Landslide hazard zonation mapping using remote sensing and GIS techniques

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Abstract: The aim of this study is to utilise the remotely sensed data and GIS techniques for slope instability assessment and prediction in the chosen study area, Cameron Highlands. Slope instability can be considered as one of the most actual issues affecting this area, lately. With the availability of different types, multi temporal and various scales of remotely sensed data, several parameter maps can be generated, emphasizing the mass movements distribution map. The mass movements distribution map is prepared where each of its polygon is assigned with a special unique code. Other parameter maps either generated or extracted from the existing ancillary data are geological map, landuse map, terrain mapping units map, slope map, aspect map and classified distance map. GIS, on the other hand, can assist in terms of speeding up processing and moreover in the hazard zonation and prediction assessment.

The result of slope instability study by using the Information Value Method has given the indication of the most relevant causative factors influencing the mass movements occurrences in this study area. The construction of the roads at steep slopes can be considered as the most important causative factor, as is borne out by its high information value especially for the main and secondary roads. Another factor which has high value is landuse besides the slope steepness and distance from fifth, sixth and higher order river, even though classified slope and distances are of lesser influence to the mass movements occurrences. Summation of causative factor maps in that method has resulted in the delineation of the mass movement hazard zonation. Hence with the classified information from the infrastructure and landuse units, the risk to the area can be assessed. The very high risk area covers 164,600 m^2, mostly emphasizing several main road slopes and part of the market gardening area in Bertam Valley and some sloping areas in Tanah Rata and surroundings.

INTRODUCTION

Landslides are one of the normal landscapes building processes in mountainous areas. They became a problem when they interfere with human activity and result in damage to properties and loss of life. Although most landslides are small and individually cause few fatalities, the cumulative losses worldwide account for around 25 percent of annual deaths from natural hazards (Hansen, 1984).

In Tropical areas, slope failures either initiated by natural processes or by human activities are a major cause of natural disasters. Although a small percentage of the individual slope failures are catastrophic, it is especially the high number of slope failures which contributes to serious economic loss such as direct damage to agricultural land and infrastructure and indirect damage to economic activity.

In Malaysia, human casualties due to landslide disaster have been recorded since as early as 1919. Table 1 below shows some of these casualties.

Since slope failure is considered as a fairly well predictable geological hazard, the economic losses due to slope failures can be reduced significantly. Landslide hazard zonation and risk zonation maps are the first step towards this end. Landslide hazard is defined as the probability of occurrence of a landslide within a specified period of time and within a given area, whereas the Landslide Hazard Zonation is defined as the division of the land in classes with equal landslide hazard (Varnes, 1984). A landslide hazard zonation provides information on the susceptibility of the terrain to slope failures and can be used for the estimation of the loss of fertile soil due to slope failures (in agriculture areas), the selection of new construction sites and road alignments (in urban or rural areas) and the preparation of landslide prevention, evacuation and mitigation plans. On the other hand, natural hazard mapping is not restricted to the delineation of occurrences of phenomena such as mass movement in the past, but it is focussed on making prediction about the occurrences of such phenomena in the future (Varnes, 1984). For the definition of others, *risk* is defined as the expected number of lives lost, persons injured, damage to property, or disruption of economic activity because of a particular natural phenomenon; and *zonation* refers to the division of land in homogeneous areas or domains and the

Paper presented at GSM Annual Geological Conference '99

Table 1. The human casualties due to landslide tragedy in Malaysia (Ibrahim, 1996).

Date of Incident	Location	Landslide Type	No. of Casualties
17 Dec 1919	IP, Perak	Rockfall	12
18 Oct 1973	Ipoh, Perak	Rockfall	40
15 Jan 1981	Puchong, Selangor	Debris flow	13
11 Dec 1993	Ampang Jaya, Selangor	Complex	48
30 Jun 1995	Genting Highlands, Selangor	Debris flow	21
30 Aug 1996	Tapah, Perak	Debris flow	44

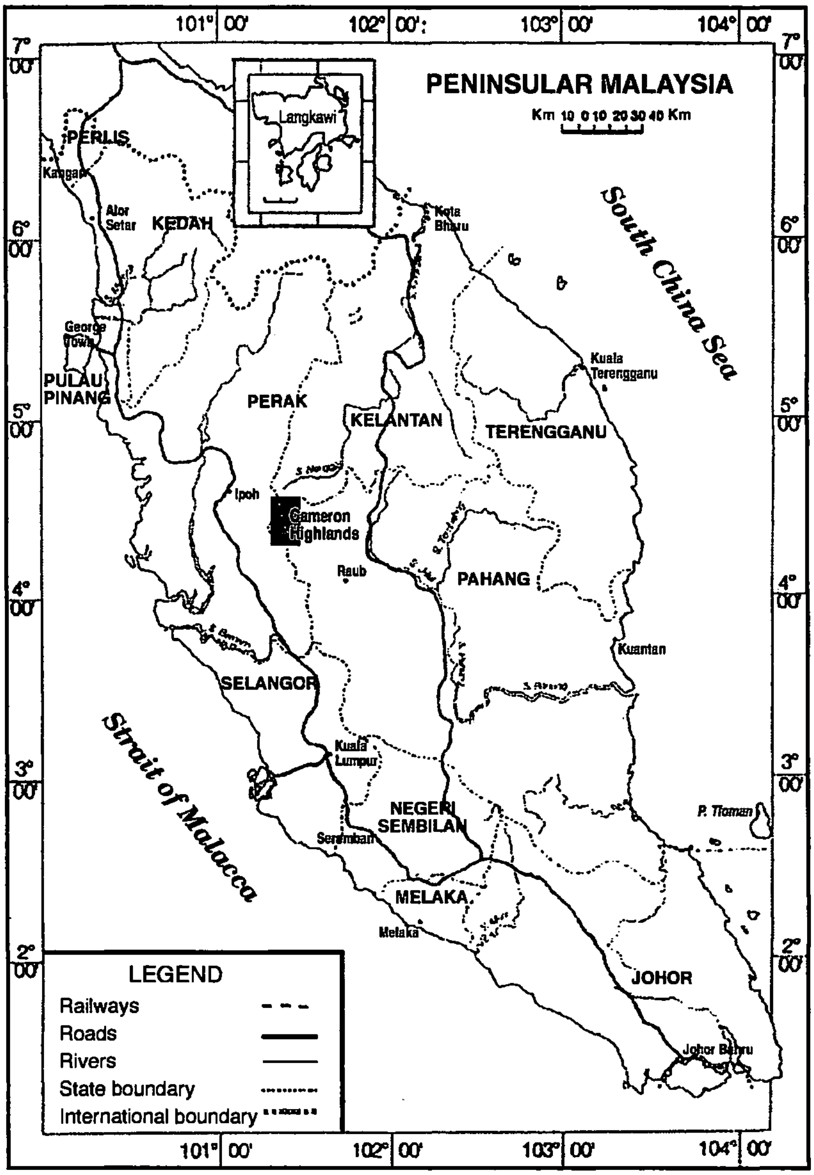

Figure 1. Location of study area.

ranking of these areas according to their degrees of actual or potential hazard caused by landslides.

STUDY AREA

The study area, which is nestled among the lofty peaks of the Main Range of Peninsular Malaysia, is located in the north–western corner of Pahang State (Fig. 1). This area is accessible only by road via Tapah, 45 kilometers away in the state of Perak. Geographically, this area is bounded by longitudes 101°20'26"E to 101°26'56"E and latitudes 4°24'38"N to 4°33'20"N. The physical relief of this area is rough and has altitude ranging from 840 m to 2,110 m above sea level.

GEOLOGY AND GEOMORPHOLOGY

The geology of this area is quite simple as most of it is covered by granitic rocks with small portions of metamorphic rocks and alluvium (Fig. 2). These granitic rocks can be subdivided into three units as follows:

i. Biotite adamellite
ii. Coarse to medium grained biotite granite
iii. Tourmaline granite

Geochronological studies using Rb-Sr from the samples of coarse grained biotite granite from Tanah Rata, suggested that these granitoids were emplaced in Upper Triassic, 210–230 Ma (Bignell and Snelling, 1977).

The metamorphic rocks, whose main constituent is quartz mica schist can be found at a few localities only. These observed localities are normally narrow, close to the granitic rocks, and can be considered as part of the bases of roof pendants.

The structure, on the other hand, interpreted from remote sensing imagery, shows four principal trends of lineaments; namely:

i. NE-SW
ii. E-W
iii. NNW-SSE
iv. WNW-ESE

The geomorphology of this area is mainly dominated by denudation landforms as it is situated in a mountainous area and has constituent of deep highly weathered material. Most parts, especially the exposed unprotected areas, like slope-cuts, abandoned agriculture sites and slope-form agriculture sites, are highly affected by this denudational action. Therefore, erosion features such as rill and gully can be clearly seen. As a consequence of this phenomenon, for certain areas, landslides occurred as these features worsen.

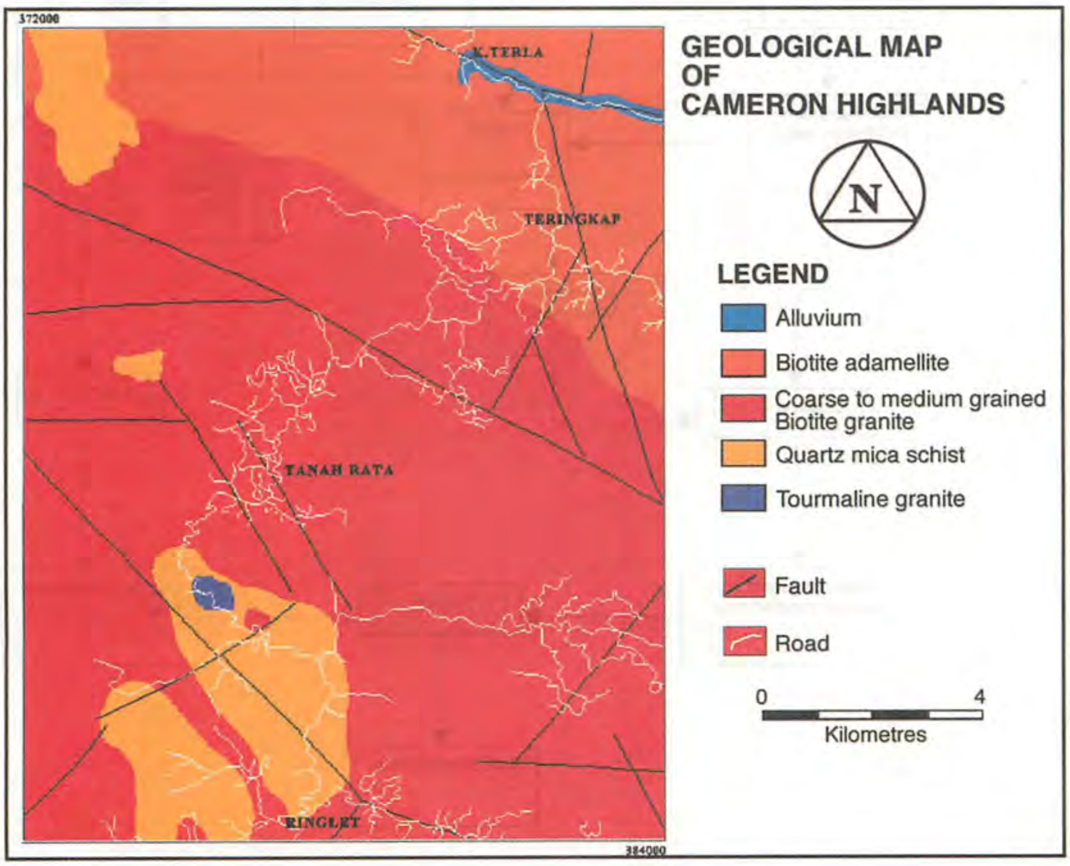

Figure 2. Geological map of Cameron Highlands.

Table 2. The calculated information value for classified distance from main road to all mass movement's occurrences.

Classified distance	No. pixel	Area (m^2)	Density in map	Density in class	Information value
0	1798254	179825400	0.007566394	0.005595091	–0.301827
1	25892	2589200	0.007566394	0.03301587	1.473272
2	22506	2250600	0.007566394	0.04744773	1.835912
3	23142	2314200	0.007566394	0.04403685	1.76131
4	21996	2199600	0.007566394	0.03237869	1.453784
5	20556	2055600	0.007566394	0.02044415	0.99398

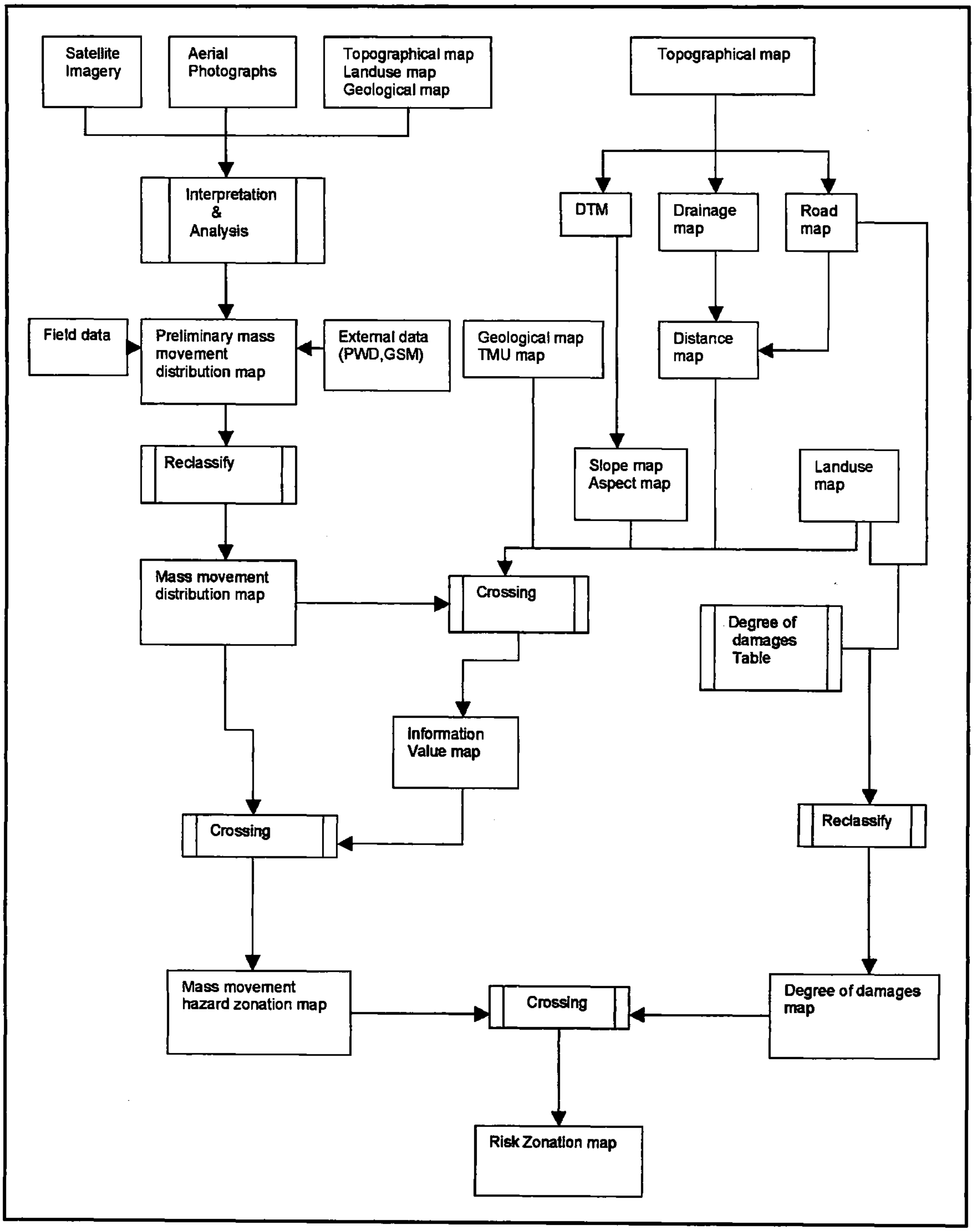

Figure 3. Flowchart of methodology.

MATERIAL AND METHODOLOGY

The procedure of the methodology can be shown as in the flow-chart in Figure 3.

The data that were used are:

i. Topographic map and digital elevation data which later were used for DTM generation
ii. Geology map
iii. Landuse map
iv. Distance map that were generated from fault, drainage and road map respectively
v. Remotely sensed data: satellite data and aerial photographs.

The preliminary mass movement distribution map was produced based on the interpretation from multi-temporal different scale aerial photographs. The aerial photos acquired in 1966 were developed on 1:25,000 scale, whereas the other, acquired in 1985 was 1:40,000 scale. The interpretation was made based on photo checklist suggested by van Westen (1993). The demarcation of mass movement occurrences were delineated as polygons which were later used for GIS analysis.

The analysis used for the landslide hazard was Information Value Method, developed by Yin and Yan (1988), and can be applied both to land units as well as on a pixel basis in calculations. However, as the study area was not split into small land units, like rock units used by Yin and Yan (1988) or sub-catchment areas used by van Westen (1993), the pixel basis was suggested for use in the calculation.

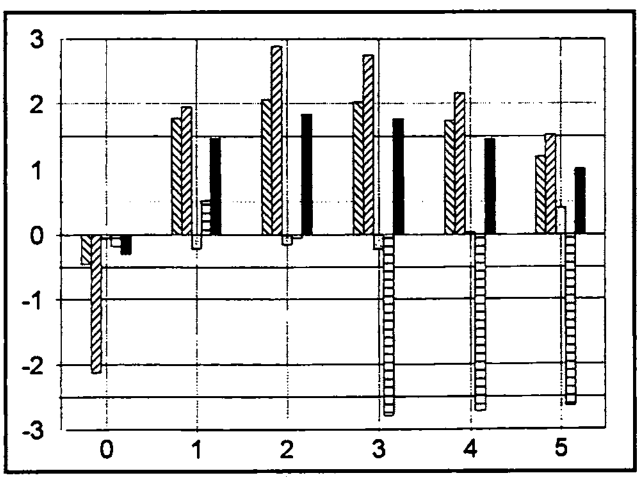

Figure 4. The graph of information value for each classified distance for main road to all types of mass movements. Types of mass movement are put according to slide, flowslide, flow, avalanche and all types in each class. Y-axis represents Information Value whereas X-axis represents Classified Distance.

The calculation applied to this hazard information method is based on the following formula, as for calculation the information value I_i for variable X_i :

$$I_i = \log \frac{S_i/N_i}{S/N}$$

In which:

S_i = the number of pixels with mass movements and the presence of variable X_i
N_i = the number of pixels with variable X_i
S = the total number of pixels with mass movements
N = the total number of pixels

The degree of hazard for a pixel j is calculated by the total information value I_j :

$$I_j = \sum_{i=0}^{m} X_{ij} I_i$$

In which:

m = number of variables
X_{ij} = 0 if the variable X_i is not present in the pixel j and 1 if the variable is present

The bigger the I_j value is the more unstable pixel j within the slope.

RESULT AND DISCUSSION

The relation of information value with causative factor maps below shows that the most relevant factors influencing the mass movements occurrences in this area. The factor maps are:

i) Distance from road
ii) Landuse
iii) Classified slope, and
iv) Distance from river

The construction of the roads at steep slopes can be considered as the most important causative factor, as is borne out by its high information value especially for the main and secondary roads. On the other hand, even though the values for the distance from tertiary and quaternary roads show positive signs, their evidence for the mass movement's occurrences is less. Table 2 and Figure 4 below show an example of the relation of the information value with the causative factor map.

Reclassifying the total information value map generated the hazard zonation map (Fig. 5). The map reclassified three arbitrary classes such as low, medium and high hazard. Low hazard can be described as the probability of occurrences of landslides are very limited even with strong triggering factors, such as heavy rainfall and tremendous landuse changes. On the other hand, the medium hazard means that, some mass movements will be generated under the influence

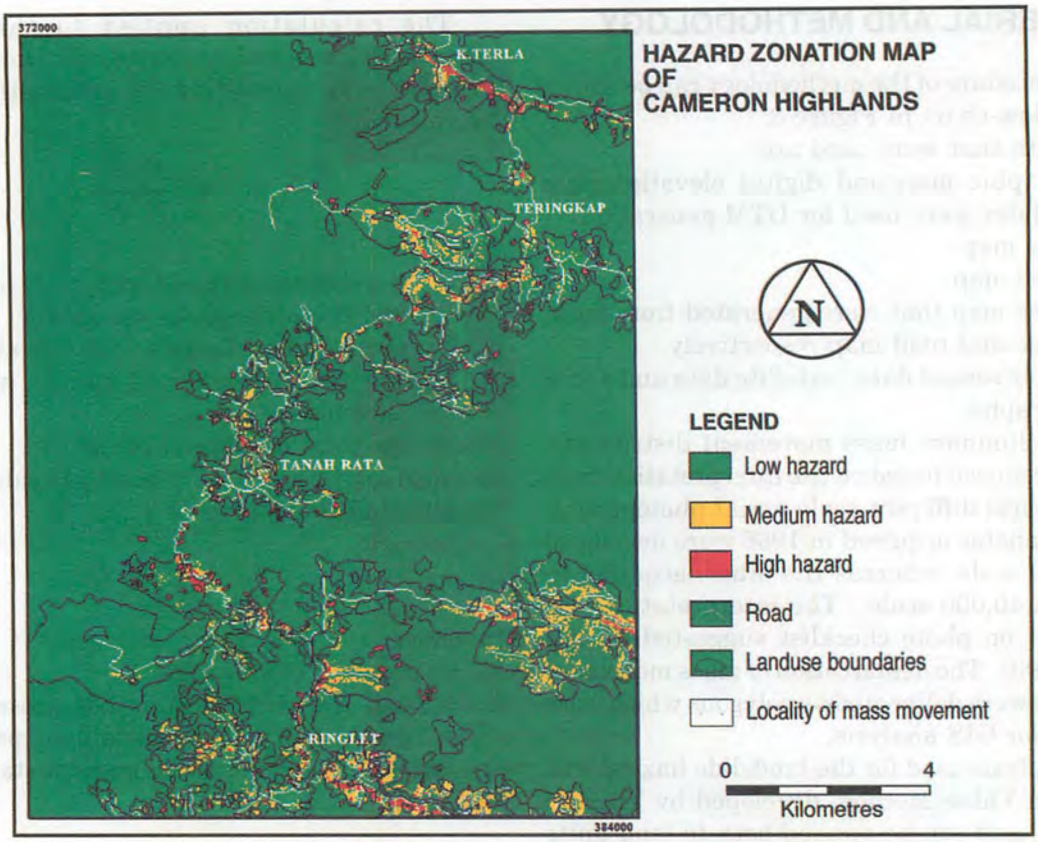

Figure 5. Hazard (landslide) zonation map of Cameron Highlands.

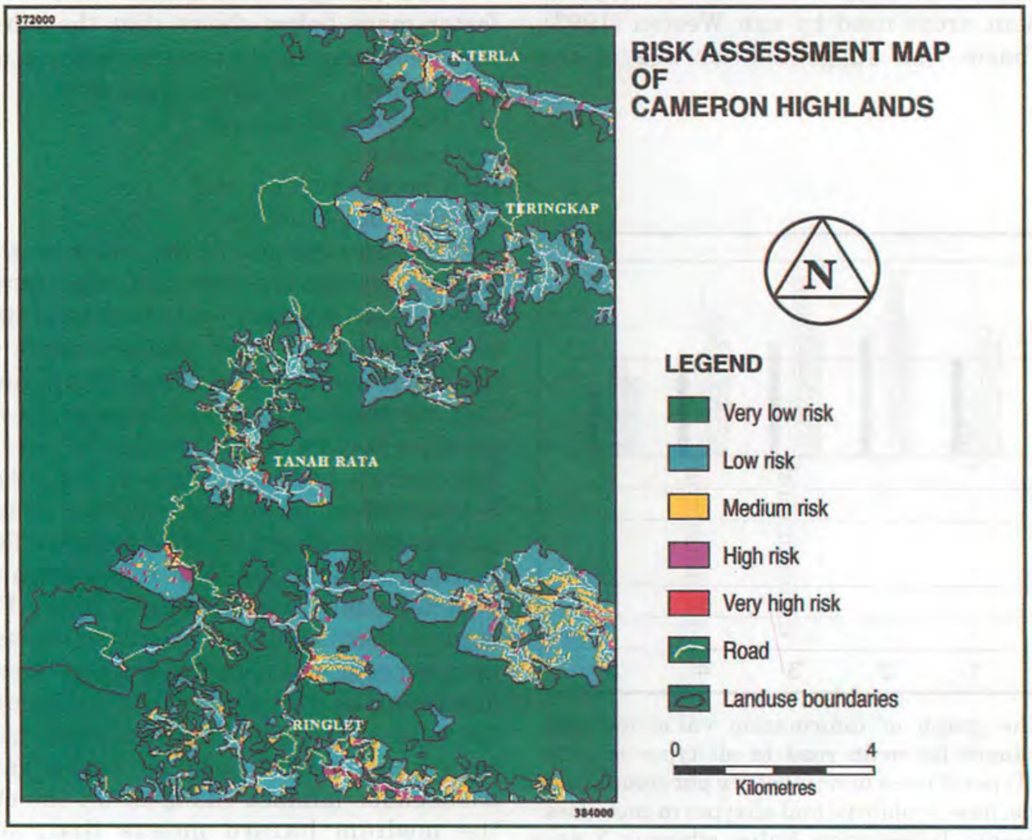

Figure 6. Risk assessment map of Cameron Highlands.

of intense triggering factors whereas for the high hazard, a considerable number of mass movements will be expected even with the presence of weak triggering factors.

The risk assessment map that was generated from hazard zonation map and degree of damages table was subdivided into five arbitrary classes from very low to very high risk.

CONCLUSION

Based on the hazard zonation and risk assessment prediction, some portions of the area need much more careful consideration of their stability especially the areas where lives and properties are involved. Very high risk areas cover 164,600 m^2; the most important of them are listed below:

i) Sloping areas either at the road slopes or in the market gardening areas in Bertam Valley, Ringlet.
ii) Some areas in Tanah Rata, especially the area located at the edge of urban area unit which is normally either bounded by hill slopes or where building is done on the constructed earthfill slopes.
iii) Some areas of slopes along the main road which are parallel to the Bharat Tea Plantation.
iv) Several road slope areas in Berinchang (north of Tanah Rata).
v) Similarly, road slopes in Ringlet, approaching the Sultan Abu Bakar Lake.

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Manuscript received 22 September 1999