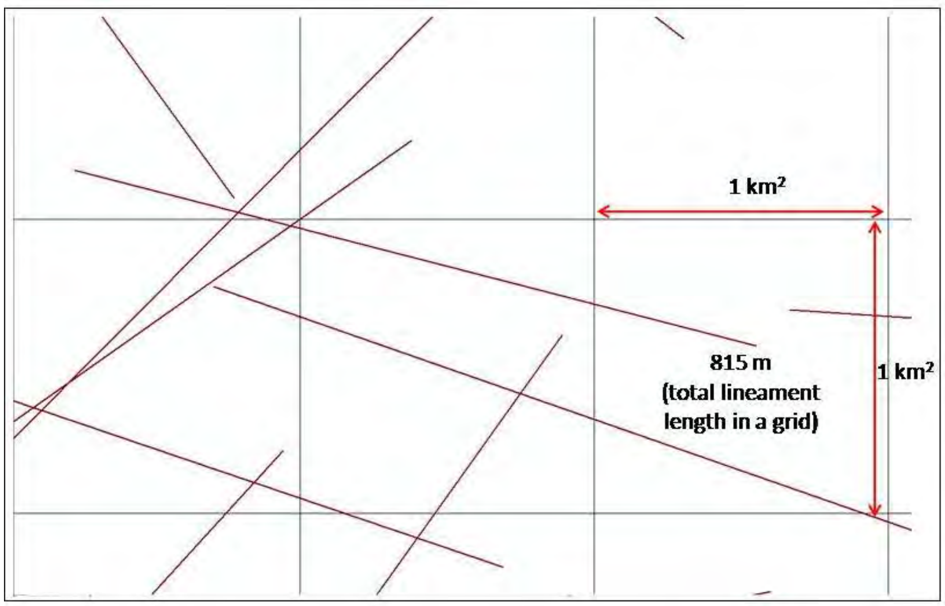

Figure 2: This example illustrates how the lineament density was calculated. The lineament density in each 1 km^2 grid is represented by the total length calculated in each grid

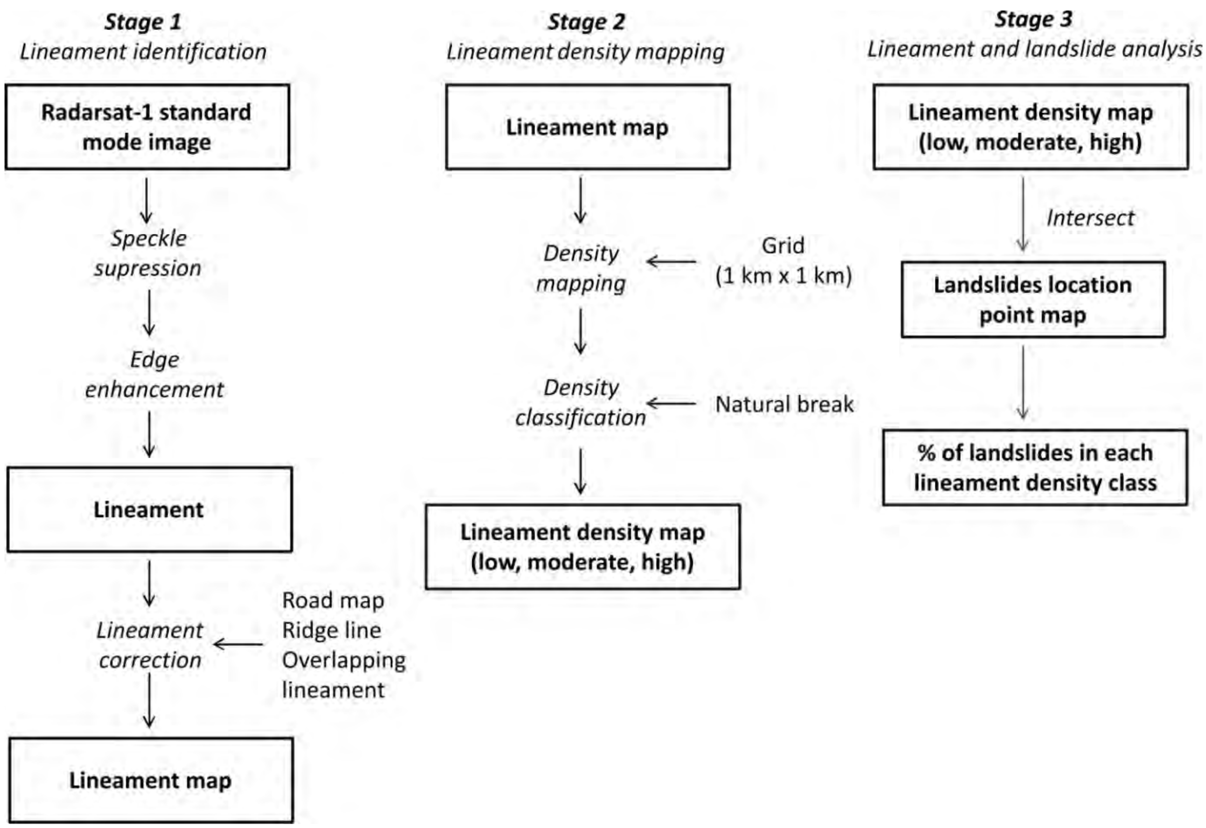

Figure 3: The methodology used in this study to produce the lineament density map consists three stages: Stage 1 is the process to identify lineaments in the image; stage 2 is the process of converting the lineament map from the first stage into a lineament density map with different classes; and stage 3 is the analysis to examine the influence of different lineament density classes with landslide occurrences

RESULT AND DISCUSSION

Landslides Along the Tambunan-Ranau Road

A total of 75 landslides were observed from the field along the 54 km Tambunan-Ranau road (Figure 4). Out of the 75 landslides, 29 were recorded in the Crocker Formation and the other 46 in the Trusmadi Formation. The length of road crossing through the Crocker and Trusmadi Formations is approximately 29 km and 24 km respectively. This shows that the landslide occurrences along the road is denser in the Trusmadi than the Crocker Formation.

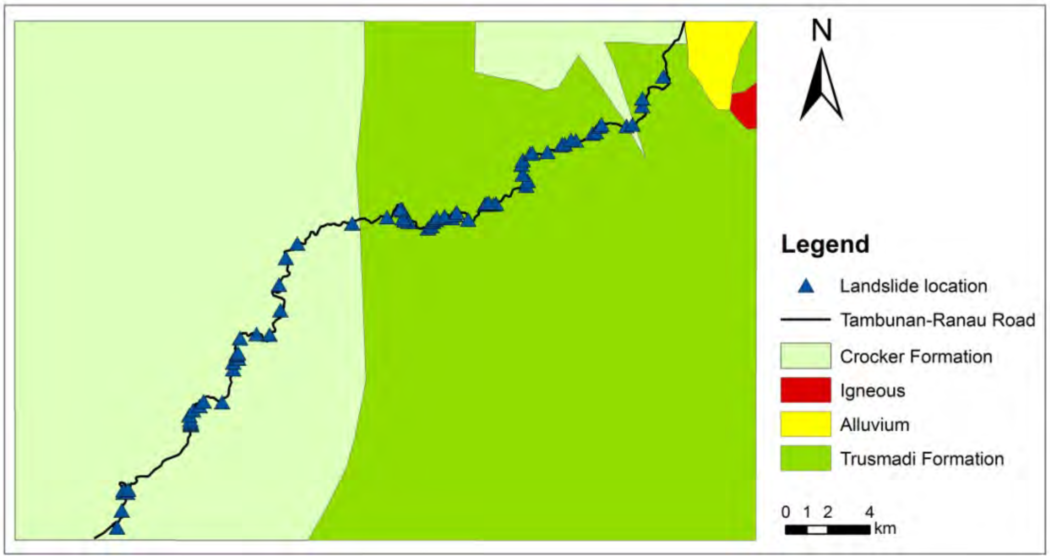

Figure 4 Distribution of landslide locations along the Ranau-Tambunan road. A total of 75 landslides were recorded. Forty six and 29 landslides were observed in the Trusmadi and Crocker Formations respectively (geological map modified from Yin, 1985)

Lineament

A total of 334 lineaments were identified from the radar image. The length of lineaments range from 1.00 km to 11.80 km with a total length of 1075.37 km. Figure 5 shows the distribution of lineaments for the different rock formations in the study area. Lineaments are more pronounced in the Trusmadi compared to the Crocker formation with 209 and 181 lineaments respectively. However, the Crocker Formation has greater lineament length (576.20 km) than the Trusmadi Formation (488.13 km). The major direction of the lineaments digitized is NW-SE, which is in agreement with Tongkul (2007) (Figure 6).

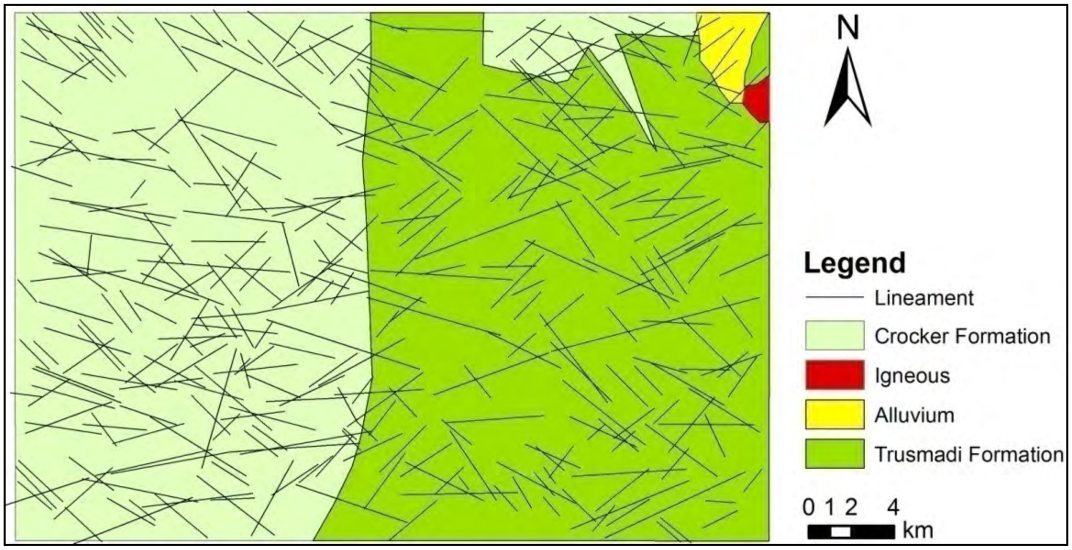

Figure 5: Distribution of lineaments for the rock formations in the study area (geological map modified fromYin, 1985)

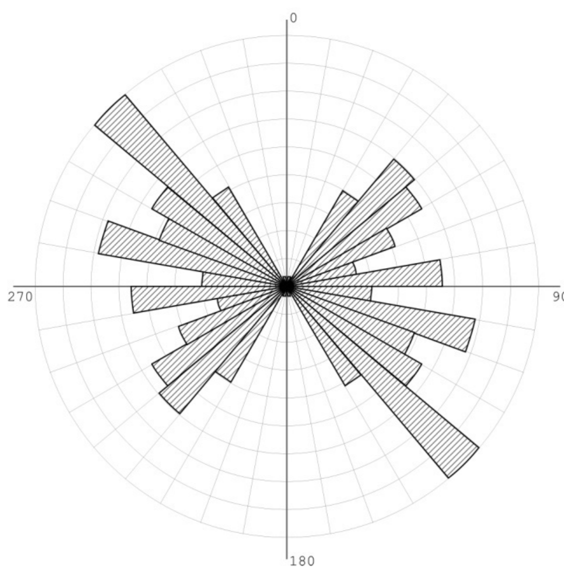

Figure 6: Lineament orientations with major directions of NW-SW. The major direction of the lineament is in agreement with Tongkul (2007)

Lineament Density, Rock Formation and Landslides

The lineament length calculated in each grid range from 0 to 1448 m. Therefore, by using the natural breaks function in the ArcGIS 9.3 software, the lineament density was classified into three classes indicating low (<318 m), moderate (319-775 m) and high (>775 m) (Figure 7). The natural breaks function is applied because it is useful to classified data that has a sudden jump in value (Ayalew & Yamagishi, 2005). Subsequently, the lineament density map was overlapped with the Crocker and Trusmadi Formations to obtain the relative area of high lineament density in both formations. Apart from overlapping the lineament density map with the rock formations, the landslide occurrences were also analyzed with the lineament density map to determine the frequency of landslides in the high lineament density class. The terrace deposits and igneous lithology are excluded from the analysis because they only cover a small portion to the NE of the study area and no landslides were recorded in these areas.

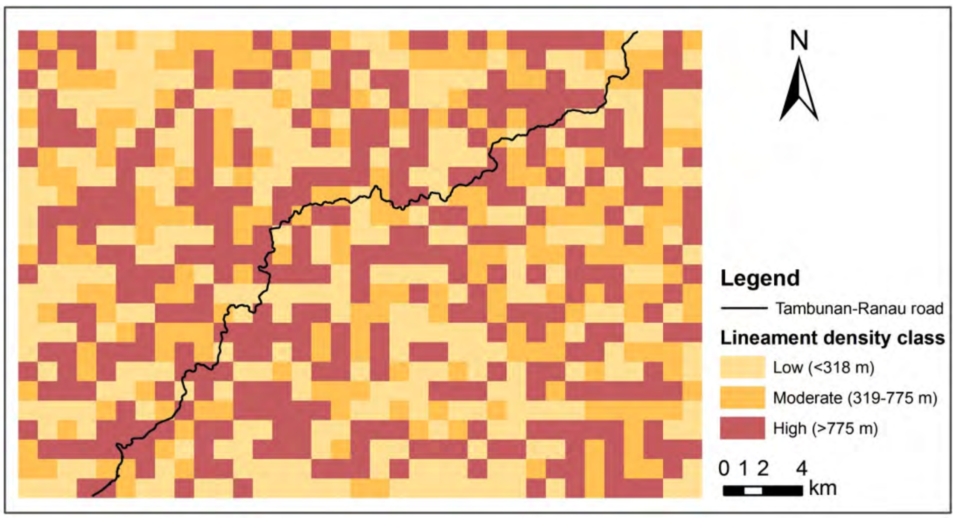

Figure 7: Distribution of lineament density classes in the study area. The lineament density was classified into three classes: Low (<318 m), moderate (319-775 m), and high (>775 m)

Based on the indicated result in Table 1, the high lineament density class covers almost 40% of the area in each rock formation. The result also indicated that the Crocker Formation recorded a higher percentage of landslides in the high lineament density class compared to the Trusmadi Formation. Landslides that occurred in the high lineament density class in both formations recorded a total of 63% out of the 75 landslides in the study area. The result shown in Table 1 imply that lineaments in the study area is an important landslide inducing factor that indirectly influence the occurrence of at least 63% landslides . In Figure 8, several landslides can be observed directly located in the high lineament density class and in some cases, cut crossed by lineaments.

Table 1: Percentage of landslides and area that are classified in the high lineament density class. The result shows that lineament in the study area is an important factor that influence at least 63% of landslides

Formation	Landslides			Area (km^2)		
	Total	High lineament density	%	High lineament density	Total	%
Crocker	29	19	66	164.7	405.5	41
Trusmadi	46	28	61	166.3	425.6	39
Total	75	47	63	331.0	831.1	40

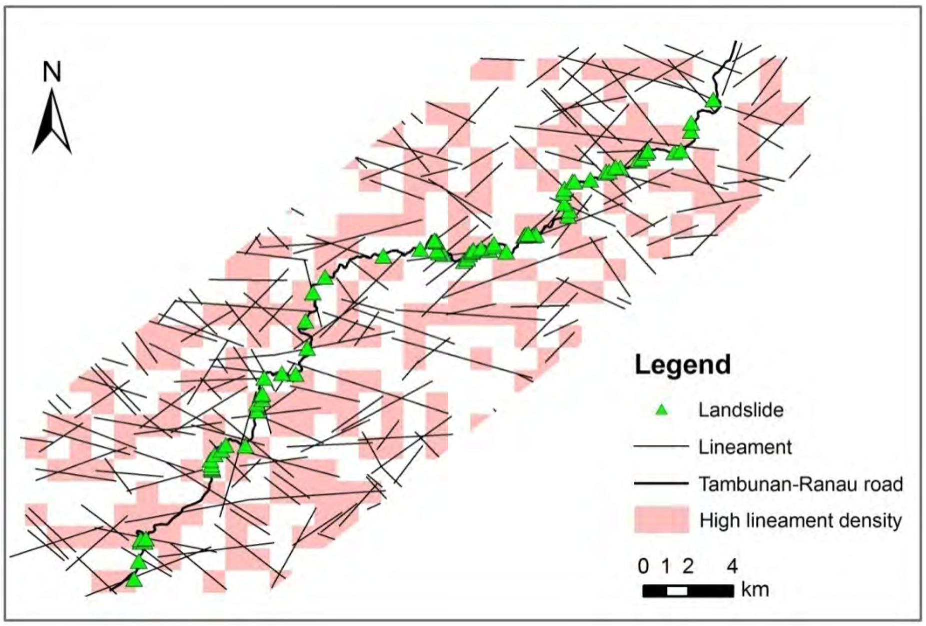

Figure 8: Lineaments and landslide distribution with the area classified as high lineament density. Several landslides can be observed located directly in the high lineament density class

CONCLUSION

This study successfully demonstrates the simple technique to calculate lineament density for landslide analysis. The 1 km^2 x 1 km^2 grid can be used as a guideline for lineament density comparison across studies in different areas, in particular with studies that involve landslide investigation. Quantification of lineament density can be systematically done by calculating the length of lineaments in each 1 km^2 grid. This technique is not restricted to landslide studies but can also be used in other lineament related studies such as in geothermal exploration.

However, the issue with the this density technique is the classification of the lineament density into different density classes. In this study, the density was classified into low, moderate and high classes based on the natural breaks method. Although this method is suitable if there is a visible jump of value in the data, this value may vary from one study to another, especially in a different area. Therefore, in terms of density value, more studies are needed to establish the degree of density. Nevertheless, the density technique provides a useful platform for comparison of lineament density across studies.

As for the analysis, the result in this study indicates that lineament plays a major role in inducing landslides in the Crocker and Trusmadi Formations, where more than half of the landslides were located in the high lineament density class. Both formations that have different types of lithology shows similar susceptibility to landsliding due to the presence of high lineament density.

ACKNOWLEDGEMENT

This publication was funded by the Young Researcher Grant (GGPM-2013-025 & GGPM-2013-082) under the National University of Malaysia. The main author would like to thank Prof. Emeritus Michael Crozier and Dr. Mairead deRoiste for their suggestion and advice on landslide analysis during the course of his study.

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