Area Based Slope Hazard and Risk Assessment in Hulu Klang, Malaysia

Ashaari Mohamad[1], Shabri Shaharom[1]
Low Tian Huat[2] Mohd Asbi Othman[2]
Mohd Fadlee Baba[3]
Saravanan Mariappan[4]

[2] Slope Engineering Branch, PWD , Malaysia
[1]Mohd Asbi & Associates, Malaysia
[3] Kumpulan IKRAM Sdn Bhd, Malaysia
Enceal Consultants Sdn Bhd, Malaysia
e-mail: low@asbi-associates.com.my

Abstract

A number of fatal landslides have been reported in Ulu Klang starting with the tragedy of Highland Tower collapse in 1993, followed by several landslides adjacent to the Highland towers. These landslides have resulted in casualties and loss of lives, notwithstanding displacement of residents and extensive damage to properties. In view of formulating a medium term and long term measures towards an effective policy of inspection and monitoring of development in the Ulu Klang areas, Malaysia Public Works Department (JKR) Slope Engineering Branch commissioned an area based landslide risk and hazard assessment study at this landslide prone location. The study covered an area of about $100km^2$ from Cheras to the North of Taman Melawati in the state of Selangor and the duration of the study was 12 months. Geographical Information System (GIS) was used as the based machine for the production of landslide hazard map. This paper highlights the area based landslide hazard and risk assessment using GIS application. The landslide hazard and risk assessment methodology and hazard and risk maps preparation using GIS application preparations for the study project are also highlighted.

Keywords: Landslide; area based; slope risk and hazard assessment; GIS; hazard map.

1.0 INTRODUCTION

The high demand in infrastructure commercial and residential developments has promoted opening up new areas of challenging terrain and encroachment into existing, otherwise stable, highland areas. The close proximity to the city of Kuala Lumpur and the panoramic location of Ulu Klang in the Klang Valley has increased the demand for its land. Ulu Klang is on a fast track urbanization. As more and more development and housing projects are taking place in this area, the hill slopes are not spared; excavation in the hilly areas around Ulu Klang is rapidly increasing, amidst regulatory concerns. This has resulted in incidences of geotechnical instability causing numerous landslips, some of which are fatal.

A number of fatal landslides have been reported in Ulu Klang starting with the tragedy of Highland Tower collapse in December 1993, followed by a landslide at Taman Hillview on 20th November 2002. Subsequently, landslides were reported at Taman Hamorni and the most recent was at Taman Zoo View Kampung Pasir on 31st May 2006. These landslides have resulted in casualties and loss of lives, notwithstanding displacements of residents and extensive damages to properties. Table 1 shows the major slope failures in Ulu Klang area from year 1993 to 2008.

Notwithstanding the availability of advances in the engineering solutions to account for such parameters as difficult topography and localized soil mechanics, emphasis on the needs for serious monitoring programs, continual reassessment and management of the associated risks involved in hill slope works has yet to be formulated and implementation of existing policies has been quite inconsistent.

In view of formulating a medium term and long term measures towards an effective policy of inspection and monitoring of development in the Ulu Klang areas, Malaysia Public Works Department (JKR) Slope Engineering Branch invited Kumpulan IKRAM Sdn Bhd to initiate a slope hazard assessment and mapping for the Ulu Klang-Ampang area. The study covered an area of about 100km^2 from Cheras to the North of Taman Melawati and the duration of the study was 12 months. The main scope of works for this study was to carry out hazard assessment and produce an area based slope risk and hazard maps.

Table 1: Major landslides in Ulu Klang area from year 1993 to 2008

No.	Date	Location of Slope Failure
1.	11.12.1993	Highland Tower
2.	14.05.1999	Bukit Antarabangsa, Ampang-Ulu Klang
3.	15.05.1999	Athanaeum Towers, Ulu Klang
4.	05.10.2000	Bukit Antarabangsa
5.	29.10.2001	Taman Zoo View, Ulu Klang
6.	08.11.2001	Taman Zoo View, Ulu Klang
7.	20.11.2002	Taman Hill View
8.	02.11.2003	Oakleaf Park Condominiums in Bukit Antarabangsa
9.	07.11.2003	Jalan Bukit Mulia, Bukit Antarabangsa, Ulu Klang
10.	31.01.2005	Jalan Tebrau in Dataran Ukay, Ulu Klang
11.	01.02.2005	Jalan Tebrau, Dataran Ukay, Ulu Klang
12.	31.05.2006	Taman Zoo View - Kg Pasir, Ulu Klang
13.	06.12.2008	Taman Bukit Mewah, Ulu Klang

2.0 LANDSLIDE HAZARD AND RISK ASSESSMENT METHODOLOGY

Slope assessment is used to assess the stability condition of slopes either individually or on a large scale. Slope assessment is also carried out to understand the likely mechanism which triggers potential occurrence of a landslide. Slope management, on the other hand, is an efficient use of available funds for slope rehabilitation works based on priority rankings of slopes using hazard and risk techniques.

Hazard maps have been used throughout the world to identify areas of either existing or potential slope instability. Such maps have been applied to land development projects, new and existing highways, and mining works. In general, hazard maps can be developed in a number of ways, ranging from simple qualitative or historical assessment, to varying degrees of site mapping and scientific analyses involving statistical and other numeric software packages.

The methods of preparing Hazard Maps have been categorized by Hutchinson (1995) into three groups, namely:

1. **The Geotechnical Approach**. This approach involves sampling, logging and testing, and generally is too expensive for large area study. The Geotechnical Approach and Direct Methods (described below) are generally adopted for site specific projects rather than large area study.

2. **Direct Methods**. These methods are based principally on geomorphological mapping, geological mapping and remote sensing (primarily aerial photography). These methods produce a landslide map that can be converted to Hazard Map, through appropriate subdivision and zoning of activity.

3. **Indirect Methods.** The simplest indirect methods involve univariate and bivariate analyses to identify single parameter or pairs of parameters that cause or contribute to slope instability. An example of univariate analysis is a plot of slope failure versus slope height and bivariate analysis, for example slope angle versus slope height. The level of complexity involves multivariate analysis. Multivariate analyses include factor mapping (herein described as factor overlay) combined with numerical methods to identify hazardous areas.

   The Indirect Methods assume that there are a number of significant factors that relate to slope instability, and that these factors combine contributing slope failure.

The common landslide hazard analysis or classification can be divided into four (4) main categories namely;

a) **Heuristic Method** (Expert Judgement approach)
a) **Statistical Method** (Discriminant or Multivariates Analysis)
b) **Deterministic Method** (common Slope Stability Analysis approach)
c) **Spatial Method** (Aerial photograph and Satellite Interpretation)

The application of these methods is subjected to the following conditions:-

a) **The scale of landslide assessment** – In general, if the scale of hazard study is small, simple method such as heuristic methods and deterministic method can be adopted. Statistical methods will only be applied when there are sufficient slope failure records and slope numbers.
b) **Availability of information** - Some assessment methods such as discriminant analysis require sufficient failure history records in order to obtain an accurate hazard classification. The failure records are required to segregate/discriminate failed and stable slopes based on landslide contributing factors. (see Othman, M.A.1989)

c) **Type of landslide assessment** - In general, landslide assessment can be divided into 2 main categories; linear based assessment and area based assessment. Linear based hazard assessment is for slope hazard assessment along linear infrastructures such as roads, expressways, railways and electric transmission lines. As for area based assessment is mainly on development area such as housing development. Spatial method using Geographical Information System (GIS) approach is recommended for the area based hazard assessment.

Landslide risk assessment is a process of making recommendations on the decision on whether existing risk is tolerable and the present risk control measures are adequate, and if not, whether alternative risk control measures are justified or should be implemented. The risk assessment incorporates the risk analysis and risk evaluation phases.

Landslide risk is defined as expected number of lives lost, persons injured, damage to property and disruption of economic activity due to particular landslide hazard for a given area and reference period.
In general, risk is a result of the product of probability or hazard (of occurrence of a landslide with a given magnitude) and the consequence of the landslide incident. The equation for Risk (R) is as follows:-

Risk = Hazard (H) x Consequences (C) ……… **Eq. 1**

A complete risk assessment requires quantitative risk assessment which involves the quantification of a number of different types of losses, such as:-

- Losses associated with general building stock: structural and non-structural cost of repair or replacement, loss of contents;
- Socioeconomic losses: number of displaced households: number of people requiring temporary shelter, casualties in categories of severity (based on different times of day)
- Transportation and utility lifelines: for components of the lifeline systems - damage probabilities, cost of repair or replacement and expected functionality for various times following a disaster
- Essential facilities: damage probabilities, probability of functionality i.e., loss of hospital beds or operation theaters etc.
- Indirect economic impact: business inventory loss, relocation costs, business income loss, employee wage loss, loss of rental income, long term economic effects on the region.

A major component of risk assessment is the risk analysis. Risk analysis is an estimation of the risk to individuals or populations, property or environment from landslide hazard based on available information. Risk analyses generally follow the following steps:-

a) Landslide identification
b) Estimation of probability of occurrence to estimate landslide hazard
c) Evaluation of the vulnerability of the element(s) at risk
d) Consequence identification
e) Risk estimation

Risk analysis can be in the form of qualitative or quantitative.
Qualitative risk analysis, which uses word form, descriptive or numeric rating scales to describe the magnitude of potential consequences and likelihood that the identified consequences will occur, while quantitative risk analysis is based on numerical values of the probability, vulnerability and consequences, and resulting in a numerical value of the risk.

3.0 PROPOSED METHODOLOGY FOR ULU KLANG STUDY

From the methods reviewed, the proposed methodology for the study is subjected to the following limitations:-

a) Limited project time frame limited the team from adopting a more accurate method to be used in this study
b) Limited landslide inventory and failure records
c) Non accessibility especially thick forest and private lands
d) Slope identification – difficult in naming the slope compared to linear based maps

In view of the limitations, the methodology for the hazard assessment for the study is specially tailored to overcome the limitation and the weakness of the methods reviewed in the desk study stage. Both methods of **Direct** and **Indirect** approach are proposed to be adopted in the study.

Direct method based on geomorphology is important in this study. Most landslide preparatory causal factors in Ulu Klang area (developed area) were due to human activities, lack of maintenance, design inadequacy and construction problems; slopes do not behave as predicted in slope stability theory. These unpredicted factors require detailed field inspection and mapping. The geomorphological map prepared from field inspection is used as calibration tools in the hazard assessment. Area distribution for geomorphological mapping works is shown in **Figure 1**.

As for the indirect methods, heuristic method is proposed to be adopted in the study. Weightings to be adopted in the factor overlay approach can be derived from the experts' survey and these will be used to classify the landslide hazards. The proposed layers for this indirect approach shall be:-

a) Geological formation (lithology)
b) Surface cover (forest/developed/bare)
c) Slope angle
d) Flow accumulation
e) Slope Failure distribution

The indirect approach is important for inaccessible areas such as forest, steep terrain and thick undergrowth. The causal "ingredients" mentioned shall not just limit to the list above. Additional layers/factors from geomorphological map shall be added as calibration layers to incorporate other unpredictable factors such as poor design, poorly maintained slopes, insufficient drainage, etc. Signs of distress i.e., tension crack, gully, erosion etc., are used as the calibration tool during the hazard rating verification works.

In this study, the risk assessment was aimed to prioritise the hazardous slopes for the purpose of slope strengthening or monitoring works for the local authorities. Due to the urgency and limited time frame (after the occurrence of Bukit Mewah Landslide end of 2008), qualitative risk assessment were adopted.

Geographical Information System (GIS) has been adopted to facilitate the slope hazard and risk assessment and analysis. GIS is a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for particular set of purposes. Therefore GIS system has been selected as the base operation software to analyse slope hazard and produce area based hazard map. Survey data from the air borne survey using LiDAR (Light Detection and Ranging) was used to produce the base map and spatial layers i.e., slope angle layer and flow accumulation layers etc., for slope hazard analysis. As for risk analysis, database from the field mapping works was adopted in the GIS environment. The overall flow chart for the study is shown in Figure 2.0.

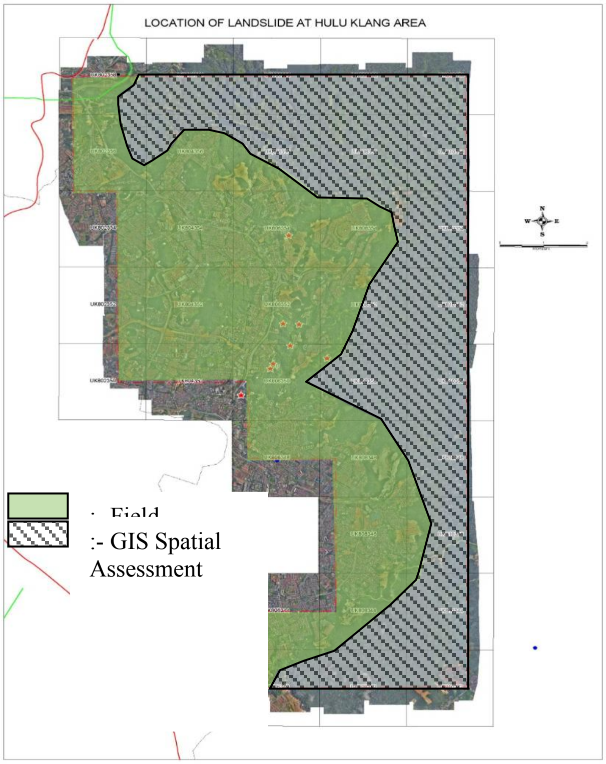


Figure 1.0 Area Distribution for Geomorphological Mapping Works

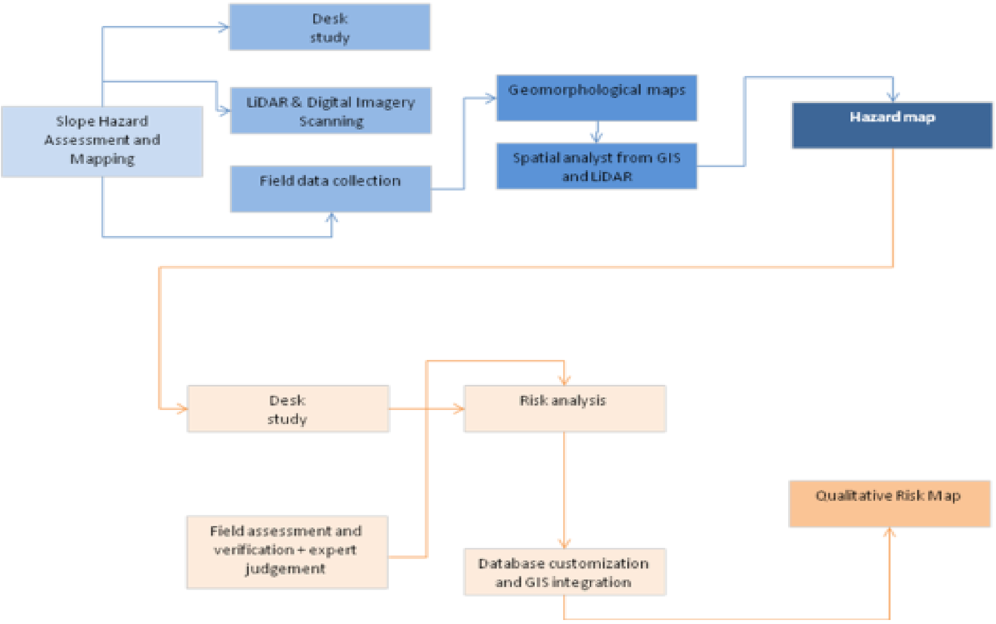


Figure 2.0: flow chart of study methodology

4.0 LiDAR (**LI**GHT **D**ETECTION **A**ND **R**ANGING) SURVEY

LiDAR is one of the best techniques to produce geomatic data for any geographical purposes. Figure 3.0 shows the schematic diagram for data capturing using LiDAR. This option has its own unique solutions to deliver close to ground data accuracy at an airborne speed with little effect from bad weather. It totally eliminates the ground control point need for imagery processing. At very high speed, the current LiDAR mapping technology can provide a very accurate terrain model to produce a contour map of terrain floor of any forest or cleared land to within 0.15m resolution. Three-dimensional spot heights are produced at 0.2m to 3m grids depending on flying height and skewing angle.

One disadvantage of this technology is the limitation to survey the information/ features that are hidden from airborne capture such as culverts, pier below bridges, etc. But the big advantage is quick mapping of hostile grounds, densely forested jungle, non-accessible areas or large area which requires high accuracy and intensity of data. Therefore, for the Ulu Klang study, field mapping works by the geotechnical engineers and geologists were proposed to overcome this limitation.

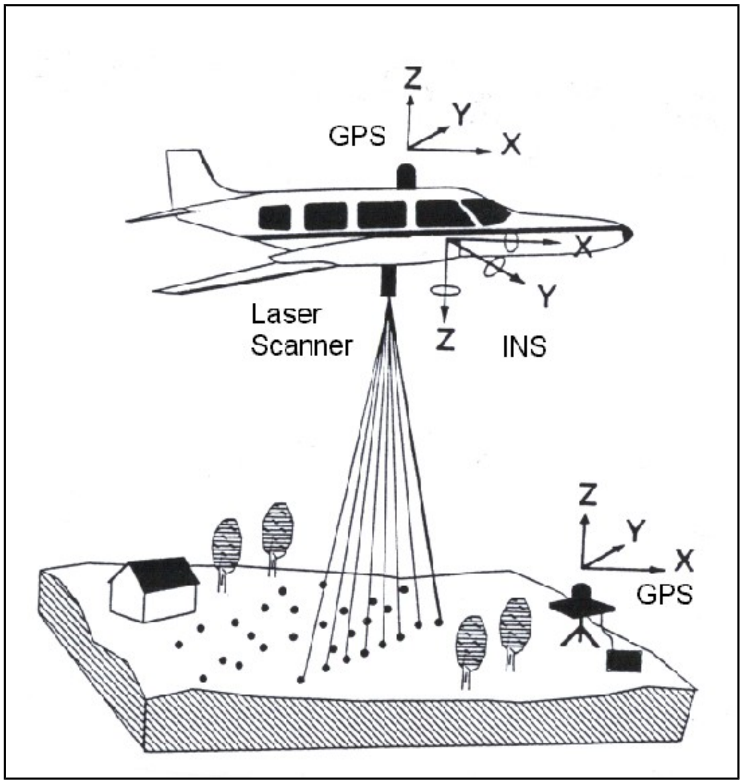


Figure 3.0: Illustration of how LiDAR sensing instrument captures elevation points

4.0 LANDSLIDE HAZARD RATING

In view of limited landslide records made available, the calculation of landslide hazard rating using statistical approach is not suitable. The common method of hazard classification using multi-variates, discriminant analysis will not provide accurate hazard rating.

Before formulating the hazard rating model, the dependent model parameter shall be identified. A landslide cause tree diagram was prepared to identify all the potential preparatory and triggering causal factors of a landslide. These geographically distributed causal factors or parameters that potentially contribute to landslides are referred to in this study as landslide dependent model parameters. The proposed dependent model parameters used are as follows:-

a) Slope Gradient
b) Geology
c) Flow accumulation
d) Land cover
e) Failure History
f) Sign of distress

Sign of distress (obtained from geomorphological mapping) i.e., tension crack, gully, rill and etc., were later taken out as the dependent parameter to avoid hazard equation being biased towards slopes within developed area (because no field mapping was carried out for forest areas). The sign of distress from the geomorphological map were used for calibration of the hazard equation. Only water seepage was used in the analysis to replace dependent parameter of “Sign of Distress”.

Within each model parameter, different weightings were proposed to different groupings depending on their correlations with landslides as perceived by experts. Groupings within a parameter class were referred to in this study as inter-parameter variables. Figure 4.0 shows the proposed dependent parameter model and the respective inter-parameter variables.

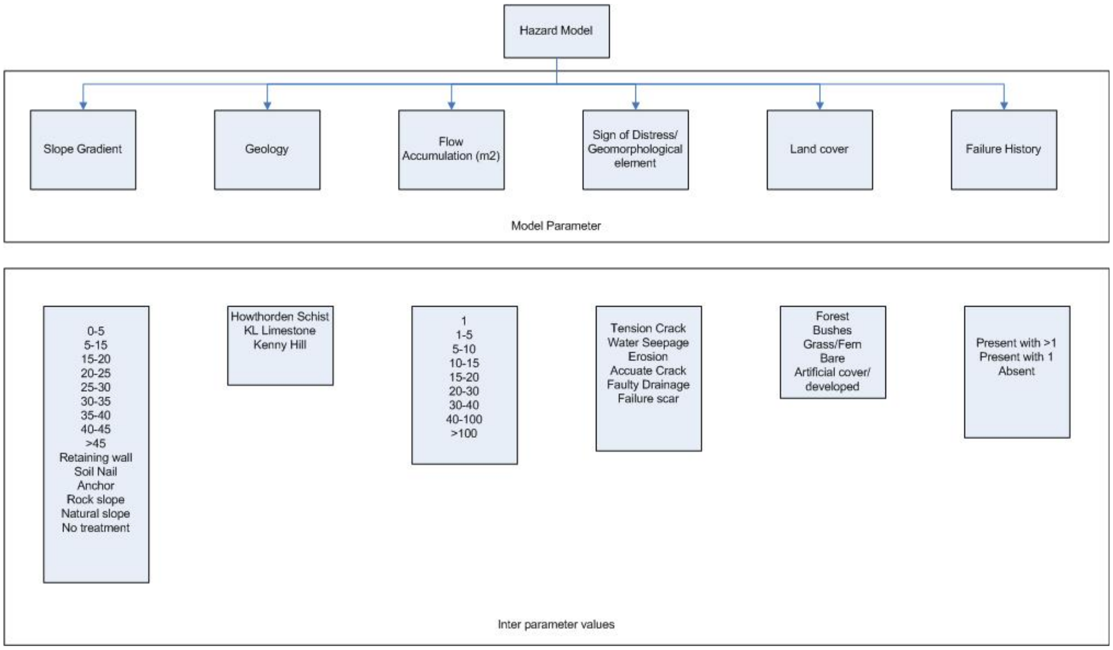


Figure 4.0: The proposed dependent parameter and inter-parameter variables

For example, several ranges of slope angle were carefully selected as the inter-parameter variables of the dependent model parameter of slope gradient. Weightings of each inter-parameter variable were assigned with numbers based on engineering judgment of the inter-parameter variables.

A high weighting value can be assigned to slope angle range which is thought to have high probability of landslide. Additional inter-parameter can be included to account for strengthening measures such as soil nails, anchors, retaining walls and steep rock cut. This would overcome the limitation in GIS hazard ratings because in general, slopes with strengthening features are designed to be steep. Negative rating can also be adopted to eliminate confusion generated from the slope angle layer. **Table 2** shows an example of ratings for inter parameters rating of dependent parameter model of slope gradient.

The weightings shall also consider elements of maintenance. Strengthening measures such as ground anchors shall be assigned lower contra weighting compared to soil nails. Ground anchors require periodic maintenance by re-stressing the anchors from time to time. The smaller contra shall be imposed to take into account the slopes with no or little maintenance.

Slope Gradient Classes (degree)	Weighting
0 – 15	0
15 - 25	1
26 - 35	2
36 - 45	3
46 - 60	4
>60	5
Natural slope	-2
Rock Slope with adverse discontinuities	1
Rock slope without adverse discontinuities	-3
Rock slope with strengthening	-3
Soil nail	-3
anchors	-1
With retaining wall	-1
No treatment	0

Table 2: Example of inter-parameter ratings for dependent parameter model slope gradient

5.0 LANDSLIDE RISK RATING

The elements that contribute to risk and consequence were studied. The elements of risk were based on the criteria that have been adopted by the Geotechnical Engineering Office (GEO) Hong Kong, and also from the SMART system established by the Cawangan Kejuruteraan Cerun (CKC) Jabatan Kerja Raya Malaysia. Semi-qualitative risk approach was adopted once the elements for risk had been identified and agreed by both the study team members and the Slope Engineering Branch. The risk score used also be incorporated in the existing slope database before the risk map was produced. The verification of the risk score was done by geotechnical experts (expert judgement).

Being a fast track study, the consequence analysis was carried out mainly by utilizing the data from the database. Layer of consequence was produced and the risk map was drawn based on the factor overlay technique in GIS environment.

5.1 ELEMENT AT RISK

During the early stage, the elements at risk were identified. These elements at risk were further categorised into;

a) High rise structures (buildings with more than 4 storeys)
b) Terraced buildings, shop lots, bungalows
c) Essential Structures (i.e., schools, hospitals, public halls, shopping malls, temples, mosques etc.)
d) Non residential structures (TNB substations, water tanks, parks, parking, IWK treatment plants etc.)
e) Utilities (water lines, electric lines, telecom lines and etc.)
f) Major Roads (main roads or roads connected to development)
g) Residential roads (roads within the development)

The elements of social and economic were indirectly included in the ranking of these elements based on the importance of these elements.

The identified elements at risk were ranked qualitatively based on the importance and impact of these elements. The rank ranged from score 1 to 5. In order to correctly rank these elements, forms were distributed among the experts within the study team and Cawangan Kejuruteraan Cerun (CKC) Jabatan Kerja Raya Malaysia. The opinion from various parties was further analyzed and the final rank was assigned as follow:-

Property's Impact		Score (based on ranking)
	Types of Property	
High Rise Structures	Condominiums, apartments	5
Terrace Houses		3
Essential Structures		5
Non Residential Structures	TNB	1
	Park	2
	Parking	2
Utilities		1
Major Roads		3
Minor Roads		2

Table 3: Element at risk ranking

5.2 CONSEQUENCE MODELLING

The consequence modeling was divided into 2 main layers, namely, property layer and infrastructure layer. The infrastructure layer is only concentrated on slopes adjacent to roads i.e., major roads and residential roads. The layer equations are as follows:-

- TP_layer = ∑Weightage x (type of property) x (Distance Impact Score)
- I_layer = ∑Weightage x (type of Road/infrastructure) x (Distance Impact Score)

Impact Score = impact based on the run-out and distance of slope to structure/facility

where,
TP_layer is the consequence layer for structures consequence
I_layer is the consequence layer of infrastructures consequence
Weightage = fatality/importance weightage

The impact score is the score of landslide impact due to the debris of landslide. The impact score can be divided into 2 main components, namely, the ratio of distance from slope and run out distance (S1) and slope angle (S2). Slope angle was chosen as one of the impact element because slope angle plays an important role in determining the impact of the landslide debris. Slopes with steep angle could be catastrophic compared to gentler ones. The scores for both the elements were qualitatively assigned and it ranged from 1 to 4.

The impact score is the product of distance ratio (S1) and slope angle (S2). The equation is as follows:-

IMPACT SCORE = S1 x S2 ………. **Eq.2**

6.0 PAIR WISE COMPARISON METHOD

The weightings of the possible model parameter in factor overlay method can be formulated using pair wise method. Pair wise comparison is used as a decision making tool in many applications to rank the relative importance of multiple variables. The Pair wise comparison process is proposed to derive the weightings for each of the landslide dependent parameter (Golder 2006).

The process is based on engineering judgment and compares individually:-

- The relative importance of the parameter in influencing the potential for landslides compared one against another, and
- The degree to which each parameter is more important than each counterpart.

Several pair wise analyses were also carried out to check the sensitivity of the weightings. The outcome of the pair wise comparison was used to assign weightings to each model parameter. The total value of all the attribute weightings was taken as 1.0. The applied weightings indicate the degree to which the potential for landslide is influenced by each model parameter, relative to the other parameters.

The formula for the hazard score is the sum of the products of the dependent parameter and inter-parameter weightings. The formula below illustrates the proposed landslide hazard formula adopted in the study:-

Hazard Score = 0.26 (SA) +0.15 (FA) + 0.24(WS) + 0.24 (FH) +0.06 (G) + 0.06 (LC)
eq1

where,

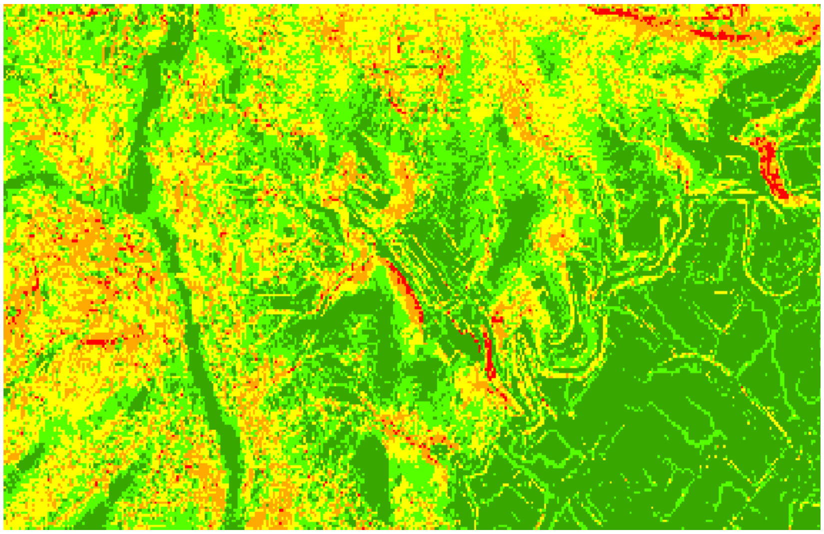
SA = the value obtained from the interparameter for **S**lope **A**ngle categories
FH = the value obtained from the interparameter for **F**ailure **H**istory categories
WS = the value obtained from the inter-parameter for **W**ater **S**eepage_ categories
FA = the value obtained from the interparameter for **F**low **A**ccumulation categories
G = the value obtained from the interparameter for **G**eological formation (lithology) categories
LC = the value obtained from the interparameter for **L**and **C**over categories

Five hazard ratings, very low through very high were adopted. The hazard classes adopted in the study are:-

a) Very High Hazard
b) High Hazard
c) Medium Hazard
d) Low Hazard
e) Very Low Hazard

The selection of these ratings is somewhat subjective. The ratings indicate the likelihood of a landslide occurring. As for this study, due to limited landslide historical records were made available during the analysis, the hazard classes were first classified by equally dividing the maximum score into 5 equal classes. Later, during the calibration and verification works the ranges for the classes were further refined based on the geomorphological map. Figure 4 shows a typical tile of ortho-rectified photograph and slope hazard map produce in GIS environment.

3a) Ortho-rectified photograph of a typical tiles in Ulu Klang area



3b) Hazard map

🟩 Very Low Hazard
🟩 Low Hazard
🟨 Medium Hazard
🟧 High Hazard
🟥 Very High Hazard

Figure 3: Ortho-rectified photograph and slope hazard map of a typical tile in Ulu Klang Area

As for risk rating, based on the pair wise approach the weightings for the TP layer for the element at risk is as in Table 4:-

Element at risk	weighting
High rise structure	0.28
Terrace structure	0.19
Essential building	0.28
Non residential	0.03
Major road	0.16
Residential road	0.05

Table 4: Weightings for element at risk based on pair wise method

Five risk ratings, very low through very high were adopted. The risk classes adopted in the study are:-

a) Very High Risk
b) High Risk
c) Medium Risk
d) Low Risk
e) Very Low Risk

A total of 460 slopes within the study area were mapped. The risk condition for these slopes are shown in **Table 5.0.**

Risk Classification	Number of slopes
Very High Risk Slope	69
High Risk Slope	66
Medium Risk Slope	75
Low Risk Slope	71
Very Low Risk Slope	179

Table 5.0: the risk condition of the slopes

7.0 EXPERT JUDGEMENT

The risk scores generated by the system were verified using the outcome from the expert judgment. A total of 13 slopes were assessed by the experts within the study team to ensure the hazard and risk scores generated by the system are in order.

8.0 CONCLUSION

Slope hazard map can be used to identify areas of either existing or potential slope instability. Calibration by means of ground mapping is essential to ensure the accuracy of the hazard map. For Ulu Klang landslide assessment study, Geographical Information System (GIS) was found to be the most suitable system for area based slope hazard and risk assessment.

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