CIDB MALAYSIA

MINISTRY OF WORKS

CREAM CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA

GUIDELINE

FOR LANDSLIDE VULNERABILITY ASSESSMENT AND RISK ANALYSIS FOR CRITICAL INFRASTRUCTURE (CI) IN MALAYSIA

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1.0 INTRODUCTION

1.1 Background

Malaysia Sustainable Development Goals, Voluntary National Review 2017, published by the Economic Planning Unit © EPU 2017, highlight Malaysia's commitment to support and implement the 2030 Agenda for Sustainable Development encompassing economic, social and environmental elements. The CIDB consortium has taken a significant effort to support and indirectly address the specific agenda related to SDG 11: Sustainable cities and communities and SDG 13: climate action plan by publishing this landslide disaster risk reduction guideline to holistically adapt to high land changing environment.

Highland is a hilly terrain that above 100m from Mean Sea Level (MSL). Utilizing geospatial data of Shuttle Radar Topography Mission (SRTM) with 30-meter spatial resolution, the percentage of highland in Peninsular and East Malaysia are 44.93% and 60.00% respectively. Malaysia has experienced numerous landslide geohazards incidences throughout the years. Most of the geohazard incidents are associated to failure of the natural hill slopes. The increasing landslide geohazards in mountainous and hilly terrain of Malaysia are often associated with soil mass wasting processes, the failed soil masses may transformed into liquefied debris or mudflow of tremendous velocity and momentum, capable of sweeping away everything found along its path. These natural geomorphological processes are common phenomena in Malaysia tropical mountainous terrain, especially during monsoon seasons. Understanding the natural geomorphic and geological processes on tropical mountainous terrain is the key to comprehend the nature and extend of the associated landslide geohazards. Landslide disaster risk is considered to be a function of landslide hazard, exposure and vulnerability, expressed as the probability to the loss of life, injury, and destroyed or damaged physical structure in a given period of time (De Bono and Mora, 2014).

Landslide risk assessment use in national Disaster Risk Reduction measures covers (UN/ISDR, 2004):

- Define scenarios that triggering the landslide(s) and evaluate their probability of occurrence
- Estimate the volume and extent of the landslide and compute the run-out distance for each scenario
- Estimate the losses of all elements at risk for each scenario

The semi-qualitative method for landslide risk assessment via risk assessment matrix (hazard and vulnerability) is adopted and recommended as it is effective and convenient. Landslide risk, **R** is defined as,

$$\mathbf{R = H \times V} \tag{1}$$

where **H -** landslide hazard and **V -** vulnerability.

It is proposed that the measurement of hazard and vulnerability are adopted from Australian Geomechanics Society's (Fell et al., 2005) where hazard measurement (H) is defined by the qualitative measures of likelihood of landsliding and vulnerability measurement (V) is define by the qualitative measures of consequences to property.

Vulnerability identifies the relationship that relate the landslide potential damages over a specific element at risk for instance critical infrastructure. It can also be defined as the degree of loss to a given element at risk or set of elements at risk resulting from the occurrence of landslide phenomenon of a given magnitude and expressed on a scale from 0 (no damage to element-at -risk) to 1 (total damage to element-at-risk) (Corominas et al., 2014). Consequently, the determination of landslides vulnerability is the most critical steps towards landslide risk analysis.

1.2 Purpose

This guideline provides a recommendation of an appropriate methodology for landslide vulnerability assessment and the subsequent risk analysis of any development with critical infrastructure (CI) in highland areas.

This guideline shall complement and enhance the present acts and regulations related to but not limited to development of highland area.

This guideline is proposed for the use of local authorities, institutional agencies and decision makers, as a supporting tool for landuse plan, prioritize landslide risk mitigation plan and risk management for urban, urban highlands, sub-urban, rural development in the creation of sustainable development areas.

1.3 Landslide Vulnerability Assessment

This guideline recommended a semi quantitative, indicator based method (IBM) of physical vulnerability which is expressed through vulnerability functions that represent the interactions between the landslide event and the critical infrastructure. Figure 1.1 shows the flow chart of risk analysis by indicator based approach.

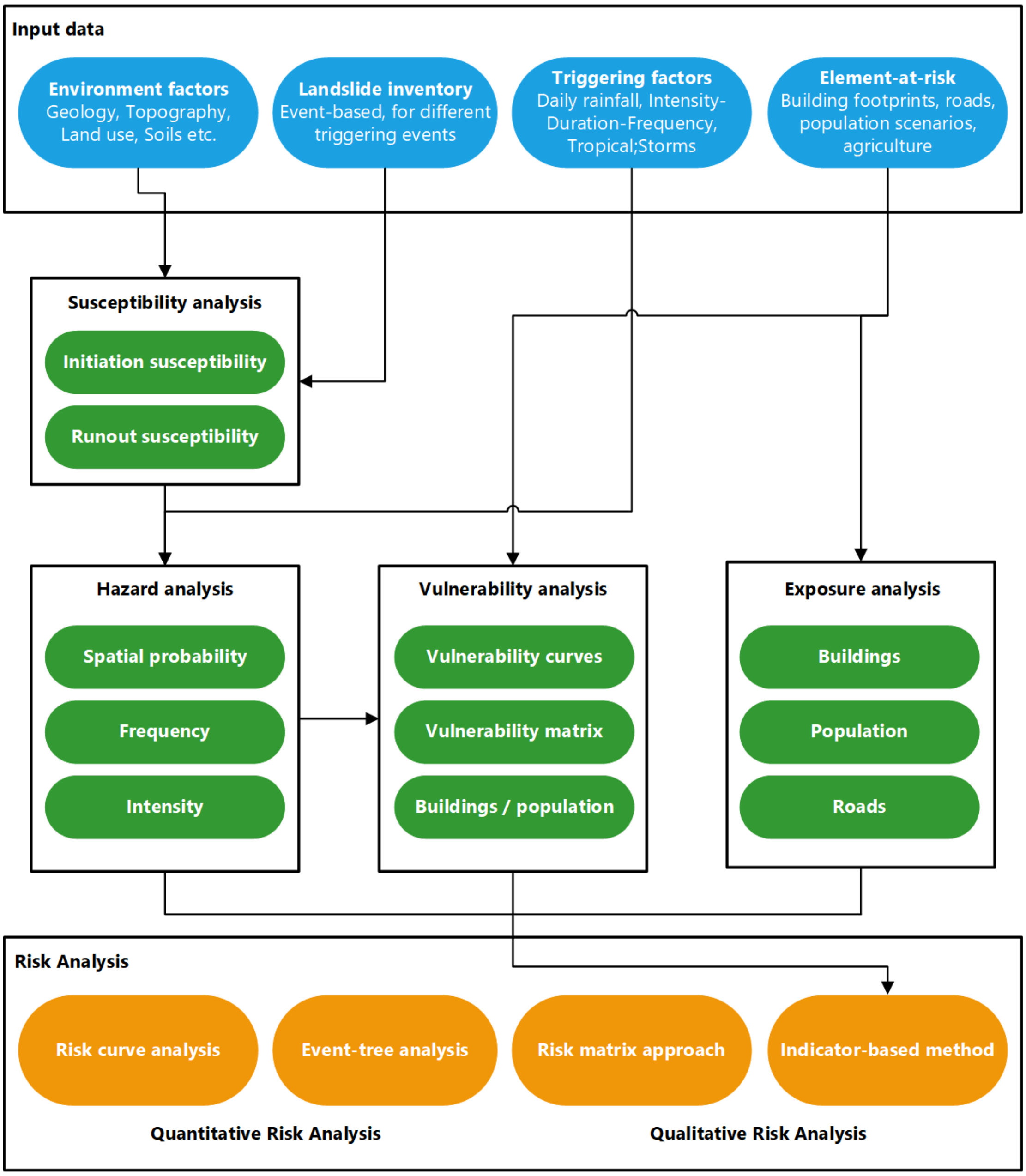


Figure 1.1 : Flow chart Landslide Risk Analysis showing adopted indicator-based method of analysis.

The semi-quantitative approach reduces level of generalization in the qualitative method (Dai and Lee, 2002). The methods are flexible reduce subjectivity, compared with the qualitative. The justification is due to lack of landslide hazards data history.

The justification for recommendation are as below;

a) Data availability: The ranking of indicators into several vulnerability classes requires less data.
b) The possibility for combining qualitative and quantitative indicators: Through predefined ranking criteria of indicators, both quantitative and qualitative indicators may be ranked and combined into a semi-quantitative vulnerability parameter.
c) The results can be easily analyzed in GIS: The vulnerability value for each CI can be easily stored with flexibility in the GIS database. This allows for effective analysis on the vulnerability data.
d) The weighting process is flexible: The weight assigned for each indicator is adjusted based on the user experiences.
e) Data collection process can be carried out by non-expert: Determination of scores of the indicators can be based on the owner of the buildings.
f) The IBM method encourage the involvement of local community: Involvement of stakeholders in data collection shall increase reliability of LVA and vulnerability reduction process.

1.4 Slope Morphology and Slope Classification

The slope morphology has significant role in determining the types of landslide for highland development planning, as per guideline *Garis Panduan Pemetaan Geologi Terrain*, GP 06 (Mineral and Geoscience Department Malaysia (JMG), 2010). The typical soil slope section morphology is as shown in Figure 1.2 (a). Similarly, the typical slope morphology detected from geospatial terrain data image is as shown in Figure 1.2 (b). The slope morphology affects the surface run-off and subsurface water runoff, absorption or dispersion. Convex slopes (e.g., wide ridges) will tend to disperse water as it moves downhill. Straight slopes concentrate water on the lower slopes and contribute to the build-up of hydrostatic pressure. Concave slopes typically exhibit swales and draws.

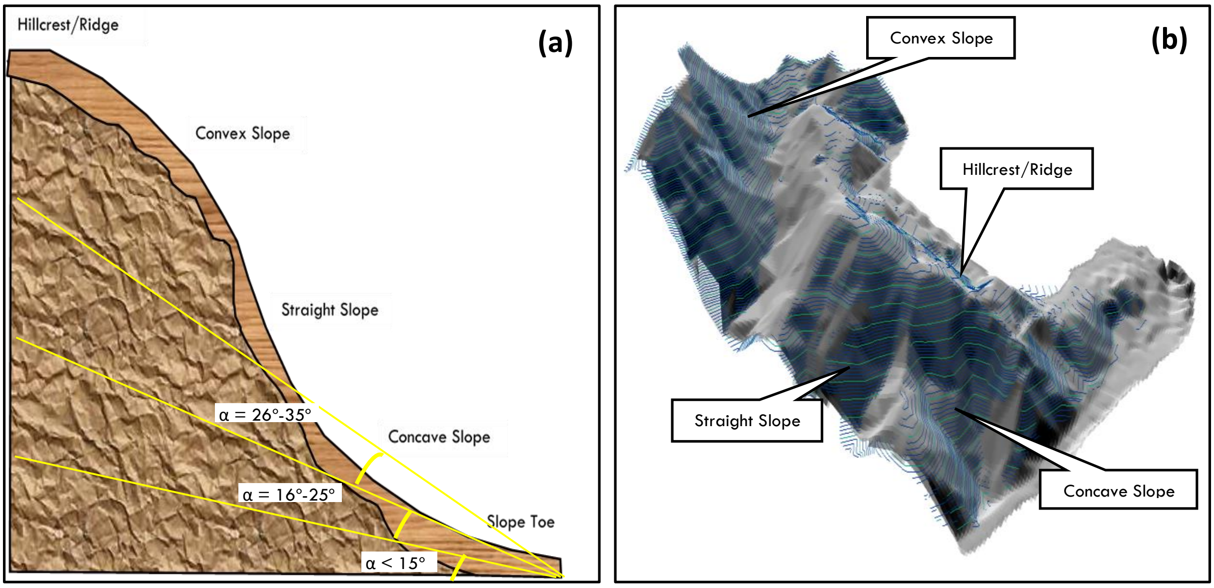


Figure 1.2: **(a)** Schematic diagram of slope segment features and **(b)** 3D slope morphology image from DEM.

The *Garis Panduan Pembangunan di Kawasan Tanah Tinggi*, Natural Resources and Environment Department of Malaysia (NRE) (2005), provide guideline on hilly terrain for physical development on highland, 300 feet above mean sea level, as summarise in Table 1.1 below. This guideline propose landslide vulnerability assessment for Class 3 and above that may help as an alternative to sustainable development environment.

Table 1.1: Malaysia Guideline on hilly terrain physical development (Natural Resources and Environment Department (NRE), 2005).

Slope Gradient (α)	**Slope classification for engineering work**	**Description**
Below 15°	Class 1	Compliance to *Garis Panduan Pembangunan Di kawasan Bukit 1997* (issued by the Local Government Department), *Garis Panduan Kawalan Hakisan dan Kelodakan, 1996* (issued by the Department of Environment) *and Manual Saliran Mesra Alam 2000* (issued by the Department of Irrigation and Drainage).
16° - 25°	Class 2	

26° - 35°	Class 3	Requires additional EIA study. Propose landslide vulnerability assessment to be conducted that may help as an alternatie sustainable development environment.
Above 36°	Class 4	Development projects within this area are not allowed at all, except for road construction that is inevitable. However require EIA study. Propose landslide vulnerability assessment to be conducted that may help as an alternative sustainable development environment.

1.5 Limitations

The content of this guideline is limited to the following scopes and limitations:

01
- The guideline only covers physical landslide vulnerability assessment and risk classification.

02
- The landslide vulnerability assessment and risk analysis will only focuses on these critical infrastructures; residential or building, road, dam and utilities (powerline).

03
- Generation of landslide vulnerability and risk maps require landslide hazard map.
- Landslide hazard map should follow certain criteria as required for example, level be details in both spatial and attribute data.
- Therefore, the capability to generate the subsequent vulnerability and risk map are dependent on the quality of the landslide hazard map of the study area.

04
- Field-based validation for vulnerability assessment and risk analysis requires proper identification of element at risk and typical landslide in the area.

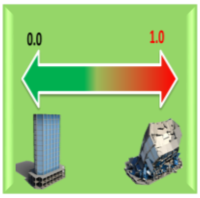
05
- Social vulnerability assessment with respect to landslide is not included in the scope of this guideline and highly recommended for future study

2.0 DEFINITIONS AND TERMINOLOGY

2.1 Definitions of Keywords

LANDSLIDE
Landslide is a general term used to describe the mass of rock movement, earth or debris down slope (Cruden, 1997).

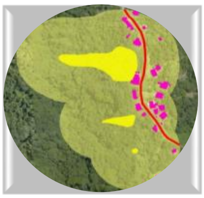
LANDSLIDE HAZARD
The use of available information to estimate the zones where landslides of a particular type, volume, velocity and runout may occur within a given period of time (Corominas et al., 2014).



VULNERABILITY
The degree of loss of a given element or set of elements exposed to the occurrence of a landslide of a given magnitude or intensity. It is often expressed on a scale of 0 (no loss) to 1 (total loss) (Corominas et al., 2014).

VULNERABILITY ASSESSMENT
Vulnerability assessment is certainly useful for disaster risk reduction and promoting an exchange of information or for improving disaster preparedness and preventing losses (Birkmann, 2006).

ELEMENT AT RISK
The population, buildings and engineering works, economic activities, public services utilities, other infrstructures and environmental values in the area potentially affected by the landslide hazard.



EXPOSURE
Population, property, systems, or other elements present in hazard zones that are thereby exposed to potential losses (Corominas et al., 2014).

RISK ANALYSIS
The use of available information to estimate the risk to individuals or populations, property and the environment, from hazards (Corominas et al., 2014).

2.2 Landslide Type and Terminology

The landslides in Figure 2.1 show the schematic illustration of the type of landslide (Varnes, 1984). The most common type of landslides disaster in Malaysia are as circled in the figure.

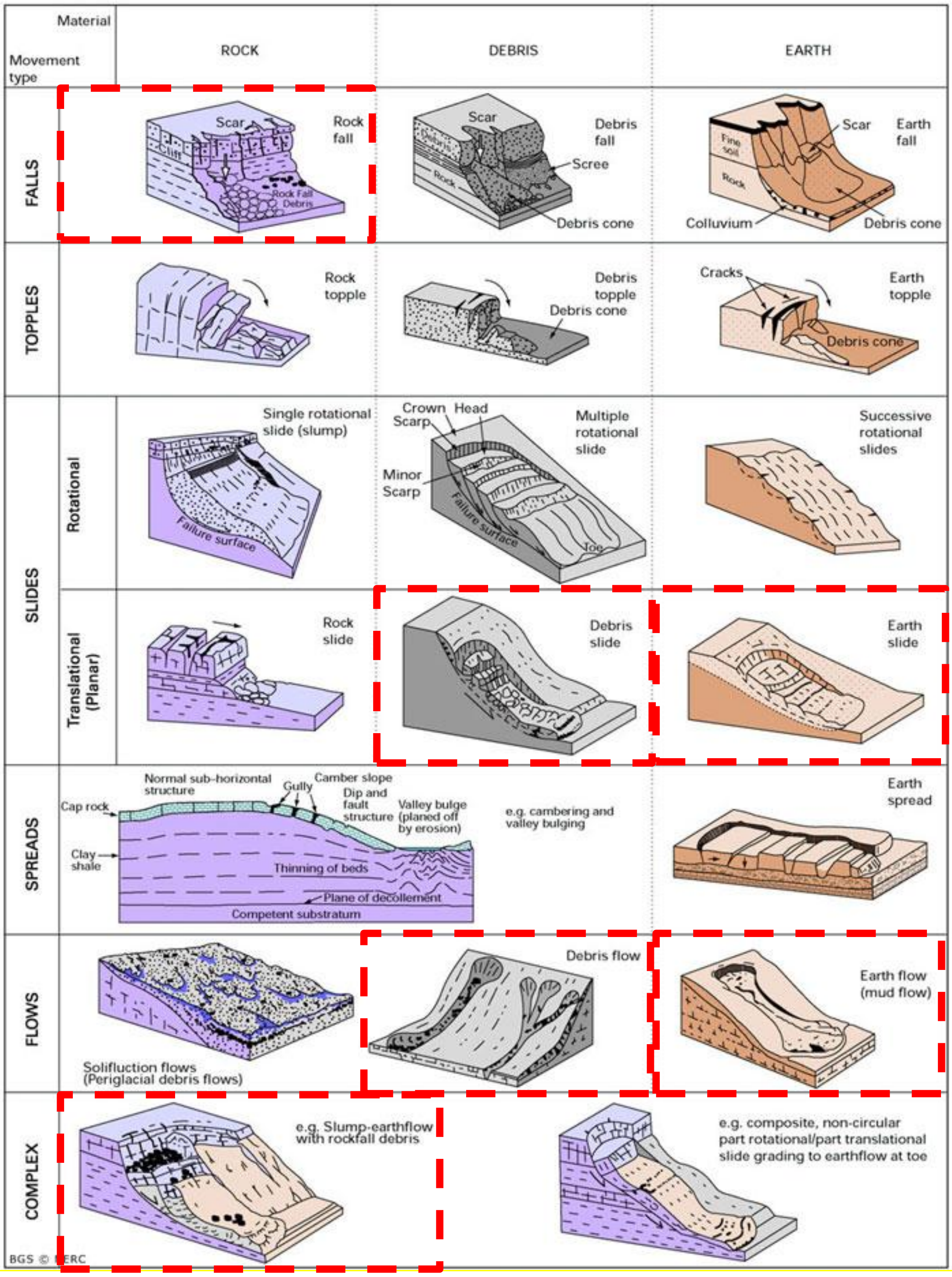


Figure 2.1: Schematic illustrations of the type of landslide (Varnes, 1984).

Landslide hazard is a function of susceptibility (spatial propensity to landslide activity) and temporal frequency of landslide triggers, and its assessment may be done on local (individual slope), regional, national, continental, or global scales (UN/ISDR, 2004).

Landslide hazard assessment shall consider topography and other factors that influence the propensity to landslide activity (susceptibility factors), as well as landslide triggering factors (precipitation, earthquakes, human activity (UN/ISDR, 2004).

Landslides vulnerability assessment is a complex process that should consider multiple dimensions and aspects, includes both physical and socioeconomic factors (UN/ISDR, 2004).

Physical vulnerability of buildings and infrastructure is a function of the intensity of the landslide event and the resistance level of the exposed element-at-risks.

2.3 Geospatial Approach of Landslide Hazard Mapping

Geographical Information System (GIS) is a tool for presenting digital visualization of geospatial data and their attributes for data editing, data storage, data updating and data analysis. It allows geospatially referenced data to be linked to geographic features and integrates common database operation such as query and statistical analysis with the unique visualization and geographical benefits on maps. In the case of geohazard, GIS can be used for prediction of potential areas and affected areas of geohazard such as slope failure and debris flow.

The geospatial data for producing landslide hazard map came from various sources such as LiDAR and high-resolution satellite images. The landslide hazard map is derived using three inputs which are: (a) landslide inventory, (b) landslide causal factors, and (c) landslide triggering factors (eg. rainfall). The triggering factors are related to climate change factors such as rainfall. Figure 2.2 shows an example of a landslide hazard map, where the image is classified by colour coding into five different classifications from very low (green) to very high (red) hazards. Field verification of landslide inventory should be validated at the site.

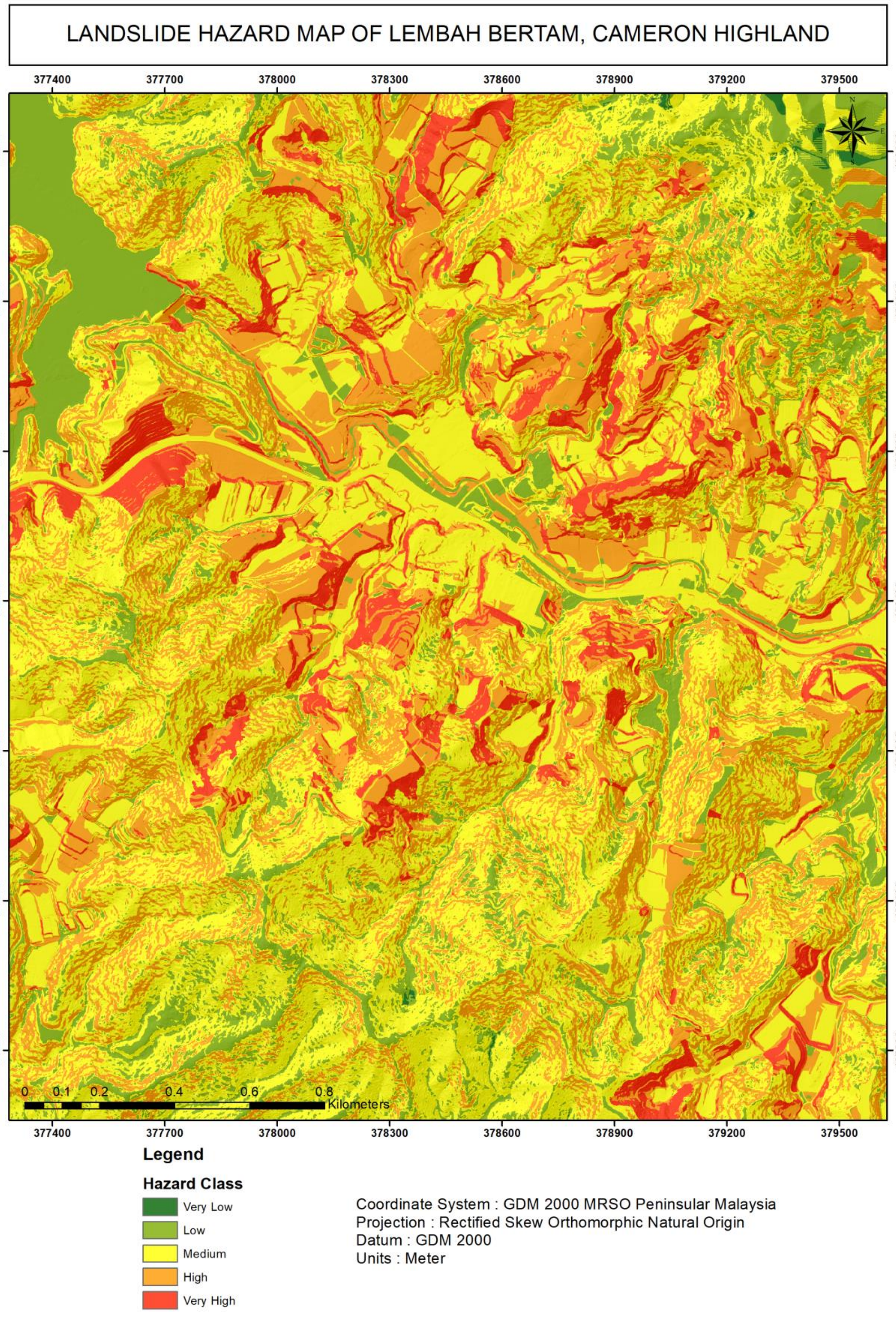


Figure 2.2: Example of landslide hazard map (Mineral and Geoscience Department Malaysia (JMG), 2018).

3.0 CRITICAL INFRASTRUCTURE

The following are examples of physical vulnerability or element-at-risk where landslide vulnerability assessment for land use planning will be beneficial:

(a) Residential land development

- New urban areas
- Redevelopment of urban areas
- Subdivision of rural land

(b) Residential development controls in existing urban areas potentially affected by landsliding.

- Within local government area.
- Federal.

(c) Development of important infrastructure.

- Hospitals, schools, fire brigades and other emergency services.
- Critical communication infrastructure.
- Major lifelines such as transport, water, gas pipelines and electricity power lines

(e) Development of new or redevelopment of existing highways, roads and railways.

- Rural.
- Urban main roads.
- Urban subdivision roads.

(g) Dam.

- Dams construction to control river flooding and debris flow along identified potential river channel with main dams (sabo dams, comb dams) at the upper stream and check dams at the mid-low stream.

This is also applicable to any other physical element-at-risk, however the indicator, sub-indicator and respective weightage may varies.

4.0 LANDSLIDE RISK ANALYSIS FRAMEWORK AND VULNERABILITY ASSESSMENT

4.1 Landslide Risk Analysis Framework

The landslide risk analysis framework emphasize on landslide vulnerability assessment, derivation of vulnerability index, derivation of risk estimation for risk classification of physical critical infrastructure and element-at-risk. The derived landslide risk map show the critical infrastructure that may be affected by landslides. This map is a common tool used by authorities and decision makers for landslide risk management.

4.2 Vulnerability measurement and Hazard measurement

Descriptions of vulnerability measurement and hazard measurement adopted in this study are according to the classification by Fell et al. (2005) as shown respectively in Table 4.1 and Table 4.2 below.

Table 4.1: Vulnerability Measurement - Qualitative Measures of Consequences to Property (Fell et al., 2005).

Level	Descriptor	Description
1	Catastrophic	Structure completely destroyed or large-scale damage requiring major engineering works for stabilisation
2	Major	Extensive damage to most of structure, or extending beyond site boundaries requiring significant stabilisation works
3	Medium	Moderate damage to some of structure, or significant part of site requiring large stabilisation works
4	Minor	Limited damage to part of structure, or part of site requiring some reinstatement/stabilisation works
5	Insignificant	Little damage

Table 4.2: Hazard Measurement - Qualitative Measures of Likelihood of Landsliding (Fell et al., 2005).

Level	Descriptor	Description
A	Almost certain	The event is expected to occur
B	Likely	The event will probably occur under adverse condition
C	Possible	The event could occur under adverse condition
D	Unlikely	The event could occur under very adverse condition
E	Rare	The event is conceivable but only under exceptional circumstances
F	Not credible	The event is inconceivable or fanciful

Figure 4.1 shows the overall landslide risk analysis framework with the landslide vulnerability assessment methodology and processes. Extraction and interpretation of landslide can be made by utilizing both remote sensing and field data in producing landslide vulnerability, hazard and risk maps.

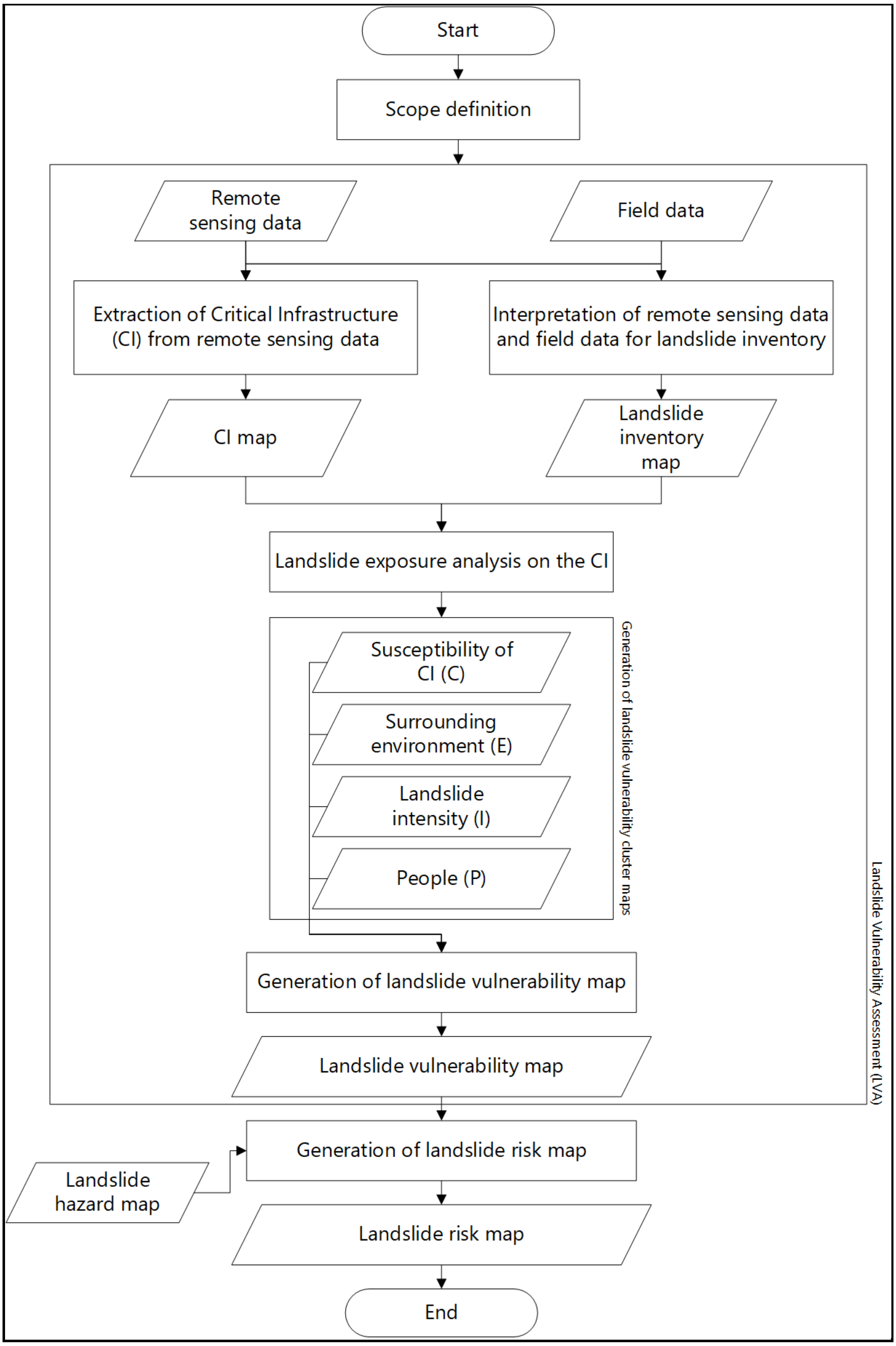


Figure 4.1: Risk analysis framework encompass of landslide vulnerability assessment approach.

4.3 Landslide Vulnerability Classes for CI

The recommended vulnerability classification for CI Building, Road, Dam and Utility are as follow in Table 4.3 and Table 4.4:

Table 4.3: Recommended Improvised Landslide vulnerability classes for Building and Road.

CI - BUILDING		CI - ROAD
Slightly non-structural damage, furnishing or fitting damaged, no human casualty expected V (0.01-0.19)	Very Low	Slight damage, does not affect traffic V (0.01-0.19)
Cracks, reparation not urgent, slight injuries of people V (0.20-0.39)		No structural damage to minor repairable damage, slightly affect traffic V (0.20-0.39)
Strong deformations, huge holes, cracks in structures, stability affected, doors & windows unusable, severe injuries, evacuation necessary V (0.40-0.69)		No structural damage to major repairable damage, severely affect road traffic V (0.40-0.69)
Structural breaks, partly destructed, reconstruction of destructed parts, severe injury (death), evacuation necessary V (0.70-0.89)		Structural damage, partly unusable road and requires road diversion V (0.70-0.89)
Severely damaged structure or totally destructed, evacuation necessary, complete reconstruction, death almost certain V (0.90-1.00)	Very High	Heavy damage, totally unusable road and immediate alternative road required V (0.90-1.00)

Table 4.4: Recommended Improvised Landslide vulnerability classes for Dam and Utility.

CI - DAM		CI - UTILITY
Slight damage, does not affect dam operation V (0.01-0.19)	Very Low	Slight damage, does not affect operation V (0.01-0.19)
No structural damage to minor repairable damage, slightly affect dam operation V (0.20-0.39)		No structural damage to minor repairable damage, slightly affect operation V (0.20-0.39)
No structural damage to major repairable damage, severely affect dam operation V (0.40-0.69)		No structural damage to major repairable damage, severely affect operation V (0.40-0.69)
Structural damage that affect stability and functionality, partly disrupted dam operation V (0.70-0.89)		Structural damage, highly interrupted operation, requires backup or alternative V (0.70-0.89)
Heavy damage, partial or total collapse, totally disrupted dam operation, immediate evacuation required V (0.90-1.00)	Very High	Heavy damage, total collapse of operation, required highly immediate backup operation V (0.90-1.00)

4.4 Landslide Risk Classification Matrix

The international risk classification matrix adopted after Ko Ko et al. (1999) is improvised and recommended as shown in Table 4.5. It classify the likelihood of landslide hazards to vulnerability of critical infrastructure or element-at-risk. The aim are as below:

a. Serve as a useful role in landslide risk management in providing a relative comparison of risks of different sites and prioritisation of follow-up actions in addressing the risk portfolio posed by a large number of sites (Fell et al., 2005).
b. Risk index is relatively simple and straightforward therefore is ideal for non-expert to judge based on landslide cases (Corangamite Catchment Management Authority, 2012).
c. Ideally used when information related to quantitative landslide risk assessment is absence (Pellicani et al., 2017).

Table 4.5: Recommended improvised International Standard Risk Assessment Matrix (Ko Ko et al., 1999).

Likelihood (hazard)	**Consequences to property (Vulnerability)**				
	Very High	**High**	**Medium**	**Low**	**Very Low**
Very High	VH	VH	H	H	M
High	VH	H	H	M	M
Medium	H	H	M	M	L
Low	H	M	M	L	VL
Very Low	M	M	L	VL	VL

where,

VH- Very high risk ; **H -** High risk ; **M -** Moderate risk ; **L -** Low risk ; **VL -** Very low risk

5.0 METHODOLOGY FOR LANDSLIDE VULNERABILITY ASSESSMENT AND RISK ANALYSIS

5.1 General

The criteria for selection of vulnerability indicators (Birkmann, 2006):

- Should be relevant and most significant indicator
- Reproducible and easily measurable
- Data availability and cost-effective
- Sensitivity, accurate and comparable

5.2 Landslide Vulnerability Assessment

The recommended selection of indicators and their weight values may be based on combination of qualitative (expert judgment on previous records) and quantitative approach (specific numerical modelling on the impact of landslides). The experts judgement recommendation may be prioritize if previous landslide damage record is insufficient. The landslide vulnerability indicators, value and index may varies for different areas of study, types of critical infrastructures (residential, building, road, dam and utility) with respect to landslide type. The indicators for landslide vulnerability, sub-indicators used in this guideline are based on comprehensive literature review, past records of landslide occurrences in Malaysia and rigorous peers review. It is further justified by the advantages and disadvantages of the published case studies comparative to present limitation of information and constraints from Malaysia landslide history.

Figure 5.1 shows the vulnerability assessment of building expose to translational landslide. The vulnerability of a building-residential for translational landslide type, constitute of four clusters ie C, E, P and I with respective indicators, sub-indicators and weightage. The allocation of weightage value for cluster should be in sequence, from 0.1(low influence to increase vulnerability) to 1.0 (high influence to increase vulnerability). The summation weight value must be equal to 1.0. The vulnerability index for CI (*V*) is defined as

$$V = \sum_{i=1}^{m} w_i \times s_i \qquad (2)$$

where, w_i = *i*-th weight of m indicators for different clusters; s_i = *i*-th weight of sub-indicators.

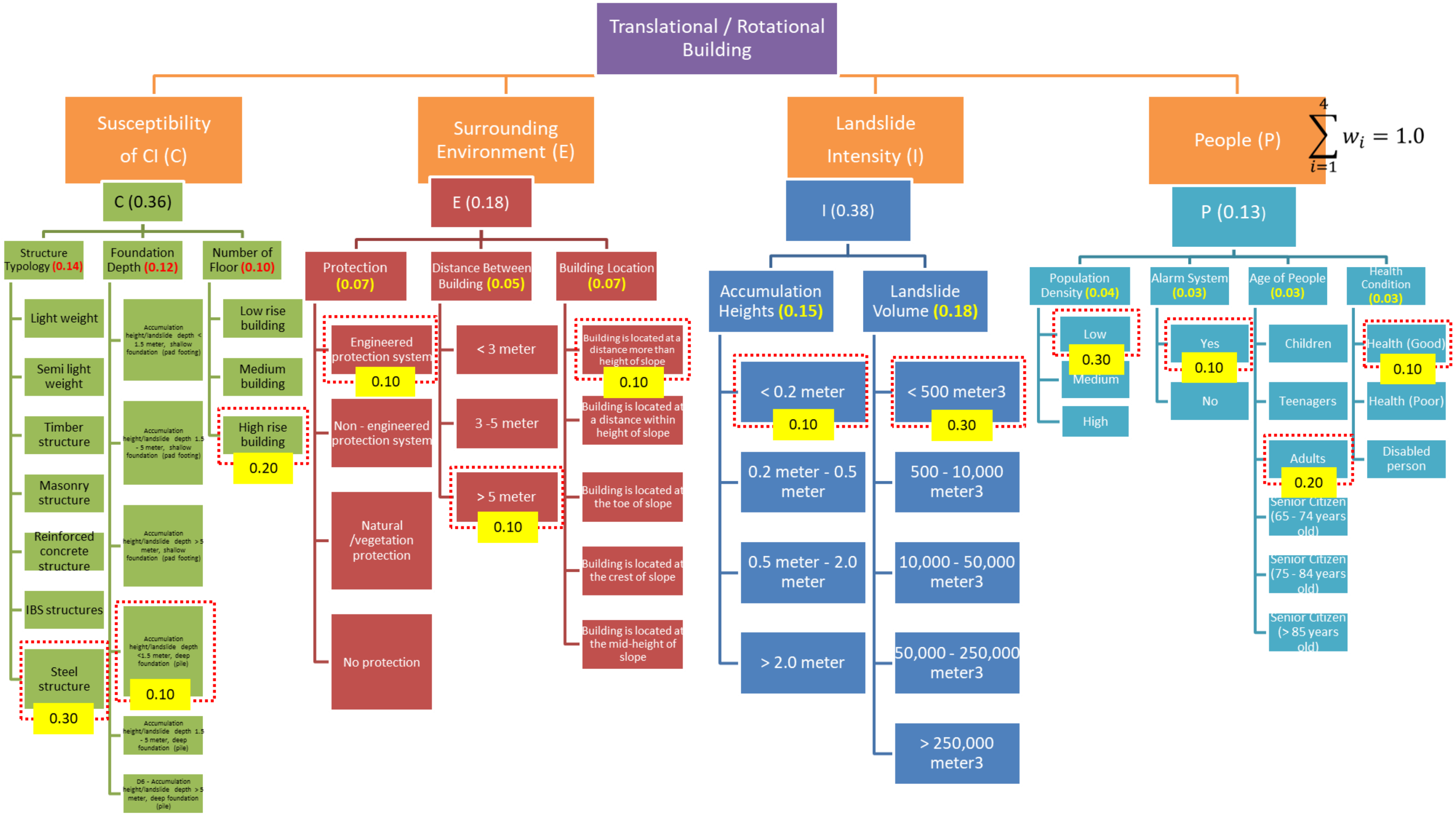


Figure 5.1: The vulnerability assessment of building expose to translational landslide.

CI- Building, Landslide Type -Translational / Rotational

C		
Structural Typology / Structure Construction Materials	Steel	Timber
	IBS	Semi Light
	Reinforced Concrete	Light
	Masonry	
Building Foundation Depth (Landslide Type vs. Shallow Foundation Building)	Ah (< 1.5 Meter), Pf (< 3.0 Meter)	
	Ah (1.5 Meter - 5.0 Meter), Pf (< 3.0 Meter)	
	Ah (> 5.0 Meter), Pf (< 3.0 Meter)	
Building Foundation Depth (Landslide Type vs. Deep Foundation Building)	Ah (< 1.5 Meter), Pile (> 3.0 Meter)	
	Ah (1.5 Meter - 5.0 Meter), Pile (> 3.0 Meter)	
	Ah (> 5.0 Meter), Pile (> 3.0 Meter)	
Number of Floor	High Rise (> 5 Storey)	
	Medium Rise (2 - 5 Storey)	
	Low Rise (Single Storey)	

E	
Presence of Protection	Engineered Protection System
	Non-Engineered Protection System
	Natural / Vegetation Protection
	No Protection
Distance Between Building	> 5 Meter
	3 - 5 Meter
	< 3 Meter
Building Location	Distance > Slope Height
	Distance ≤ Slope Height
	Building at the toe of slope.
	Building at the crest of slope.
	Building at the mid-height of slope.

I	
Accumulation Heights	< 0.2 Meter
	0.2 Meter - 0.5 Meter
	0.5 Meter - 2.0 Meter
	> 2.0 Meter
Landslide Volume	< 500m³
	500m³ - 10000m³
	10000m³ - 50000m³
	50000m³ - 250000m³
	> 250000m³

P	
Population Density	Low
	Medium
	High
Evacuation of Alarm System	Yes
	No
Age of People	Adults
	Teenagers
	Children
	Senior Citizen (65 - 74 Years Old)
	Senior Citizen (75 - 84 Years Old)
	Senior Citizen (> 85 Years Old)
Health Condition	Health (Good)
	Health (Poor)
	Disabled Person

Figure 5.2: Chart of building expose to translational landslide type: C, E, I, P indicators, sub-indicators and respected weightage.

5.2.1 Data Requirement

The geospatial data will be used to extract and characterize the critical infrastructures in the study area using various image processing and spatial analysis methods. Table 5.1 shows the data requirement for vulnerability assessment. The output from the landslide hazard and risk project in the study area will be used to generate landslide hazard map. However, the applicability of the landslide hazard information will heavily rely on the quality of the hazard map and the requirement of the proposed vulnerability method.

Table 5.1: Data requirement.

Type of Data	Source of Data	Data Information
Critical infrastructure	Remotely sensed data, LIDAR	Geometric features, footprint, height, size and length of CI
	Fieldwork inspection	Classification of slope, geology, condition of slope face, drainage system, slope distress, slope stabilization, facilities, scale of failure, slope geometry, vulnerability
Slope information	In-situ drone survey remotely sensed data; LiDAR	Slope gradient, slope aspect, plan curvature, stream network, watershed
Topography map	Survey and Mapping Department Malaysia (JUPEM)	Slope angle, road, river, contour, DEM
Aerial photo	Survey and Mapping Department Malaysia (JUPEM), private sector	Detail visualization of study area

a. Generation of Landslide Inventory Map

Landslide inventory map is derived based on geospatial data of the area of study. It is in the format of geospatial contour map. The basic principles and methods of landslide identification and detection of landslide inventory is as described in Figure 5.3, thus resulted in the derivation of landslide inventory map. The map represent the plan view of the schematic soil mass area, shape and probable direction of sliding towards critical infrastructure. The skill and experience of the personal plotting of landslide inventory map contribute to the level of accuracy of the inventory map. Figure 5.4 shows the contour pattern of concave features and convex features that give indicators on potential landslide or instabilities.

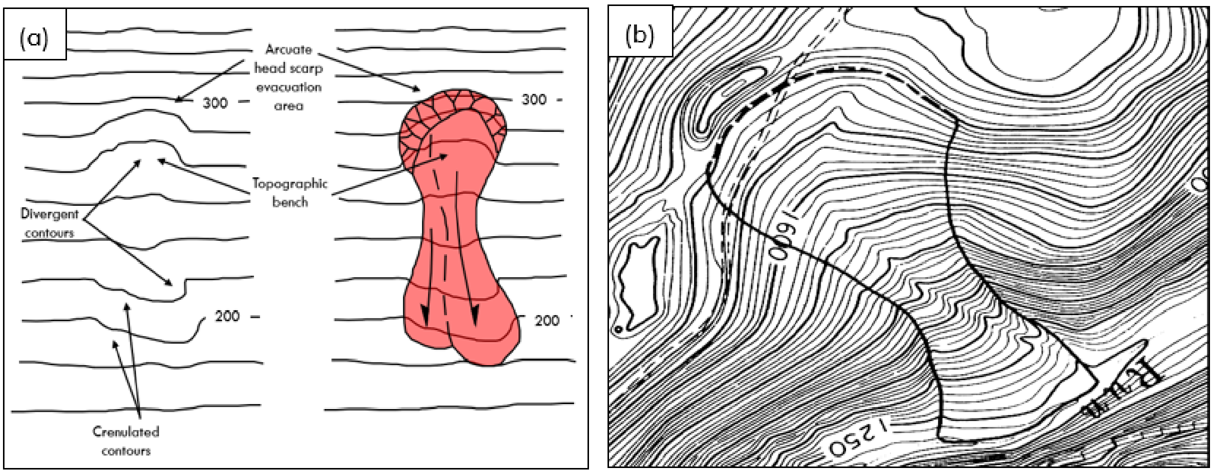


Figure 5.3: Landslide detection based on topographic expressions and pattern of contour lines (a) Earthflows, (b) Actual example of earthflow in the Appalachian highlands mapped by USGS.

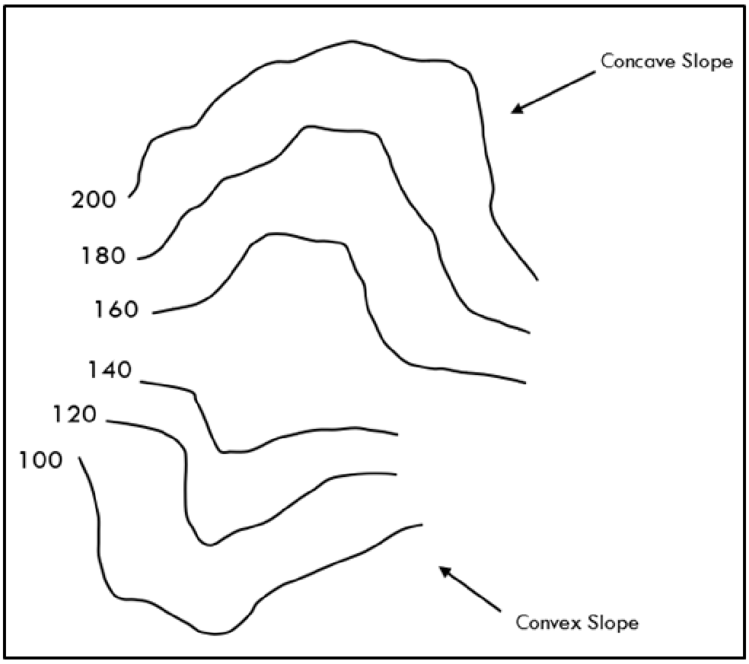


Figure 5.4: Contour pattern of concave features and convex features that give indicators on potential landslide or instabilities.

Landslide inventory map (Figure 5.5) should be generated using hillshade from DEM of high resolution remote sensing data overlay with contour for visualization (image interpretation) to delineate area of landslide, possible landslide runout and detailed characteristics of each landslide as required by the landslide intensity cluster (*I*) indicators of the landslide vulnerability assessment i.e. landslide volume, landslide velocity and accumulation height.

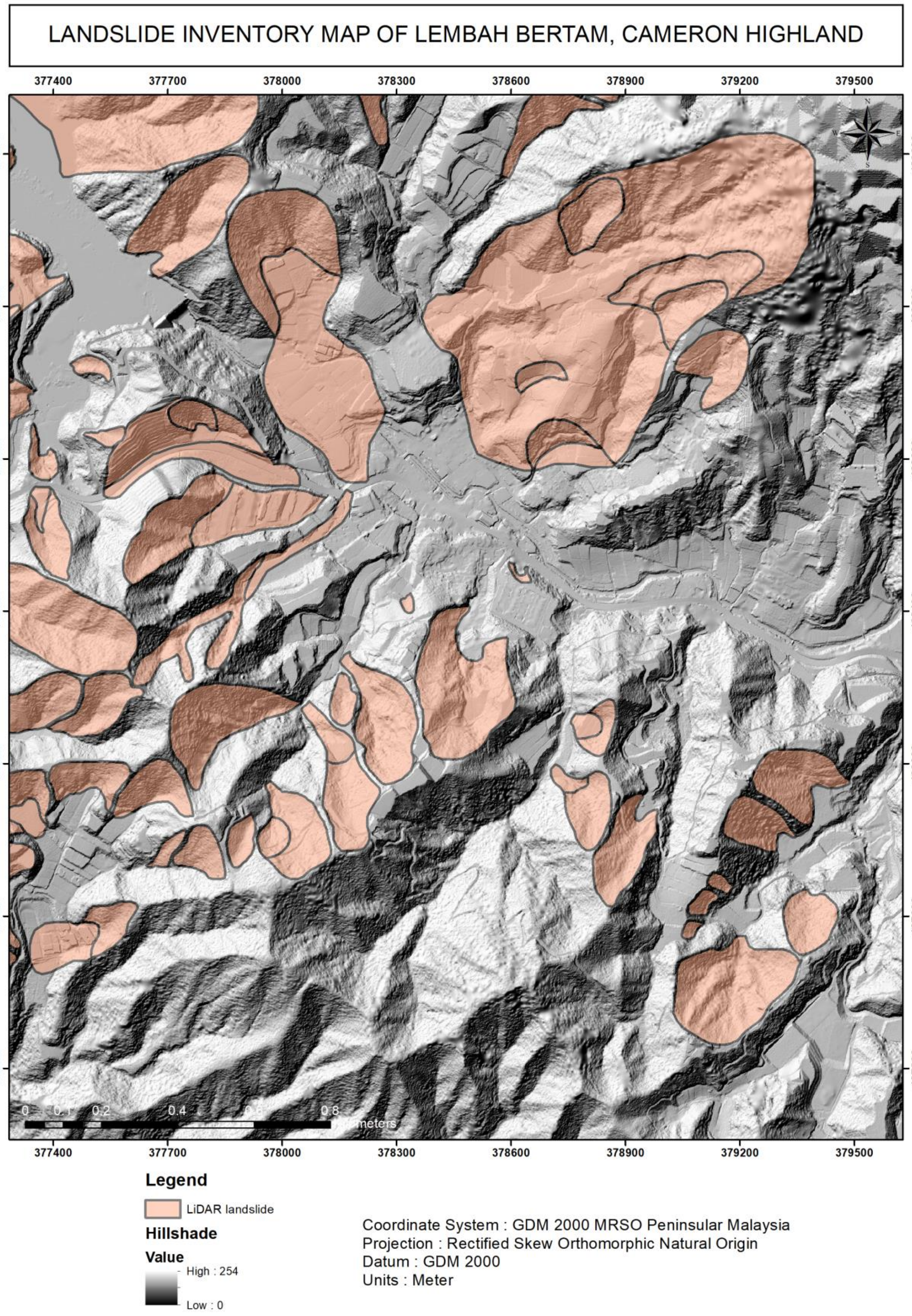


Figure 5.5: Example of derived landslide inventory map of Lembah Bertam, Cameron Highlands.

b. Generation of CI Map

Generation of CI maps should be done using high spatial resolution remote sensing data. The boundary of each CI should be delineated either manually or based on digital image classification process. The generation of CI maps using digital image processing approach should be based on the supervised image classification process. Various parametric and non-parametric algorithms for example maximum likelihood, artificial neural network, support vector machine can be used to produce CI map using high spatial resolution remote sensing data. The classified remote sensing data is in raster format and should be converted into vector format in the next data processing stage. Figure 5.6 shows the CI map of Lembah Bertam, Cameron Highlands.

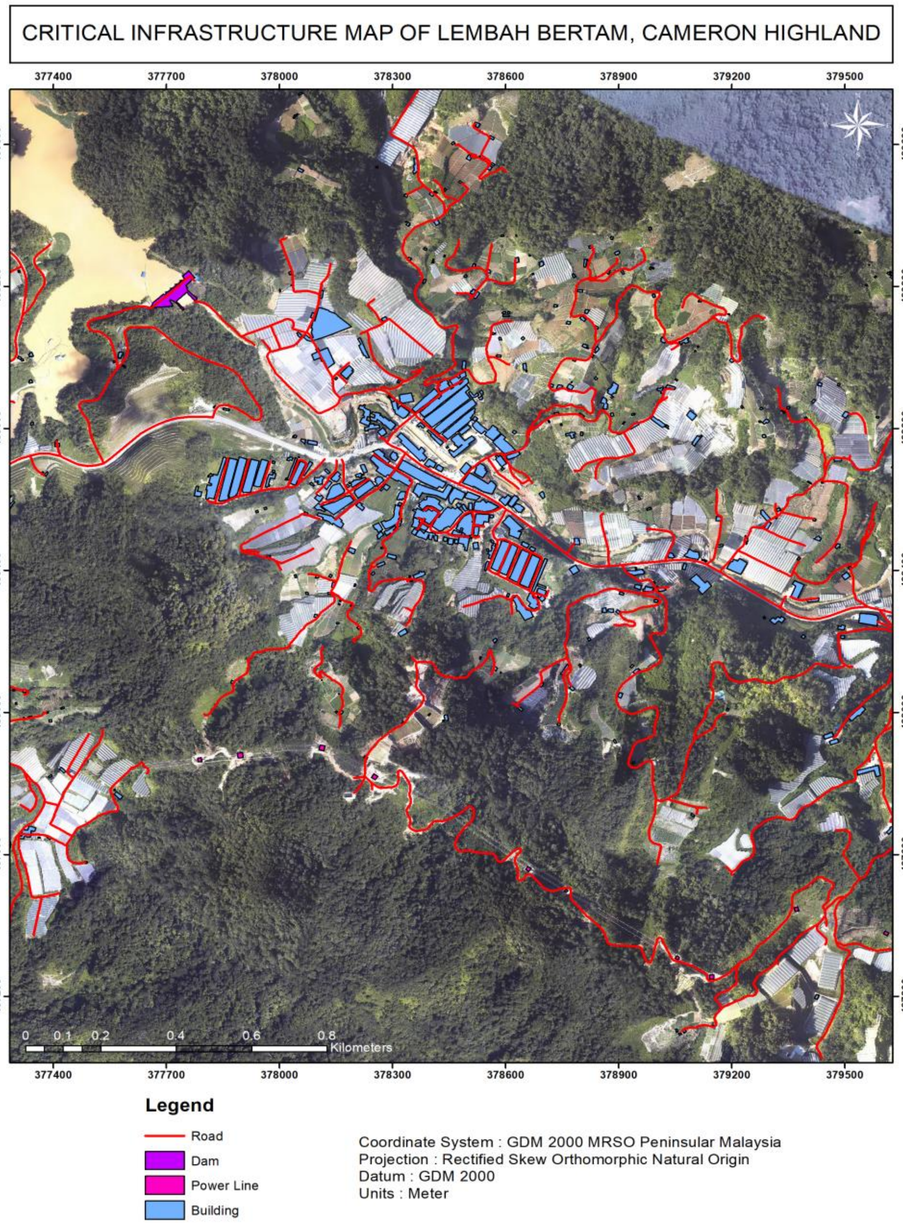


Figure 5.6: CI map of Lembah Bertam, Cameron Highlands.

c. Landslide Exposure Analysis on CI

The landslide exposure analysis involves the process of identifying the exposed CI within the landslide and run-out zones. The CI map is overlaid with the landslide hazard map. Each CI is marked based on its location either within the landslide and runout zones or outside both zones. Figure 5.7 shows the landslide exposure map of Lembah Bertam, Cameron Highlands.

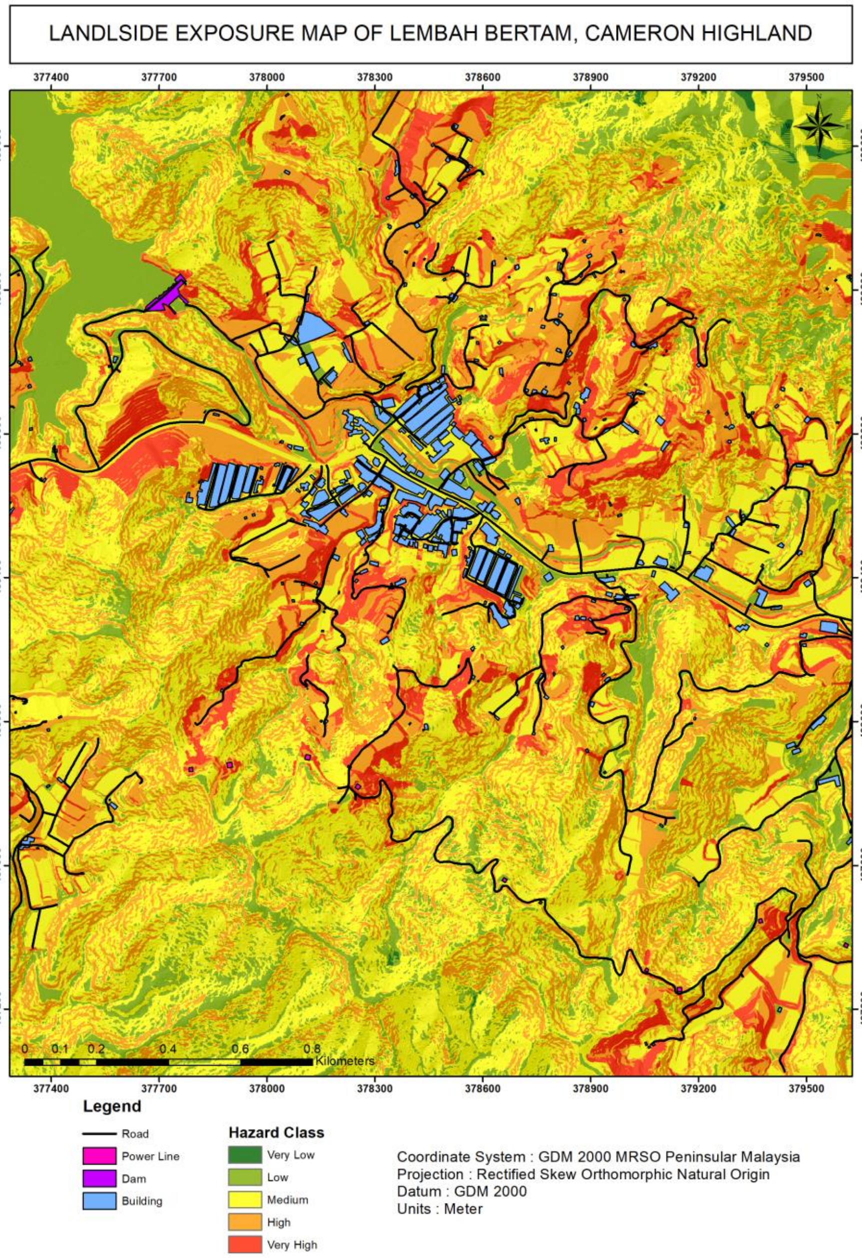


Figure 5.7: Landslide Exposure Map of Lembah Bertam, Cameron Highlands.

5.2.2 Generation of Landslide Vulnerability Cluster Maps

The landslide vulnerability cluster maps Susceptibility of CI (C), Surrounding Environment (E), Landslide Intensity (I) and People (P) should be generated depending on the type of CI identified from the CI maps and landslide types obtained from landslide inventory map. Suitable weight value for indicators and sub-indicators for each landslide cluster should be determined and stored in each polygon of CI in the CI map.

The landslide vulnerability cluster maps that should be generated are as follow:-

a. Generation of C map
b. Generation of E map
c. Generation of I map
d. Generation of P map

a. Generation of C Map

Generation of C map aims at characterizing the susceptibility of CI by taking into account all the indicators in the C cluster. The CI map that contains information on the location of the CI is required as the main input. The map for cluster C should be generated for each CI, in which detailed information as required by each indicator and sub-indicator have to be determined for each polygon of CI. Finally, weight value should be assigned to each indicator and sub-indicator of each polygon of CI in the map. The map in Figure 5.8 is the map of cluster C for respective CI.

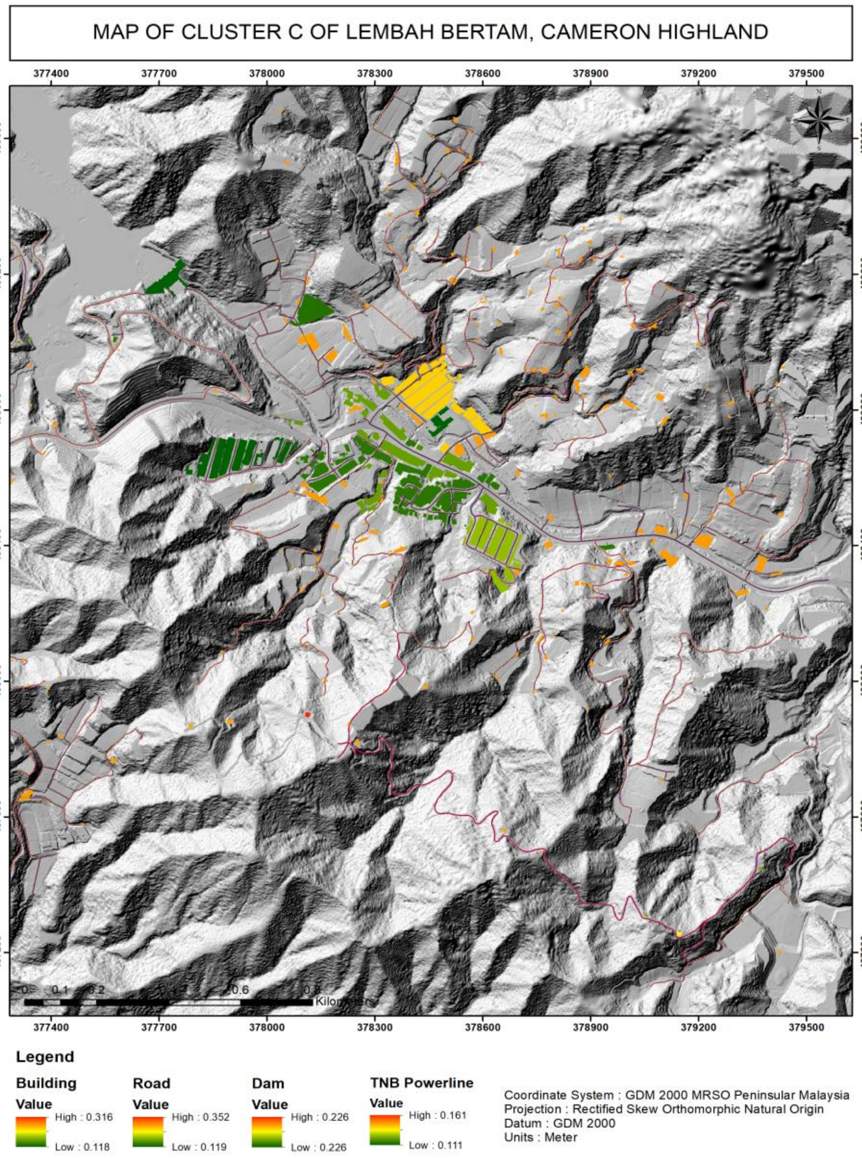


Figure 5.8: Map of cluster C of Lembah Bertam, Cameron Highlands.

b. Generation of E Map

The E cluster map focuses on characterizing the impact of surrounding land features towards vulnerability of CI. The impact of landslide on a specific CI either can be increased or reduced by the surrounding environment of the CI. For example, slope mitigation measures will reduce the impact of landslide or vulnerability of CI. Indicators and sub-indicators of the surrounding environment (E) cluster should be observed within a specific distance from each CI polygon. Next, the corresponding weight value for indicator and sub-indicator should be assigned for each CI polygon of the CI map. The map as in Figure 5.9 represent the map of cluster E for respective CI.

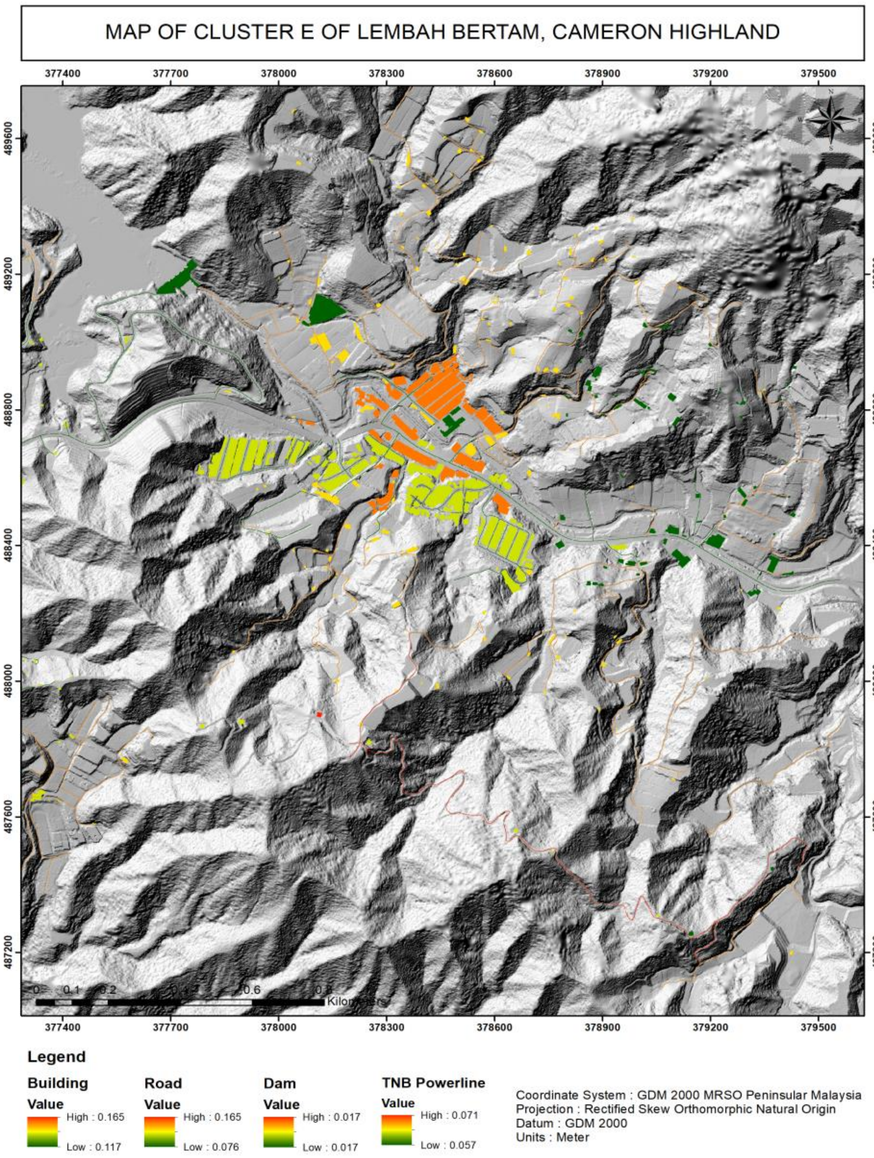


Figure 5.9: Map of cluster E of Lembah Bertam, Cameron Highlands.

c. Generation of I Map

The I cluster map shows the landslide intensity that describe the characteristic of particular landslide body. Landslide intensity is very important to evaluate the vulnerability of element at risk such as buildings, roads, dam and utilities. In this case, three (3) indicators are chosen to be evaluated and identified which are; i) accumulation high of the landslides, ii) landslide thickness and iii) landslide volume. Weightage are given to these three (3) indicators and will be calculated in a sum together with the other indicators depend on the types of element at risk. The map as in Figure 5.10 is representing the map of cluster I for respective CI.

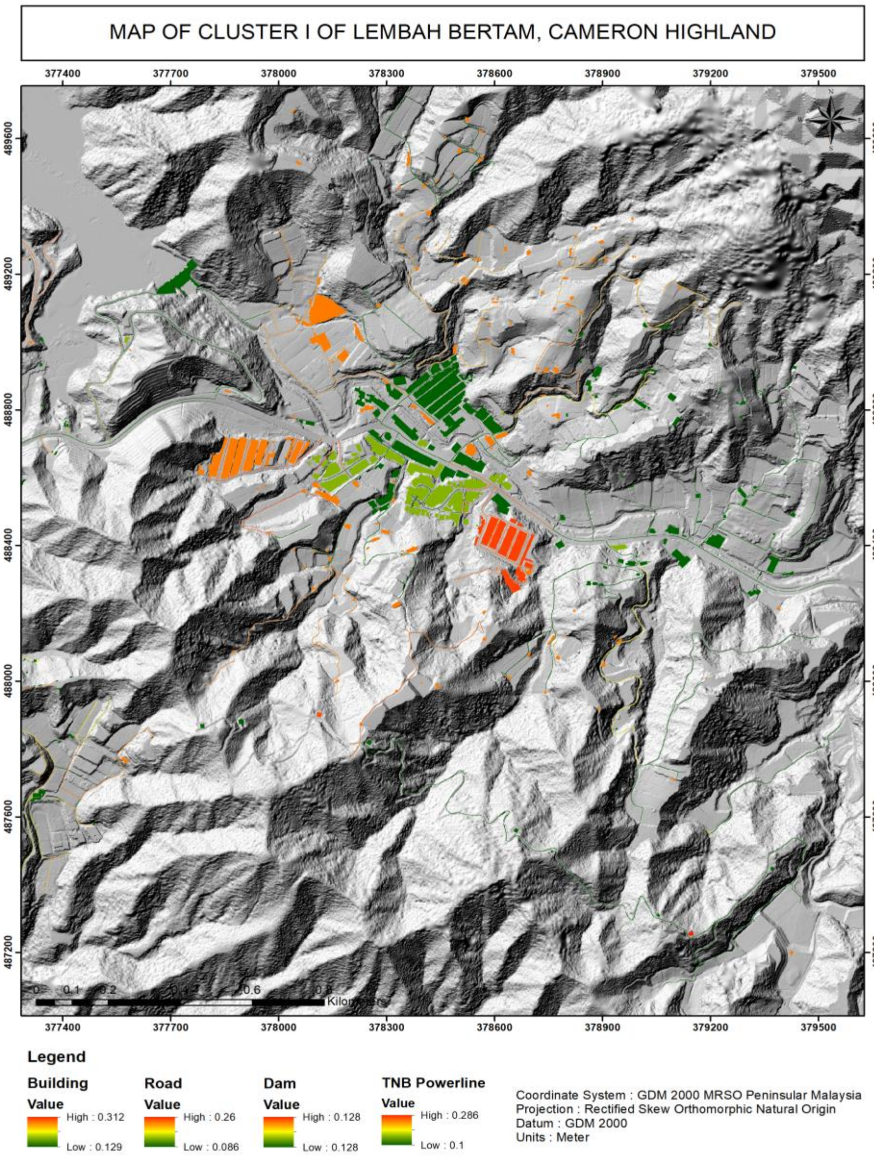


Figure 5.10: Map of cluster I of Lembah Bertam, Cameron Highlands.

d. Generation of P Map

Generation of P cluster map accounts the impact of damaged or disrupted CI services on community. Indicators and sub-indicators of P cluster should be selected for each CI polygon, in which suitable weight will be assigned into each CI polygon. The map as in Figure 5.11 is representing the map of cluster P for respective CI.

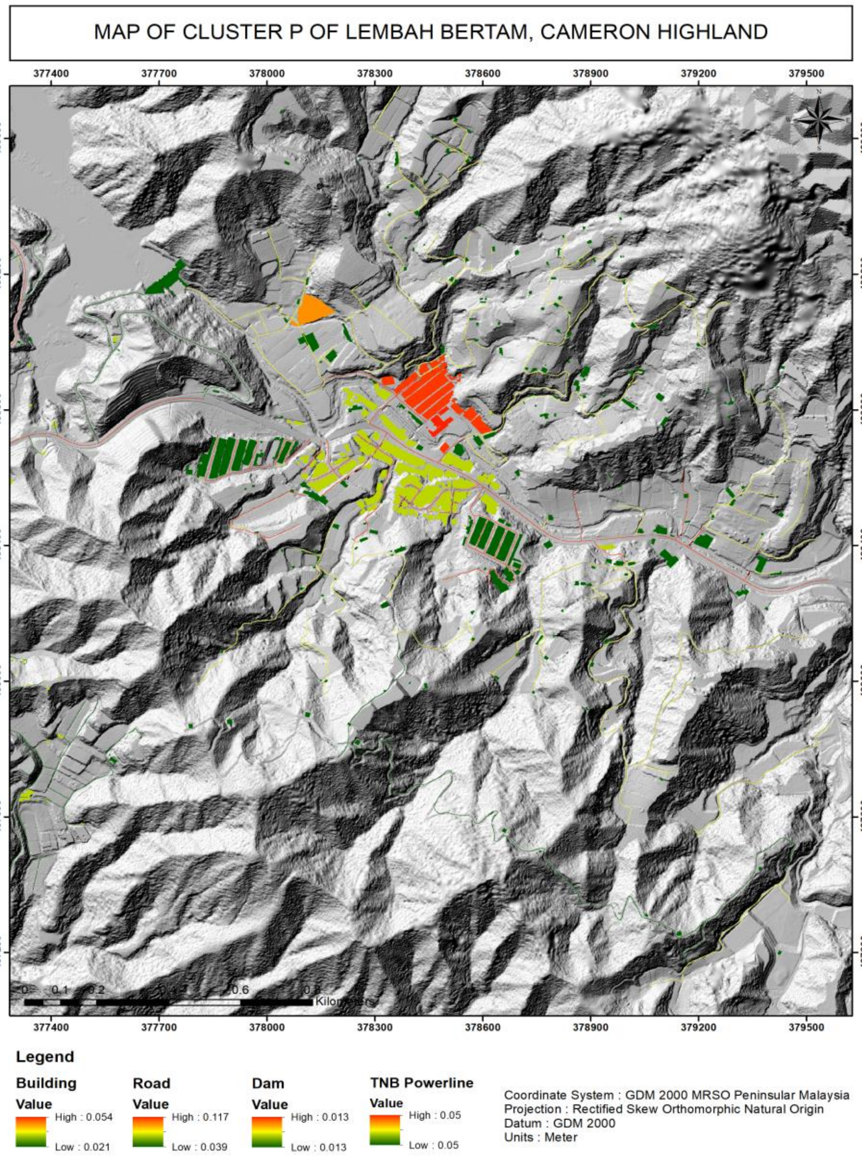


Figure 5.11: Map of cluster P of Lembah Bertam, Cameron Highands.

5.2.3 Generation of Landslide Vulnerability Map for CI

The landslide vulnerability map for respective CI is generated by combining all cluster maps, C, E, I and P. The resulting landslide vulnerability index by using Equation 2 is classified into its specific vulnerability class for each CI as shown in Table 4.3.

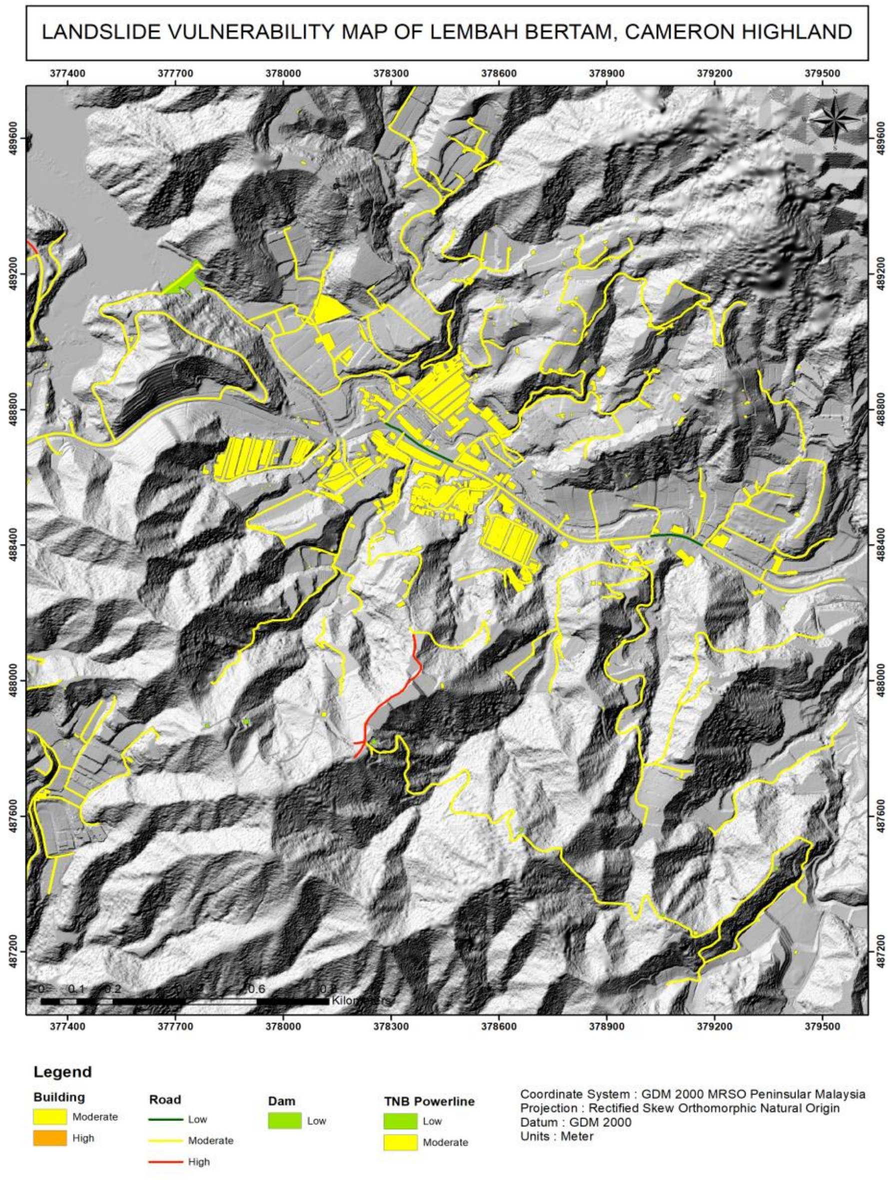


Figure 5.12: Landslide vulnerability map of Lembah Bertam, Cameron Highlands.

5.2.4 Generation of Landslide Risk Map for CI

Landslide risk map is produced by combination of landslide hazard and landslide vulnerability maps. A geospatial raster processing method of combining both maps called 'raster calculator' has the specific ability of merging two or more raster layers to come out with a single output raster layer. Figure 5.13 shows the final landslide risk map of the same area for respective CI. Similarly as the vulnerability map, the landslide risk map has only five classifications from very low until very high.

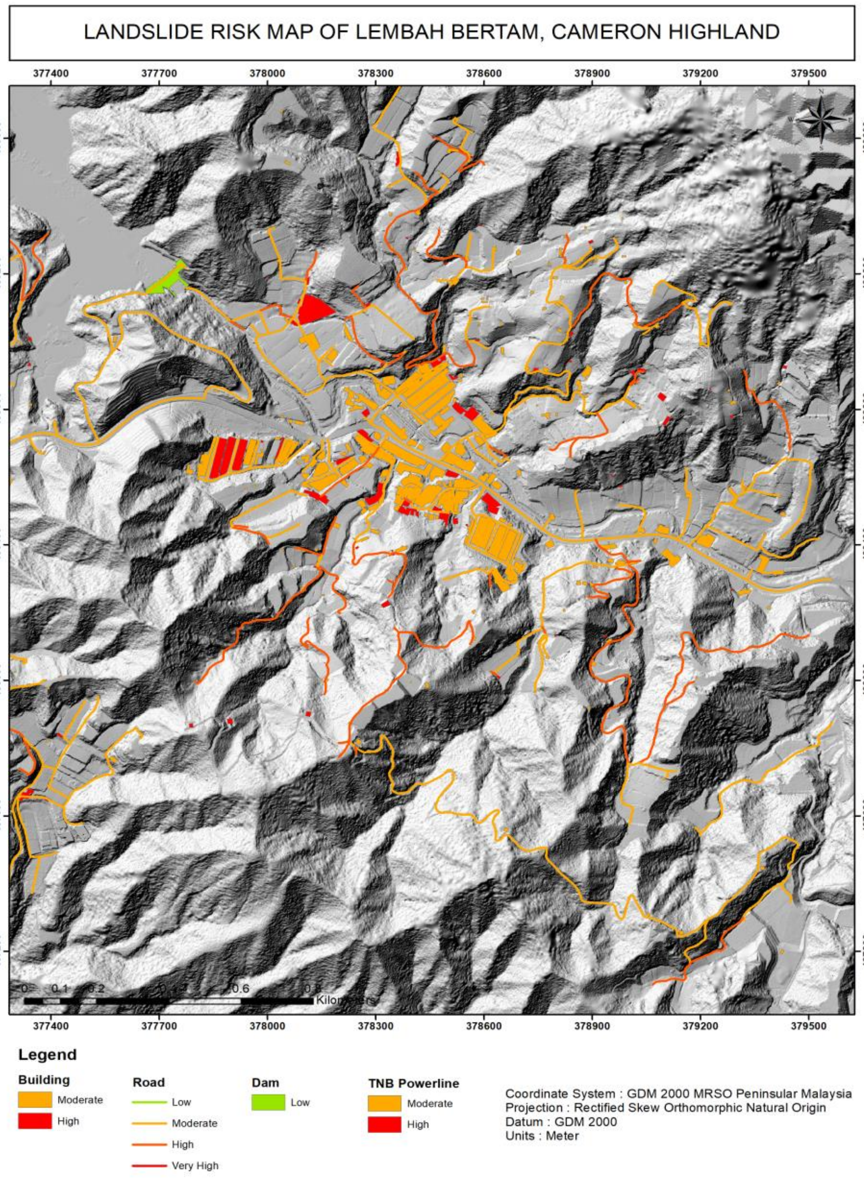


Figure 5.13: Landslide risk map of Lembah Bertam, Cameron Highlands.

6.0 SELECTION OF C, E, I, AND P INDICATORS, SUB-INDICATORS AND WEIGHTAGE

6.1 General

Landslide vulnerability assessment procedure for a critical infrastructure is as shown in Figure 6.1. It begins with the selection of indicators that are related to four (4) clusters C, E, I and P until to the derivation of CI level of risk.

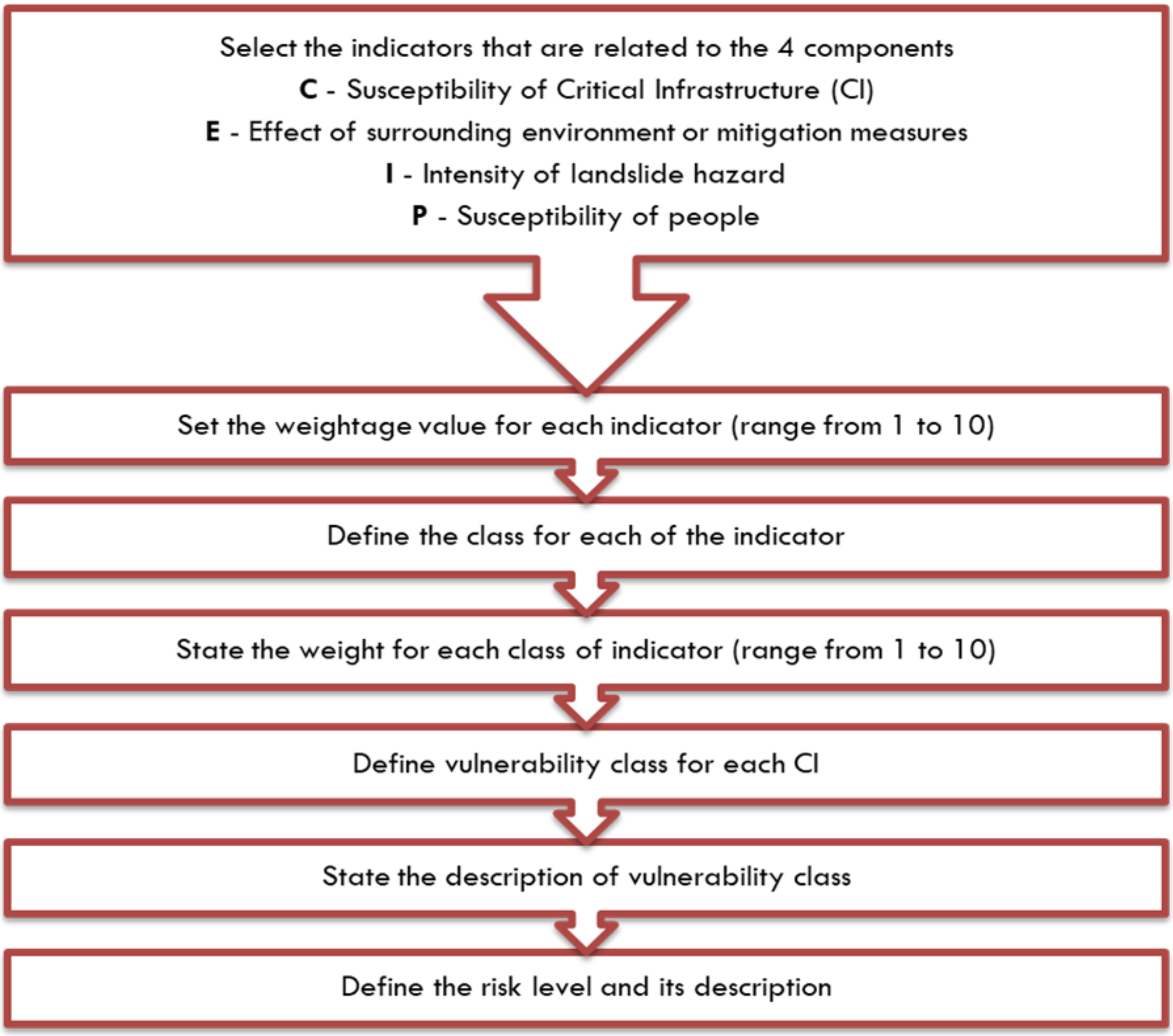


Figure 6.1: Step by step instruction to fill out the landslide vulnerability survey forms for each CI and landslide type.

6.2 Cluster Indicators and Sub-Indicators

Besides literature , the selection and determination of appropriate cluster indicators and sub-indicators has been derived from series of forum with the stake holder, local authorities, government agencies and professional that has vast experineces related to Malaysia landslide hazards. The recommended cluster indicator and sub-indicators are as follows:

Table 6.1: Group of cluster indicator (C, E, I and P) for building.

CI- Building, Landslide Type -Translational / Rotational

C		
Structural Typology / Structure Construction Materials	Steel	Timber
	IBS	Semi Light
	Reinforced Concrete	Light
	Masonry	
Building Foundation Depth (Landslide Type vs. Shallow Foundation Building)	Ah (< 1.5 Meter), Pf (< 3.0 Meter)	
	Ah (1.5 Meter - 5.0 Meter), Pf (< 3.0 Meter)	
	Ah (> 5.0 Meter), Pf (< 3.0 Meter)	
Building Foundation Depth (Landslide Type vs. Deep Foundation Building)	Ah (< 1.5 Meter), Pile (> 3.0 Meter)	
	Ah (1.5 Meter - 5.0 Meter), Pile (> 3.0 Meter)	
	Ah (> 5.0 Meter), Pile (> 3.0 Meter)	
Number of Floor	High Rise (> 5 Storey)	
	Medium Rise (2 - 5 Storey)	
	Low Rise (Single Storey)	

E	
Presence of Protection	Engineered Protection System
	Non-Engineered Protection System
	Natural / Vegetation Protection
	No Protection
Distance Between Building	> 5 Meter
	3 - 5 Meter
	< 3 Meter
Building Location	Distance > Slope Height
	Distance ≤ Slope Height
	Building at the toe of slope.
	Building at the crest of slope.
	Building at the mid-height of slope.

I	
Accumulation Heights	< 0.2 Meter
	0.2 Meter - 0.5 Meter
	0.5 Meter - 2.0 Meter
	> 2.0 Meter
Landslide Volume	< 500m^3
	500m^3 - 10000m^3
	10000m^3 - 50000m^3
	50000m^3 - 250000m^3
	> 250000m^3

P	
Population Density	Low
	Medium
	High
Evacuation of Alarm System	Yes
	No
Age of People	Adults
	Teenagers
	Children
	Senior Citizen (65 - 74 Years Old)
	Senior Citizen (75 - 84 Years Old)
	Senior Citizen (> 85 Years Old)
Health Condition	Health (Good)
	Health (Poor)
	Disabled Person

Table 6.2: Group of cluster indicator (C, E, I and P) for road.

CI-Road, **Landslide Type-**Translational / Rotational

C

Road Category (JKR Standard Design)	R6	U3/U4
	U6	R3/R4
	R5	R1/R1a/R2
	U4/U5	U1/U1a/U2/U3
	R4/R5	
Location of Road	Distance > Slope Height	
	Distance ≤ Slope Height	
	Road at the toe of slope.	
	Road at the crest of slope.	
	Road at the mid-height of slope.	
Road Material	Rigid Pavement / Concrete Road	
	Flexible Pavement / Bituminous Road	
	Unpaved Road	
Road Maintenance	Good Maintenance	
	Poor Maintenance	
	No	

E

Presence of Protection	Engineered Protection Sytem
	Non-Engineered Protection System
	Natural / Vegetation Protection
	No Protection
Presence of Warning System	Yes
	No
Road Drainage System	Yes
	No

I

Accumulation Heights	< 0.2 Meter
	0.2 Meter - 0.5 Meter
	0.5 Meter - 2.0 Meter
	> 2.0 Meter
Accumulation Thickness	< 1.5 Meter
	1.5 Meter - 5.0 Meter
	5.0 Meter - 20.0 Meter
	> 20.0 Meter
Landslide Volume	< 500m^3
	500m^3 - 10000m^3
	10000m^3 - 50000m^3
	50000m^3 - 250000m^3
	> 250000m^3

P

Traffic Volume	R2/R1/R1a/U2/U1/U1a (ADT ≤ 1000)
	R3/U3 (1000 < ADT < 3000)
	R4/U4 (3000 < ADT < 10000)
	R5/U5 (ADT > 10000)
	R6/R5/U6 (High Traffic Volume)

Table 6.3: Group of cluster indicator (C, E, I and P) for dam.

CI-Dam, Landslide Type -Transitional / Rotational

C

Basin / Catchment	Very Large, > 100 km^2	Small, 5 - 25 km^2
	Large, 50 - 100 km^2	Very Small, < 5 km^2
	Medium, 25 - 50 km^2	
Reservoir	Very High, > 30 km^2	Low, 1 - 5 km^2
	High, 11 - 30 km^2	Very Low, < 1 km^2
	Medium, 6 - 10 km^2	
Dam Dimension (Main Structure - Height)	< 5 Meter	51 - 99 Meter
	6 - 15 Meter	> 100 Meter
	16 - 50 Meter	
Dam Dimension (Main Structure - Length)	> 300 Meter	51 - 100 Meter
	201 - 300 Meter	< 50 Meter
	101 - 200 Meter	
Dam Typology/Categories	Sedimentation/Recreational	Power Generation
	Flood Mitigation	Water Supply
	Irrigation	
Dam Construction Materials	Reinforced Concrete	Rockfill
	Composite	Earthfill

E

Presence of Protection	Fully Engineered Protection System
	Partially Man-Made Protection System
	Natural Protection (Vegetation)
	No Protection
Presence of Warning System	Yes
	No

I

Landslide Volume	< $500m^3$
	$500m^3$ - $10000m^3$
	$10000m^3$ - $50000m^3$
	$50000m^3$ - $250000m^3$
	> $250000m^3$

P

Population Density	Low (< 25 People / km^2)
	Medium (25 - 50 People / km^2)
	High (> 50 People / km^2)

Table 6.1: Group of cluster indicator (C, E, I and P) for utility (powerline).

CI-TNB Powerline, Landslide Type-Translational / Rotational

C

Typology of Utilities	Telco Tower	Hybrid Tower	
	Substation 33kV	GRID 500kV	
	PMU	GRID 275kV	
	GRID 132kV		
Tower & Tower Component Material	Composite	Steel	Wood
Building Structure Foundation (Telco, PMU, Substation 33kV)	Surficial (<1.5 Meter)	Deep (5.0 - 20.0 Meter)	
	Shallow (1.5 - 5.0 Meter)	Very Deep (>20.0 Meter)	
Tower Structure Foundation (132kV, 275kV, 500kV, Hybrid)	Surficial (<1.5 Meter)	Deep (5.0 - 20.0 Meter)	
	Shallow (1.5 - 5.0 Meter)	Very Deep (>20.0 Meter)	
Location of Tower	Toe of Slope		
	Top of Slope		
	Face of Slope		

E

Presence of Protection	Engineered	Natural / Vegetation	
	Non-Engineered	No Protection	
Slope Morphology (Shape)	Straight	Convex	Concave
Presence of Warning System	Yes	No	
Distance of Tower From The River	> 50 Meter		
	25 - 50 Meter		
	10 - 25 Meter		
	< 10 Meter		
Presence of Erosion	No Erosion		
	Sheet		
	Rill		
	Gully		

I

Accumulation Heights	< 0.2 Meter
	0.2 Meter - 0.5 Meter
	0.5 Meter - 2.0 Meter
	> 2.0 Meter
Landslide Thickness	Surficial (<1.5 Meter)
	Shallow (1.5 - 5.0 Meter)
	Deep Seated (5.0 - 20.0 Meter)
	Very Deep Seated (>20.0 Meter)
Landslide Volume	< $50m^3$
	$50m^3$ - $500m^3$
	$500m^3$ - $10000m^3$
	$10000m^3$ - $50000m^3$
	$50000m^3$ - $250000m^3$
	> $250000m^3$

P

Population Density	Low (< 25 People / km^2)
	Medium (25 - 50 People / km^2)
	High (> 50 People / km^2)

6.3 Cluster Weightage Matrix and Descriptions

The weightage distribution for each cluster C, E, I, P components must represent the degree of contribution of each component towards the development of VI. The vulnerability of any critical infrastructure shall exist as a result of two main components i.e landslide hazards and critical infrastructure.

The establishment of weightage value of cluster C, E, I, P for CI is based on the following assumptions:

i. Existence of landslide hazards (causal factor) and CI (element-at-risk)
ii. The weightage value of these two contributing components (I and C) must be of the highest weightage value.
iii. The weightage value for E and P is the lowest, as the presnt of these cluster may determine the level of severity of vulnerability.
iv. The weightage value allocated to each cluster C, E, I and P should be realistic and able to capture the whole range of vulnerability index or vulnerability classes from very low to very high as tabulated in Table 4.3.

The recommended cluster weightage value matrix is as follows:

Table 6.2: Recommended cluster weightage value matrix.

Cluster	Cluster weightage value		
	Option1	**Option2**	**Option3**
Lanslide Intensity **(I)**	0.5	0.3	0.36
Critical Infrastructure **(C)**	0.3	0.3	0.33
Surrounding Environment **(E)**	0.1	0.2	0.18
People inside Building **(P)**	0.1	0.2	0.13
Total	**1.0**	**1.0**	**1.0**

However, this proposed cluster weightage can further be revised with the availability of new data. An example of the scenario based simulation using recommended cluster weightage value option to derive vulnerability class is elaborated in the manual section 5.1.4 Table 5.11.

7.0 DETERMINATION OF VULNERABILITY INDEX AND RISK CLASSIFICATION FOR CRITICAL INFRASTRUCTURE

7.1 General

From the recommended procedure, Figure 7.1 tabulated an example of the overall process of landslide vulnerability assessment of a particular CI (building) presumably subjected to translational or rotational landslide hazard in deriving to the vulnerability index of the CI.

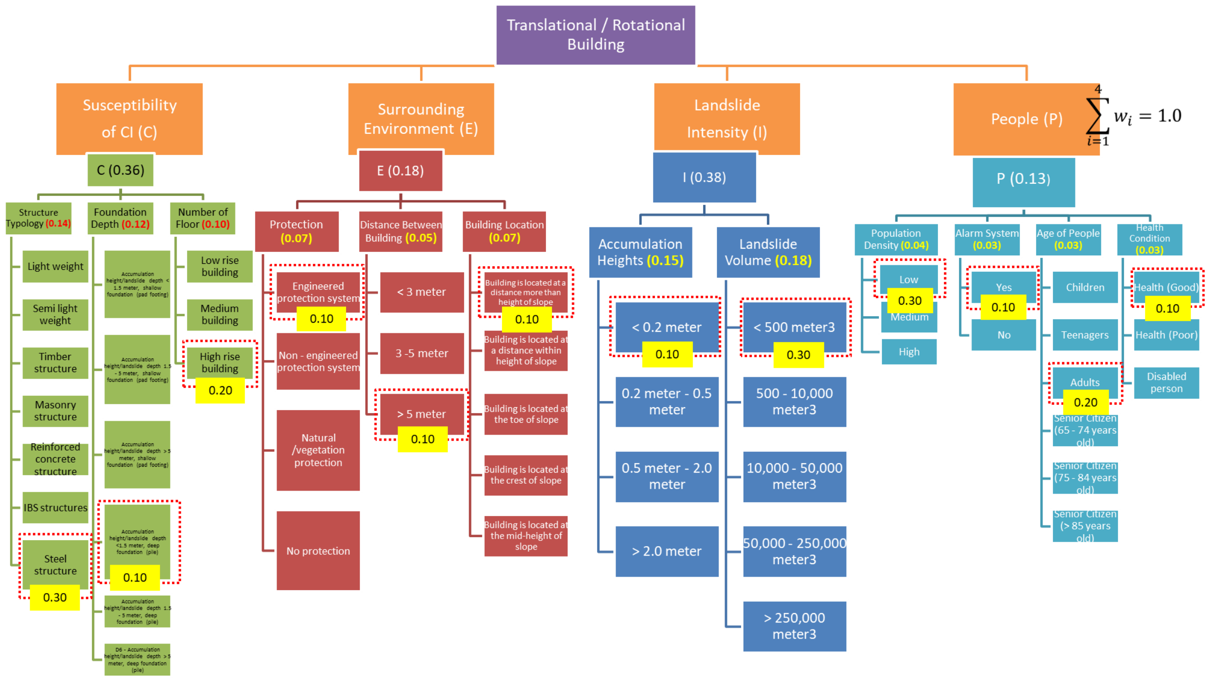


Figure 7.1: Conceptual division of indicators, sub-indicators and weight value for landslide vulnerability assessment scenario.

7.2 Vulnerability Index for CI

Vulnerability index is a score derived from landslide vulnerability assessment, expressed on a scale from 0 (no damage) to 1 (total damage). The score defined the level of severity of loss to the CI from the occurrence of landslide hazards of a certain magnitude.

Example Scenario 1, Figure 7.2: The summation of scores shall derive to a vulnerability index. The index is then referred to the vulnerability classes (Table 4.3) and description of possible degree of severity of damage to the critical infrastructure is determined.

Landslide Type: Translational/Rotational

CI Type: Building/Residential $\boldsymbol{V} = \sum_{i=1}^{m} w_i \times s_i$

Susceptibility of CI

((0.14 x 0.30) + (0.12 x 0.10) + (0.10 x 0.20)) + ((0.07 x 0.10) + (0.05 x 0.10) + (0.07 x 0.10)) + ((0.15 x 0.10) + (0.18 x 0.30)) + ((0.04 x 0.30) + (0.03 x 0.10) + (0.03 x 0.20) + (0.03 X 0.10))

VI = 0.20 (Low Vulnerability)

Cracks in the wall, stability not affected, reparation not urgent and slight injuries of people in the building

Figure 7.2: The corresponding calculation for building and residential vulnerability of the scenario.

Table 7.1 summarises the total number of 358 buildings within the study area. The number of building base on hazards classification and vulnerability classes is as shown. Ultimately the risk classification of building were determined from the respective maps.

Table 7.1: Statistics of buildings from Hazard, Vulnerability and Risk maps at Lembah Bertam.

Buildings at Lembah Bertam	No. of buildings
Total Building	358
Hazard	
Building at Hazard (Low)	13
Building at Hazard (Medium)	104
Building at Hazard (High)	150
Building at Hazard (Very High)	91
Vulnerability	
Building at Vulnerability (Moderate)	358

Risk	
Building at Risk (Medium)	117
Building at Risk (High)	241

7.3 Risk Classification for CI

By adopting the concept of qualitative risk, landslide risk map is derived from the cross-over of vulnerability map of CI and landslide hazard map. Figure 5.13 in section 5.2.4 show an example of derived landslide risk map (Lembah Bertam), among all the buildings in this area, 117 numbers were categorized as Medium risk while the rests (241 numbers) were identified as High risk.

A case study at Lembah Bertam, from the vulnerability map shows that all the buildings within the study area, a total of 332 were categorized as Moderate class while the rests (2 numbers) were identified as High class. The resultant risk map however shows that, 191 number of the buildings were categorized as Medium Risk while the rests of the buildings at this area (243 numbers) were categorized as High Risk.

8.0 LANDSLIDE VULNERABILITY ASSESSMENT AND RISK ANALYSIS MAP SCALES AND PARAMETERS

8.1 Map Scales

The data acquisition is depends on the study areas. It can be divided into three categories, regional scale, medium scale and large scale. The regional scale of study areas with less than 1:100,000 is used to identify affected residential areas, commercial areas and roads due to landslide.

Table 8.1 shows the recommended types and levels of maps scales related to landslide assessment (Fell et al., 2008). Landslide vulnerability assessment is suggested to be prepared at large scale of 1:5,000 to 1:25,000 (suitable for local zoning), which is proposed for local authorities as a basic information or supporting information for land use plan, mitigation purposes and risk assessment for any development of the critical infrastructure.

Table 8.1: Landslide zoning mapping scales and their application (Fell et al., 2008).

SCALE DESCRIPTION	INDICATIVE RANGE OF SCALES	EXAMPLES OF ZONING APPLICATION	TYPICAL AREA OF ZONING
Small	<1:100,000	Landslide inventory and susceptibility to inform policy makers and the general public	>10,000 km^2 square kilometers
Medium	1:100,000 to 1:25,000	Landslide inventory and susceptibility zoning for regional development; or very large-scale engineering projects. Preliminary level hazard mapping for local areas Preliminary level hazard mapping for local areas	1,000 –10,000 km^2 square kilometres
Large	1:25,000 to 1:5,000	Landslide inventory, susceptibility and hazard zoning for local areas. Intermediate to advanced level hazard zoning for regional development. Preliminary to intermediate level risk zoning for local areas and the advanced stages of planning for large engineering structures, roads and railways. Preliminary to intermediate level risk zoning for local areas and the advanced stages of planning for large engineering structures, roads and railways	10 – 1,000 km^2 square kilometres
Detailed	1:5,000 or less	Intermediate and advanced level hazard and risk zoning for local and site-specific areas and for the design phase of large engineering structures, roads and railways	Several hectares to tens of square kilometres

9.0 RELIABILITY OF LANDSLIDE VULNERABILITY ASSESSMENT AND RISK ANALYSIS

9.1 Potential Sources of Error

a) Landslide inventories

The landslide inventory maps are prepared using the interpretation of digital elevation model (DEM) data derived from LiDAR combined with orthophotos from the same source. The production of landslide inventory maps using this method is known to be subjective and error-prone operation where the accuracy of the maps depends on the experience and skills of the person. If the study sites are large and interpretation are done by different groups of people, there are chances that errors can occur. The data acquisition of landslide inventory maps from previous interpretation or existing landslide body one with the latest set of inventories will most likely produce some inconsistencies of landslide body and associate landslide intensity sub-indicators. Therefore, it is recommended that inventory maps derived from remotely sensed data may calibrated by field verification at the study area.

b) Estimation of intensity values

One of the important components in constructing the vulnerability index using indicator-based method is the landslide intensity. High landslide intensity values indicate vulnerable CI. As there is no specific procedure and standard approach to compute landslide intensity in Malaysia, computation is based on three parameters (accumulation high of the landslides, landslides thickness and landslide volume). These parameters are estimated from expert judgement as no proper record about landslide dimension are available. Proper method to quantitatively measure the landslide dimension can improve the accuracy and minimize the error of estimating landslide intensity values.

9.2 Validation of Mapping

a) Peer review

There should be a peer reviewer appointed to provide independent assessment of the vulnerability and risk analysis of CI. The peer reviewer selected should have high level of skills and experience in related field. The peer reviewer should meet with those carrying out the study at the beginning of the study and, after selecting weights (indicator and sub-indicator) and after initial mapping of vulnerability index for CI. This forms as a basic quality control and validation process during the period of the project.

b) Formal validation

To provide high level of confidence for the construction of vulnerability index and risk assessment using the landslide inventory dataset, a proper validation is needed. To do this the landslide inventory is randomly split in two groups: one for analysis and one for validation purpose. The analysis is carried out in part of the study area (model) and tested in another part with different landslides. An alternative approach is for an analysis to be carried out with landslides that have occurred in a certain period whilst validation is performed upon landslides that have occurred in a different period.

9.3 Rationalization of Clusters Weightage Distribution

The establishment of cluster weightage value distribution for CI was initially based on literature since Malaysia has yet to have landslide data inventory. The test on landslide vulnerability assessment by indicator based method was done at Cameron Highland site where frequent landslide hazards had occurred. Despite the calculated vulnerability index derived from the recommended procedure, a rationalization of clusters weightage values was recommended so as the outcome is logical based on local technical expert experiences.

General principles:

1. Vulnerability of any critical infrastructure will come to exist if two main components i.e Causal factor (landslide hazard) and effect i.e Element at risk (Building, etc) do exist.
2. The value of the weightage for each component should represent the degree of contribution of each component towards the development of VI.
3. The value of the two main contributing components (C and I) should be of the highest weightage value.
4. The value of Vulnerability Index derives from selected option of cluster weightage value must be realistic and able to capture the whole range of vulnerability classes from very low to very high at any case.

10.0 APPLICATION OF LANDSLIDE VULNERABILITY INDEX AND RISK CLASSIFICATION

10.1 Typical Development Controls Applied to Landslide

The following are examples where landsliding is potentially an issue in land use planning:

(a) Where there is a history of landsliding
(b) Where there is no history of sliding but the topography dictates sliding may occur.
(c) When there is no history of sliding but geological and geomorphologic conditions
(d) Where there are constructed features which, should they fail, may travel rapidly
(e) Forestry works and agricultural land clearing where landsliding may lead to damage to the environment by degrading streams and other receiving water bodies.

It should be noted that the magnitude and speed of landslide mass movement significantly contribute to the severity of risk classes of CI. For example, rapid sliding is important because of the potential for life loss. However slow and very slow moving landslides are also of importance because they may also lead to property damage.

11.0 UNDERTAKING LANDSLIDE VULNERABILITY ASSESSMENT AND RISK ANALYSIS STUDY

11.1 General

Landslide vulnerability assessment and risk analysis is a science that should be done by well qualified personals or professionals who are experienced in mapping and who understand slope processes, risk assessment and geotechnical slope engineering. The team of professionals should comprise of but not limited to engineering geologist, geomorphologist (for zoning of natural slopes where geomorphology mapping is required) and a geotechnical engineer. It should be noted that and experience personals are preferable who understand the soil and rock mechanics of slope processes pre and post-failure are involved in the landslide susceptibility, hazard and risk assessments.

11.2 Preparing a Brief

The following are some matters which should be considered in preparing for a landslide zoning study.

- Define the objective of the study and how it will be used.
- Define area of study.
- Define what type of zoning is required: landslide susceptibility, hazard or risk.
- Define the level of zoning required and whether it will be staged.
- Identify the various stake holders and their interests.
- Describe what, if any, public consultation process will be required.
- State relevant legal and regulatory controls.
- Set out the documentation required for the results of the zoning, including details of what maps are required, map scales, and electronic formats and the supporting report describing the zoning processes, methods used, validation and limitations.
- Set a program Gantt chart for the study.
- Set a budget consistent with the scope and expectations of the study.
- Describe the peer review process which will apply.
- List the available data and the format it is in.
- Detail the expected method for the study.
- Define the terminology to be used to describe susceptibility, hazard and risk.

11.3 Provide All Relevant Data

It is essential that the appointed team is provided with all the available data regarding the incidence of landsliding in the study area.

National slope master plan recommended that where there is limited data on the incidence of landslides in the area, those responsible will greatly benefit by establishing and maintaining a landslide inventory (Slope Engineering Branch (JKR), 2009).

12.0 REFERRED ACTS AND REGULATIONS

Acts, regulations and guidelines on development planning in the hilly area are referred to as follows:-

- Akta 171: Akta Kerajaan Tempatan (1976)
- Akta 172 : Akta Perancangan Bandar dan desa (1976)
- Environmental Quality (Prescribes Activities) (Environmental Impact Assessment) Order 2015. Federal Government Gazette. P.U. (A) 195 (2015)
- Garis Panduan Pembangunan Di Kawasan Tanah Tinggi (2005)
- Manual Garis Panduan dan Piawaian Perancangan Negeri Selangor (2010)
- National Slope Master Plan (2009)

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This cross-disciplinary research was assigned to a team of professionals from geosciences, land surveyors, geotechnical engineers, industry players and academicians.

14.0 REFERENCES

BIRKMANN, J. 2006. Measuring vulnerability to promote disaster-resilient societies: Conceptual frameworks and definitions. *Institute for Environment and Human Security Journal,* 5, 7-54.

CORANGAMITE CATCHMENT MANAGEMENT AUTHORITY. 2012. *Risk Assessment - Landslides* [Online]. Available: http://www.ccma.vic.gov.au/soilhealth/documents/outputs/education_and_training/training_manuals/documents/manuals/landslides/Risk_Assessment_Landslides_TM_LR.pdf [Accessed August 22, 2018].

COROMINAS, J., VAN WESTEN, C., FRATTINI, P., CASCINI, L., MALET, J. P., FOTOPOULOU, S., CATANI, F., VAN DEN EECKHAUT, M., MAVROULI, O., AGLIARDI, F., PITILAKIS, K., WINTER, M. G., PASTOR, M., FERLISI, S., TOFANI, V., HERVÁS, J. & SMITH, J. T. 2014. Recommendations for the quantitative analysis of landslide risk. *Bulletin of Engineering Geology and the Environment*.

CRUDEN, D. M. 1997. Estimating the risks from landslides using historical data. *In:* CRUDEN, D. M. & FELL, R. (eds.) *Landslide Risk Assessment*. Balkema, Rotterdam.

DAI, F. C. & LEE, C. F. 2002. Landslide characteristics and slope instability modeling using GIS, Lantau Island, Hong Kong. *Geomorphology,* 42, 213-228.

DE BONO, A. & MORA, M. G. 2014. A global exposure model for disaster risk assessment. *International Journal of Disaster Risk Reduction,* 10, 442-451.

FEDERAL DEPARTMENT OF TOWN AND COUNTRY PLANNING (JPBD) 1976. Akta 172 Akta Perancangan Bandar dan Desa. Federal Department of Town and Country Planning (JPBD).

FEDERAL DEPARTMENT OF TOWN AND COUNTRY PLANNING (JPBD) 2010. Manual Garis Panduan dan Piawaian Perancangan Negeri Selangor. Second Edition ed.

FEDERAL GOVERNMENT GAZETTE 2015. Environmental Quality (Prescribed Activities) (Environmental Impact Assessment) Order 2015. Attorney General's Chambers.

FELL, R., COROMINAS, J., BONNARD, C., CASCINI, L., LEROI, E. & SAVAGE, W. Z. 2008. Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. *Engineering Geology,* 102, 83-84.

FELL, R., HO, K. K. S., LACASSE, S. & LEROI, E. A framework for landslide risk assessment and management. *In:* HUNGR, O., FELL, R., COUTURE, R. & EBERHARDT, E., eds. Landslide Risk Management - International Conference on Landslide Risk Management, 2005 Vancouver, Canada. A. A. Balkema Publishers.

KO KO, C., FLENTJE, P. N. & CHOWDHURY, R. N. Landslide risk assessment - development of a hazard consequence approach. The International Symposium on Slope Stability Engineering: Geotechnical and GeoEnvironmental Aspects, 1999 United Kingdom: Balkema. 1309-1315.

MINERAL AND GEOSCIENCE DEPARTMENT MALAYSIA (JMG) 2010. Garis Panduan Pemetaan Geologi Terain. Mineral and Geoscience Department Malaysia (JMG).

MINERAL AND GEOSCIENCE DEPARTMENT MALAYSIA (JMG) 2018. Landslide Hazard Map of Cameron Highland. Mineral and Geoscience Department Malaysia (JMG).

MINISTRY OF HOUSING AND LOCAL GOVERNMENT (KPKT) 1976. Akta 171 - Akta Kerajaan Tempatan. *In:* (KPKT), M. O. H. A. L. G. (ed.).

NATURAL RESOURCES AND ENVIRONMENT DEPARTMENT (NRE) 2005. Garis Panduan Pembangunan di Kawasan Tanah Tinggi. Ministry of Water, Land and Natural Resources.

PELLICANI, R., ARGENTIERO, I. & SPILOTRO, G. 2017. GIS-based predictive models for regional-scale landslide susceptibility assessment and risk mapping along road corridors. *Geomatics, Natural Hazards and Risk,* 8, 1012-1033.

SLOPE ENGINEERING BRANCH (JKR) 2009. *National Slope Master Plan 2009-2023,* Kuala Lumpur, Malaysian Public Works Department.

UN/ISDR 2004. Living with risk - a global review of disaster risk reduction initiatives (volume II). New York and geneva: United Nations Inter Agency Secretariat of the International Strategy for Disaster Reduction.

VARNES, D. J. 1984. *Landslide hazard zonation - a review of principles and practice,* France.

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