Landslide hazard and risk assessment: The Malaysian experience

SUHAIMI JAMALUDIN[1] & AHMAD NADZRI HUSSEIN[2]

[1]*Slope Engineering Branch, PWD Malaysia (e-mail: suhaimij@jkr.gov.my)*
[2]*Slope Engineering Branch, PWD Malaysia (e-mail: hanadzri@jkr.gov.my)*

Abstract: Each year, landslides around the world create huge economic loss and disruption, and often result in loss of life. Landslides can occur almost anywhere, from man-made slopes to natural and pristine ground. Social and economic loss due to landsliding can be reduced by means of effective management and planning. This involves landslide hazard and risk assessment and mapping, mitigation measures, and warning systems. For the past few decades, there have been a number of methodologies developed for a better understanding of landslide hazard and risk. Hazard and risk assessment have become an important tool in addressing uncertainty inherent in mass movement. In Malaysia, due to its rapid development since the 1980s, suitable low-lying areas for development have become increasingly unavailable. As a result, development of highland or hilly terrain has increased, particularly in areas proximal to densely populated cities. Development of slope assessment systems in Malaysia to predict the likelihood of landslide occurrence began in the early 1990s. Various parties, including government agencies and private organizations, are involved in an effort to reduce landslide hazards and their consequences. Slope assessment projects carried out in Malaysia can be divided into two categories by the scale of assessment: large-scale or medium- to small-scale. Large-scale assessments are widely used in prioritizing slope maintenance along roads and highways while medium- to small-scale assessments are a tool for controling development in hilly areas. Large-scale assessments are mostly carried out by the Public Works Department (PWD), the main technical department in Malaysia, whereas the medium- to small-scale assessments are carried out by the Department of Mineral and Geosciences (DMG) and the Centre of Remote Sensing (MACRES). This paper will present experiences of various parties in Malaysia in the use of landslide hazard and risk assessment.

Résumé: Les glissements de terrains peuvent entraîner un nombre considérable de blessés et des pertes économiques importantes dans le monde entier. Les glissements de terrain peuvent se produire presque partout, que ce soit sur les pentes artificielles ou sur les sols naturels encore vierge. On peut réduire les pertes sociales et économiques dues aux glissements de terrain au moyen d'une planification efficace et d'une gestion incluant l'évaluation des risques et dangers liés aux glissements de terrain, des mesures d'atténuation et des systèmes d'alerte. Lors des dernières décennies, on a développé un certain nombre de méthodologies qui permettent de mieux comprendre les risques et dangers liés aux glissements de terrain. L'évaluation des risques et dangers est devenue un outil important quand on se penche sur l'incertitude inhérente aux risques et dangers liés aux glissements de terrain. La Malaisie, suite à son rapide développement depuis les années 80, fait actuellement face à une situation où les basses terres stratégiques et utilisables sont de moins en moins disponibles. A cause de cela, l'utilisation des montagnes moyennes et des terrains onduleux a augmenté, en particulier à proximité de régions densément peuplées. Le développement de systèmes d'évaluation des pentes afin de calculer les probabilités de glissements de terrain a vu le jour dans les années 90. De nombreuses parties incluant les agences gouvernementales aux différentes disciplines ainsi que des organisations privées se sont impliquées afin de réduire les dangers liés aux glissements de terrain et leurs conséquences. Les projets d'évaluation des pentes mis en place en Malaisie peuvent être classés en deux catégories, selon l'échelle de l'évaluation : les projets à grande échelle et les projets à moyenne et petite échelle. Les projets à grande échelle sont largement utilisés pour accorder la priorité aux pentes le long des routes et des autoroutes tandis qu'on a recours aux projets à moyenne et petite échelle pour le contrôle du développement des terrains onduleux. Les évaluations à grande échelle sont essentiellement effectuées par le Département des Travaux publics, le principal département technique de Malaisie, alors que les évaluations à moyenne et petite échelle sont effectués par le Département des Minéraux et de la Géoscience (DMG) et le Centre de Détection à Distance (MACRES). Cet article a pour but de présenter les expériences des différentes parties intervenant en Malaisie dans le domaine de l'évaluation des risques et dangers liés aux glissements de terrain.

Keywords: Landslides, risk assessment, highways, land use, mapping, terrain analysis.

INTRODUCTION

Landslides have resulted in large numbers of casualties and huge economic loss in hilly and mountainous areas in Malaysia. Due to a rapid development since the 1980s, strategic and suitable low-lying areas for development have become increasingly unavailable in Malaysia. As a result, the development of highland or hilly terrain has increased, particularly in areas adjacent to densely populated cities thereby exposing urban communities to an increased risk of landslide occurrence. From 1993 to 2004, there were six major landslides (both in cuttings and natural slopes) reported near to or within densely populated cities in Malaysia. These landslides resulted in nearly 100 fatalities (Table 1). There are also landslides occurrences that create significant disruption but without any fatalities such as:

- May 1999: Athenaeum Condominium, Ulu Kelang
- 2003: rock slope failure at Bukit Lanjan on the New Kelang Valley Expressway

Table 1. Series of major landslide occurrences in urban area of Malaysia for the past decade and resulting fatalities

Date	Location	Type and Nature of Landslides	No. of Death	Notes
December 1993	Ulu Klang, outskirt of Kuala Lumpur City	Shallow rotational slide. Prolonged and heavy rain triggered retrogressive failure of cut slope behind the Highland Tower apartment - toppled Block A	48	Cut slope in granitic formation
June 1995	Karak Highway - Genting Highland slip road, Selangor – Pahang border, 20km to Kuala Lumpur City	Debris flow. Failure of upstream natural dam during heavy rain triggered 'snowball effect' debris avalanche	22	Natural slope in meta-sediment formation
January 1999	Squatters settlement, Sandakan Town, Sabah	Shallow rotational slide. Heavy rain triggered landslide - buried a number of squatter houses / huts	13	Natural slope in meta-sediment formation
November 2002	Hillview, Ulu Kelang, outskirt of Kuala Lumpur City	Debris flow. Sliding / flowing of debris soil of abandoned projects during heavy rain - toppled a bungalow at the toe of the hill	8	Dumping area of abandoned project in granitic formation
November 2004	Taman Harmonis, Gombak, outskirt of Kuala Lumpur City	Debris flow. Sliding / flowing of debris soil from uphill bungalow project - toppled the back-portion of neighbouring down-slope bungalow after a week of continuous rain.	1	Dumping area of ongoing project in meta-sediment formation
December 2004	Bercham, Ipoh City, Perak	Rock fall - buried back portion of illegal factory at the foot of limestone hill.	2	Natural limestone cliff in karsts formation

Figure 1 shows examples of landslides occurring close to Kuala Lumpur city centre. Figure 1(a) shows a landslide occurred in 1999 at Ulu Kelang, approximately 5 kilometres from the Kuala Lumpur city centre. This landslide destroyed the access road of the surrounding neighbourhoods. It also affected the occupancy and rental rate of the Athenaeum Condominium located at the top of the hill. Figure 1(b) shows a rock slope failure that occurred at Bukit Lanjan in 2003 on the New Kelang Valley Expressway, one of the main entrances to the Kuala Lumpur city centre. This rock slope failure caused major disruption and resulted in the diversion of traffic flows for six months.

In the past decade, several projects on landslide hazard and risk assessment have been carried out by Malaysian government agencies. These projects have been for various applications such as land use, agriculture and slope management. Landslide occurrence and severity probability has been studied using statistics, landslide inventory, heuristics and a deterministic approach (Varnes 1984; Soeters & Van Westen 1996; Hussein, Omar & Jamaludin 2004). Ali Jawid (2000), Rosenbaum, Senneset & Popescu, (1997) and Tangestani (2003) described an attempt to use fuzzy set theory analysis. Kubota (1996) and Yi et al. (2000) used fractal dimension, a mathematical theory that describes the quality of complex shapes of images in nature to evaluating landslide hazard.

(a) (b)

Figure 1. (a) Landslide in front of Athenaeum Condominium, Ulu Kelang. (b) Rock slope failure at Bukit Lanjan on the New Kelang Valley Expressway.

MALAYSIAN EXPERIENCE IN LANDSLIDE ASSESSMENT

The Malaysian government departments involved in landslide mitigation are the Public Works Department (PWD), Department of Mineral and Geosciences (DMG) and Centre of Remote Sensing (MACRES). PWD is the main technical department in Malaysia and is largely involved in slope remedial works (active action) as well as the development of slope assessment and management (passive action). The main contribution of the DMG and MACRES is to inform the government of areas prone to landsliding. They have produced slope or terrain hazard zonation maps and these are widely used by the government agencies as a guideline in the development of hilly and mountainous areas.

Public Works Department (PWD)

Much of the landslides hazard and risk assessment work carried out by the PWD is based on the linear type of slope assessment, mainly carried out for road maintenance projects. The assessment level of the works carried out by the PWD is mainly at large scale. Large-scale assessments refer to maps between 1:5,000 and 1:15,000 scale (IAEG 1976). A variety of assessment methods are used, from heuristic to statistical methods.

Landslides assessment was first introduced to the PWD in 1993 for slope management along the East-West highway, linking Gerik town in Perak to Jeli town in Kelantan. The slope management system introduced in the East-West highway has reduced the annual expenditure on slope remedial works from 4.2% to 2.3% of the original road construction costs (Lloyd et al. 2001).

Altogether five landslides assessment projects have been carried out by the PWD. Two of these are summarised in Table 2. The results from these studies have highlighted the number of high and very high risk slopes thereby increasing the need for further work to minimize landslides and their consequences.

Table 2. Summary of two landslide assessment projects carried out the PWD

Landslide Assessment Project / Works	**Year completed**	**Objectives**
East-West Highway Long Term Preventive Measures and Stability Study	1996	Assessment of slopes along the East-West Highway, Gerik - Jeli
Slope Protection Study for Federal Route 22, Tamparuli – Sandakan, Sabah	2004	Assessment of slopes along the Federal Route 22, Tamparuli – Sandakan, Sabah

East-West Highway Long Term Preventive Measures and Stability Study (EWH study)

The EWH Study was the first landslide assessment project carried out by the PWD (PWD Malaysia 1996). In this study, a slope inspection proforma was devised and data for the 1,040 numbers of non-failed and failed slopes along the highway were collected. The parameters captured for each slope include age, batter height, bench width, ratio of crest length to edge length, number of culverts, relationship between slope and topography and the distance to ridge/gully. Spatial data was also collected using Digital Video Geographic (DVG) survey which integrates helicopter positioning, video imagery and laser profiling.

Using the discriminant analysis, significant slope parameters that contributed to landsliding along the highway were determined. The weightings for each parameter were then calculated using factor-overlay analysis, similar to the method proposed by Anbalagan (1995). A maximum parameter weighting of 2 was assigned to the relatively most hazardous sub-parameters. The weighting for other sub-parameters was calculated using equation (1) below.

$$\text{Weighting} = \frac{\text{Landslides frequency for sub-parameters}}{\text{Total number of landslides}} \times \frac{\text{Maximum parameters}}{\text{weighting}} \qquad (1)$$

For example, out of 100 known landslides, 5 numbers were in the range of 8 to 11 year old slope, so the weighting for this age range is 0.1 (i.e. 5 divided by 100 and multiply by 2). Using this method, the weightings for other slope parameters based on 7 geological formations were established. Table 3 shows an example of hazard weighting for cut slopes in the main range granite as used in the study. This hazard weighting was based on 74 cuttings (of which 31 had failed) in the main range granite formation along the East-West Highway of Peninsular Malaysia.

Table 3. Hazard weighting used in the EWH study; for cut slopes of main range granite (PWD Malaysia 1996)

Parameter	Sub-parameter	Weighting
Age in years	< 8	0.1
	8-11	0.1
	12	2.0
Culverts	Culvert	0.13
	No Culverts	2.0
Erosion	Gully; Very severe	2.0
	Gully; Moderate to severe	1.6
	Gully; Minor	1.27
	Rill; Very severe	0.87
	Rill; Moderate to severe	0.73
	Rill; Minor	0.6
	Sheet; Very severe	0 (no occurrences)
	Sheet; Moderate to severe	0 (no occurrences)
	Sheet; Minor	0 (no occurrences)
	No Erosion	0.53
Percentage of Feature Uncovered	0-19 percent	0.46
	20-39	0.67
	40-59	1.07
	60-79	1.47
	80-100	2.0
Feature Aspect in Degrees	0-59 degrees	0.2
	60-119	0.1
	120-179	0.87
	180-239	2.0
	240-299	0.4
	300-360	1.33
Rock Condition Profile	Claystone	0 (no occurrences)
	Conglomerate	0 (no occurrences)
	Granite	2.0
	Limestone	1.8
	Phyllite	1.33
	Sandstone	0.27

To establish risk, economic consequence criteria were determined that relate to the landslides occurrence. There are 3 parameters considered: *size*, *impact* and *time*. *Size* refers to the likely size of the landslide based on slope type and geometry, defined in four volume ranges (< 100 m^3, 100 to 1,000 m^3, 1,000 to 5,000 m^3 and > 5,000 m^3). *Impact* refers to the impact the landslide would have on the highway; for embankments this was failure scar regression; for cutting this was failure travel distance. Impact is defined by slope angle categories (0^0 to < 45^0, 45^0 to 60^0 and > 60^0) and distance range from slope toe or crest (0 to 5m, 5 to 10m and 10 to 20m) for each of three slope –high categories (< 10m, 10 to 30m and > 30m). *Time* is the time it would take to divert the route or reconstruct the embankment or to clear failure debris on the highway. Time is defined in four time ranges (1 day, 2 days, 3 days and ≥ 4 days).

Risk values were then obtained using the following equation:

Risk = Hazard x Consequence.

The factors affecting consequence values used in the EWH study are as described by Feiner & Ali (1999) and further details are described by Jamaludin, Muda & Alias (1999) and Lloyd et al. (2001). The risk score and rating used in the EWH study is shown in Table 4.

Table 4. Risk level and range of risk rating in percentage used in the EWH study (PWD Malaysia 1996)

Risk Score	Risk Rating / Level
80.1% -100%	Very High
60.1% - 80%	High
40.1% – 60%	Medium
20.1% – 40%	Low
0% – 20%	Very Low

The series of risk rating along the East-West Highway was then presented as Risk Maps. Figure 2 shows example of a Risk Map for a section of the EWH Study.

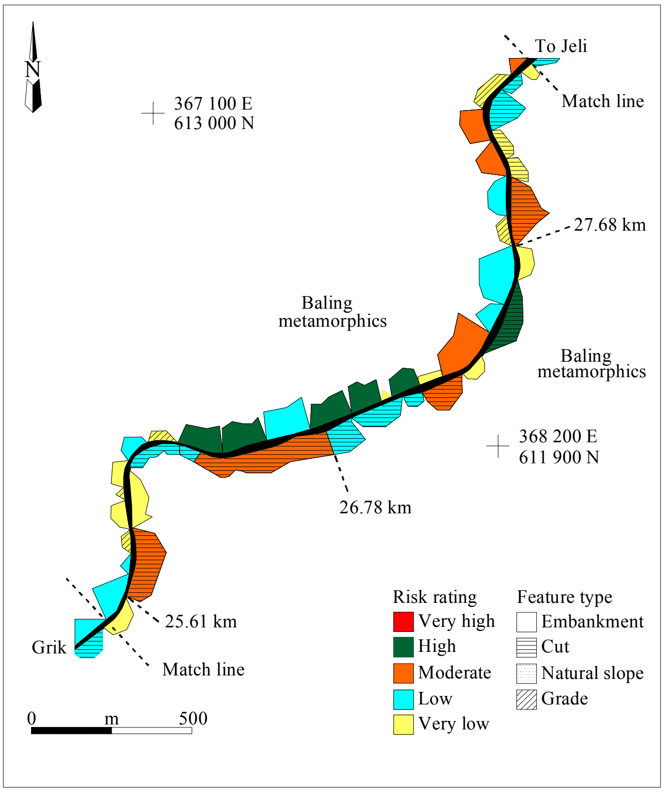

Figure 2. Typical risk map for a section of the East-West Highway study in Malaysia (Lloyd et al. 2001).

Slope Protection Study for Federal Route 22, Tamparuli – Sandakan, Sabah (TSR study)

The Slope Protection Study for Federal Route 22, Tamparuli – Sandakan, Sabah is the latest study carried out by the PWD. One of the main objectives of this study is to develop a slope management system for the road connecting Tamparuli Town and Sandakan Town (PWD Malaysia 2004) where there have been numerous landslide occurrences. The system called SMART (Slope Management and Risk Tracking System) has been completed but is subject to further verification before it can be used. The system uses slope inventory forms similar to the EWH Study with some slight modifications. The study also uses spatial data taken from LiDAR (Light Detection and Ranging).

In SMART the total risk score (TS) and associated risk rating assigned to each slope feature along the TSR is the product of an instability score (IS) and consequence score (CS). The IS ranges from 0 to 1 and is derived through the integration of results from 3 assessment methods: - Statistical Method (using discriminant analysis), Deterministic Method (the Factor of Safety determine by Combined Hydrology And Stability Model [CHASM] then converted to probability using Monte-Carlo simulations) and, if where appropriate, Heuristic Method (Expert Knowledge). The CS, which also ranges from 0 to 1, is derived using a method adapted from the Hong Kong GEO, Report No. 68: The New Priority Classification Systems for Slopes and Retaining Walls.

Following the calculation of TS, the data is then categorized in qualitative terms for the purpose of interpretation and action. The risk rating categories designed for this purpose are Very Low, Low, Medium, High and Very High.

The IS is calculated by a weighted average of two probabilities belonging to a failed (or unstable) group. One of these is derived from discriminant analysis and the other from Monte-Carlo simulations. The equation used to derive this is:

$$IS = \alpha DS + \beta MC \quad (2)$$

where,

DS =Discriminant Score which is the probability of a Slope Feature belonging to the failed slope group, ranging from 0 to 1

MC= Monte-Carlo probability score which is the probability of the Factor of Safety < 1 for the 1 in 100 yr 24 hour return period storm ranging from 0 to 1

$\alpha + \beta = 1$, where $\alpha = 0.9$ and $\beta = 0.1$

The variables identified as being significant in the discrimination (through Discriminant Analysis) of stable and failed slopes are defined, in order of significance, for each category of features (embankment and cuttings/natural slopes) along Tamparuli – Sandakan Road are as shown in Table 5.

Table 5. Variables significant in the discrimination of stable and failed slopes in the TSR study (PWD Malaysia 2004)

Embankment Slope	**Cutting / Natural Slope**
Main Cover type	Vegetation condition
Vegetation condition	Height
Slope Angle	Presence of Core stone boulders
Geology of the area upon which the embankment is constructed	Measure of ground saturation
Plan Profile	Slope Angle
Presence of structures	Cutting Topography relationship
Up slope / Down slope Geometry	Slope Shape
	Exposed Percentage (rock)
	Rock Condition Profile
	Plan Profile
	Surface Drainage rating

In terms of deriving the hazard rating categories, the following classification have been applied (Table 6):

Table 6. Instability score and category used in the TSR study (PWD Malaysia 2004)

Instability Score	**Instability Category**
0.0 – 0.2	Very Low
0.2 – 0.4	Low
0.4 - 0.6	Medium
0.6 – 0.8	High
0.8 – 1.0	Very High

The CS reflects the likely consequence of embankment or cut slope failure. The key factors considered and the ranges of the score that may be assigned are summarized below. The model in the TSR Study has a maximum possible score for a slope feature of 480. To aid analysis and interpretation, the CS is unitized (i.e. divided by 480).

Factor	Range of Score
Type and Proximity of Crest Facility	
Type and Proximity of Toe Facility	
Type and Proximity of Road Facility	0 - 480
Upslope and Down slope Topography	
Likely Scale of Failure	
Consequence Factor	

The consequence score is calculated according to equations (Eq. 3) to (Eq. 7).

$$CS = K\ (F+GJ+R)\ V \quad (3)$$

where;

$$F = F_1\ (H-F_2/\ H) > 0 \quad (4)$$

$$GJ = 2G_1\ ((1.5+ J)\ H-G_2/\ (1.5+ J)\ H) \quad (5)$$

$$R = 2R_1\ ((1.5+ J)\ H-R_2/\ (1.5+ J)\ H) \quad (6)$$

$$V = \gamma H \quad (7)$$

Notes: (1) γ = 1.0 for full-scale failure, 0.7 for partial failure and 0.4 for minor failure

(2) If H> 30m, take H = 30m in calculating V

where:

F = Above crest of feature component, GJ = Below crest of feature component, R= Road facility component, J = Upslope and Downslope topography, H = Slope Height (m), F_1= Above crest of feature facility score, F_2 = Distance from crest of feature to the facility (m), G_1= Below crest of feature facility score, G_2= Distance from toe of feature to the facility (m), R_1= Road facility score, R_2= Distance from slope crest or slope toe to the road facility (m) and K= Consequence to life / economy rating (default = 1, alternative = 1.25 for highly populated area). For the TSR Study a value of 1 has been applied to cuts whilst a value of 1.1 has been applied to embankments.

For the consequence analysis, it has been assumed that full-scale failure will occur at each slope feature (i.e. $\gamma = 1$ in equation (8)). The consequence score equation has been adapted from the GEO method via the inclusion of the road facility score. The rating categories for G I and Fl facility types follow the same methodology as described in GEO Report No. 68.

In terms of categorizing the CS, the following has been applied (Table 7):

Table 7. Consequence score and category used in the TSR study (PWD Malaysia 2004)

Consequence Score	Consequence Category
0.0 – 0.2	Very Low
0.2 – 0.4	Low
0.4 - 0.6	Medium
0.6 – 0.8	High
0.8 – 1.0	Very High

The TS is the product of the instability score and consequence score (equation 8):

$$TS = IS \cdot CS \qquad (8)$$

Note that TS ranges between 0 and 1 and each of the components (IS and CS) carries equal weight. Following the calculation of TS, the scores are categorised according to the score as shown in Table 8.

Table 8. Total risk score and category used in the TSR study (PWD Malaysia 2004)

Total Risk Score	Total Risk Category
0.0 – 0.1	Very Low
0.1 – 0.2	Low
0.2 - 0.4	Medium
0.4 – 0.6	High
0.6 – 1.0	Very High

The series of risk rating along the Tamparuli – Sandakan Road was then presented in form of Risk Maps. Figure 3 shows example of Risk Maps for a section of the Tamparuli – Sandakan Road study.

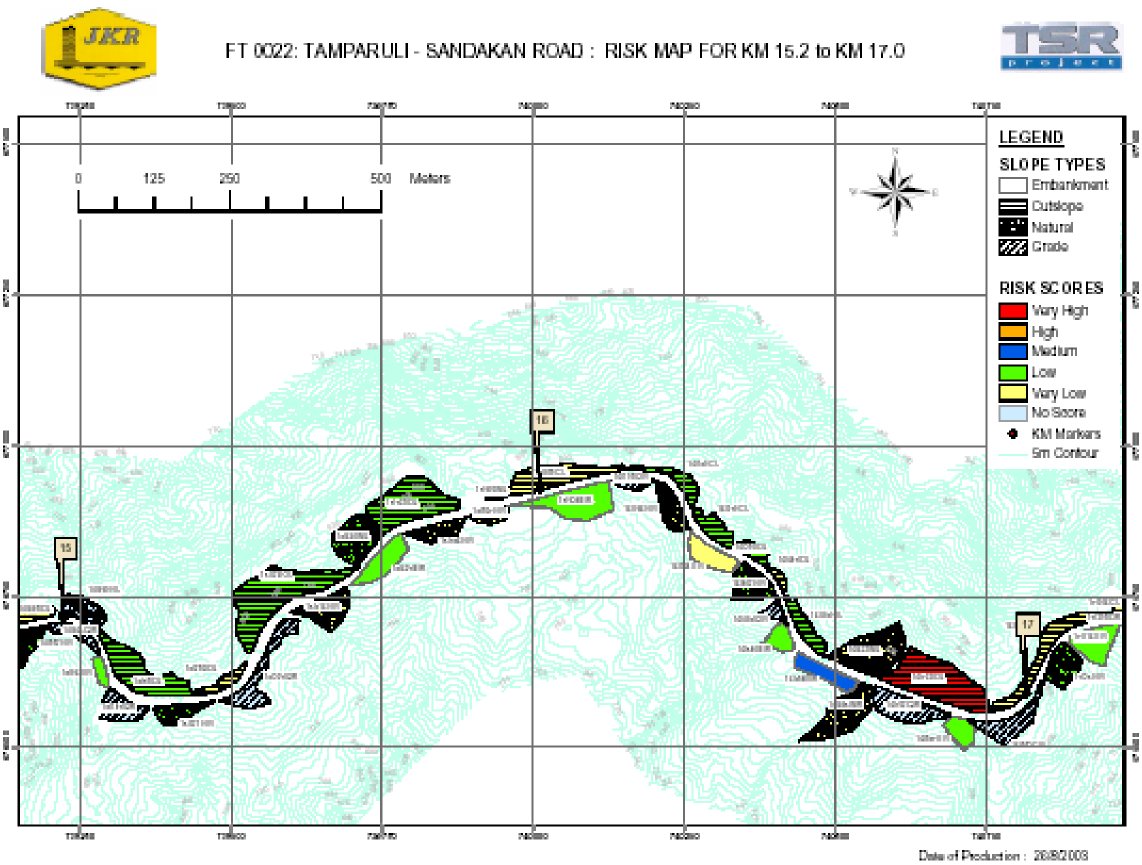

Figure 3. Typical risk map for a section of the TSR study (PWD Malaysia 2004)

Malaysian Center for Remote Sensing

The landslide assessment system developed by MACRES is based on a large assessment for land use planning. The assessment level of the project is mainly at a medium scale, from 1:25,000 to 1:50,000 (IAEG 1976), and uses statistical analysis.

Ab. Talib (1997) describes the use of remote sensing data and Geographical Information System (GIS) techniques for the development of hazard mapping for slope instability and prediction in the Cameron Highlands in the State of Pahang. This study used the Information Values method to indicate the most relevant factors influencing slope instability. Ab. Talib (2001) also describes the use of the same technique as outlined above to produce hazard zonation mapping for the State of Selangor. Parameter maps were generated from geological, land use, geomorphological, slope and distance maps. All the parameter maps were analyzed using ILWIS and ARC-Info software. Results showed that part of the Hulu Langat, Cheras, Ampang and Sungei Buluh areas have frequent landslide occurrences in the State of Selangor.

Both projects used the Information Values method developed by Yin & Yan (1988) and Kobashi & Suzuki (1988), given by equation below;

$$Ii = \ln (Si/Ni)/S/N \qquad (9)$$

where;

Ii = information value associated with variable X;
Si = number of pixels with mass movements (landslide) associated with variable X;
Ni = the number of pixels of variable X;
S = the total number of pixels with mass movements;
N = the total number of pixels in the study area.

The degree of hazard for a pixel j is determined by the total information values Ij which is given by equation below;

$$I_j = \sum_{i=0}^{m} XijIi \qquad (10)$$

where, m = number of variables, and $Xij = 0$ if the variable x is not present in the pixel j and 1 if the variable is present.

Ab. Talib also gave weightage values based on the information method for slope classes and geomorphological unit for the study areas as shown in Tables 9 and 10.

Table 9. Information value weightage for slope classes (Ab. Talib 2001).

Slope classes	Slope range	Information value weightage
1	0-10 degrees	-0.3563
2	10-20 degrees	0.6225
3	20-30 degrees	0.3024
4	30-40 degrees	0.6064
5	40-50 degrees	0.6096
6	50-60 degrees	0.8093
7	> 60 degrees	1.63

Table 10. Information values weightage for geomorphological unit (Ab. Talib 2001).

Gormorphological unit	Information value weightage
Alluvial plain	-0.9875
Water body	0.3734
Flood plain	-0.0774
River/fluvial terrace	-1.9232
Valley fill	-0.8116
Residual hill	0.2408
Denudational hill	0.5746
Structural hill	1.1471
Piedmont zone	1.0676
Blocky hill	0.6477
Scarp	2.3586
Top Hill	2.1556

Department of Mineral and Geoscience Department

The landslide assessment system developed by DMG is, like that by MACRES, based on a large assessment for land use planning. The assessment level of the works carried out by DMG is mainly at medium scale, and uses Qualitative Map Combination method of assessment.

Chow & Mohamad (2002) describe the use of terrain analysis and classification maps by DMG, which are based on four attributes: slope gradient, morphology, activity and erosion & instability. Derivative maps are then prepared using a GIS (ArcInfo or TIN software). The various map themes produced are landform, erosion, physical constraints, engineering geology and land use suitability. A case study of Cameron Highlands is described.

Landslide hazard maps are then created after the vegetation cover and seepage is studied. The classification of hazard and the hazard score used by DMG is shown in Table 11.

Table 11. Classification of landslide hazards rating used by the DMG (Chow & Mohamad 2002).

Class	Hazard rating	Hazard score
1	Low	< 0.25
2	Moderate	0.26-0.5
3	High	0.51-0.75
4	Very High	≥ 0.76

Landslide risk scores are then calculated using the standard equation (Risk = Hazard x Consequence). The consequence and risk scores suggested by Chow & Mohamad (2002) are shown in Tables 12 and Table 13.

Table 12. Weightage for consequential score used by the DMG (Chow & Mohamad 2002).

Type of risk	Land use / premises	Weightage
Risk of lives	Critical buildings affected	20
	Normal buildings affected	10
	Isolated building affected	5
	Very busy trunk road	10
	Busy trunk road	7
	Moderately used trunk road	5
	Seldom used trunk road	1
Economic loss	Damage to farm/park	3
	Business area (only access)	10
	Only access to housing area	6
	Temp. diversion (> 1 day)	3
	Temp. diversion (≤ 1 day)	0
	Alternative road (≥ 5km)	3
	Alternative road (< 5km)	0
Public Utilities	Affected	10
	Not affected	0
Proximity of building to suspected landslide	Very close	10
	Close	5
	Possibly affected	2
	Unlikely to be affected	0
	Not affected	0

Table 13. Classification of landslide risk rating used by the DMG (Chow & Mohamad 2002).

Rating	Total score
Low risk	< 12.5
Moderate risk	12.6-25
High risk	26-35
Very high risk	> 35

SUMMARY

The three government departments involved with landslide assessment projects in Malaysia were discussed. In general, these projects can be categorized into two scales of slope hazard and risk: large and medium scale (according to IAEG 1976). Slope hazard and risk assessments carried out by MACRES and DMG are most applicable for medium scale while work carried out by PWD is more applicable for large scale.

The EWH Study, carried out by PWD, used a combination of statistical analysis and factor overlay methods to determine significant slope parameters and to establish their hazard weightings. The TSR Study, also carried out by PWD, used a combination of three analyses: statistical analysis, deterministic approach and a heuristic method to establish the hazard ratings of the study area. The TSR Study used the most current in airborne survey, LiDAR compared to the earlier EWH Study, which used DVG.

The works carried out by MACRES used a statistical method where remote sensing data were analysed using a GIS (ILWIS and ARC-Info software) to create landslide hazard and risk maps. Similar methods were used by DMG.

The hazards and risk maps produced by PWD have enabled slope maintenance along the roads and highways in the study area. The landslide zonation maps produced by MACRES and DMG were used widely for land use planning by related government agencies and local authorities.

Corresponding author: Mr Suhaimi Jamaludin, Slope Engineering Branch, Public Works Department, Jalan Sultan Salahuddin, Kuala Lumpur, Wilayah Persekutuan, 50582, Malaysia. Tel: +60 03 26967369. Email: suhaimij@jkr.gov.my.

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