CIDB MALAYSIA
CREAM CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA

GUIDELINES

FOR LANDSLIDE VULNERABILITY ASSESSMENT AND DEVELOPMENT OF RISK INDEX FOR CRITICAL INFRASTRUCTURE (CI) IN MALAYSIA

JULY 2020

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FOREWORD

The technical committee set up by Construction Research Institute of Malaysia (CREAM) has been working on this study for two years so as to come up with appropriate guidelines for policy makers, developers and engineers for landslide vulnerability assessment and risk analysis for critical infrastructures in Malaysia. It is hoped that these guidelines will assist the local authorities to make informed decisions on hillsite developments that are more transparent and for the developers to understand how the decisions are made. The committee consists of representatives from relevant government agencies, academicians, local council, utility company and landslide experts. Consultations were also sought from practicing engineers, council engineers and approving authorities.

The critical infrastructures chosen are considered vulnerable to landslides and could impact the country's economy, social, environmental, and political matters. The critical infrastructures considered are residential areas and buildings, roads, dams, and utilities. Since landslide risk is defined as hazard multiply by vulnerability, a semi-quantitative assessment of risk is possible by the use of these guidelines, where sets of vulnerability indices are generated in this study to be used in combination with hazard maps that have already being produced in many critical areas. In areas where hazard maps are lacking, appropriate procedures can be used to produce hazard maps, which can then be used to generate risk rating.

The guidelines produced is the first of its kind in Malaysia, further improvements can be made with more data input. The committee would like to recommend that further study or research should be carried out for more accuracy and reliability of the outcome.

Finally on behalf of this committee, I would like to record my appreciation of the support given by CREAM of CIDB and my thanks to the committee members, the consultants, the agencies that assist and the persons who provided input for this study.

Dato' Ir. Dr. Che Hassandi Abdullah
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1. INTRODUCTION

1.1 Background

Malaysia has experienced numerous geohazards throughout the years. Most of these geohazards are associated with the failure of natural hill slopes. The increasing geohazards in the mountainous and hilly terrain of Malaysia are often associated with soil mass wasting. The failed soil masses are transformed into liquefied debris or mudflow of tremendous velocity and momentum, capable of sweeping away everything found along its path. Understanding the natural geomorphic and geological processes on tropical mountainous terrain is the key to understanding the nature and extent of the associated landslides.

The Construction Industry Development Board consortium has taken significant efforts to support and directly address specific agenda related to SDG 11 (sustainable cities and communities) and SDG 13 (climate action) by publishing the present document on landslide disaster risk reduction guidelines to holistically adapt to climate changes.

Landslide risk assessment as prescribed in the national disaster risk reduction framework means that effective landslide risk mitigation should be implemented at the local (individual slope) or regional level. At the local level, the design of a risk mitigation measure, for example, an early warning system, can be based on a number of reasonable scenarios and may involve the following steps (UNISDR, 2004):

- Define the scenarios triggering the landslide, and evaluate their probability of occurrence.
- Estimate the volume and extent of the landslide, and compute the runout distance for each scenario.
- Estimate the losses of all elements-at-risk for each scenario.

Landslide disaster risk is a function of landslide hazard, exposure, and vulnerability, expressed as the probability of loss of life, injury, and destroyed or damaged physical structures at a given time (De Bono and Mora, 2014). A risk map can be generated by combining three contributing factors: the probability of occurrence of a landslide of a given magnitude (hazard), the value of the elements-at-risk (elements-at-risk), and the expected degree of loss resulting from the specified landslide magnitude (vulnerability) (Vega and Hidalgo, 2016). In this guideline document, the qualitative method for landslide risk assessment via a risk assessment matrix only considers hazard and vulnerability, which affect the convenience of public and mass users.

Landslide risk, R, is defined as

$$\mathrm{R} = \mathrm{H} \times \mathrm{V}, \qquad (1)$$

where H is the hazard measurement, and V is the vulnerability measurement.

The measurement of hazard and vulnerability is taken from the Australian Geomechanics Society (Fell et al., 2005), in which hazard measurement (H) is defined by the qualitative measures of likelihood of landsliding, and vulnerability measurement (V) is defined by the qualitative measures of consequences to property.

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

1.2 Purpose

This guideline document recommends an appropriate method for landslide vulnerability assessment and the subsequent risk analysis of any development with CI in highland areas. The document shall complement and enhance current acts and regulations related to but not limited to the development of highland areas.

The guidelines here are intended to be used by local authorities, institutional agencies, and decision makers as a supporting tool for land use planning, prioritization of landslide risk mitigation plans, and risk management for urban, urban highlands, sub-urban, and rural developments in the formation of sustainable development cities.

1.3 Landslide Vulnerability Assessment

A semi-quantitative, indicator-based method (IBM) of physical vulnerability is expressed through vulnerability functions that represent the interactions between the landslide event and the CI. Figure 1.1 shows the flowchart of risk analysis using the IBM.

The semi-quantitative approach reduces the level of generalization in the qualitative method (Dai and Lee, 2002). It is flexible and reduces subjectivity compared with the qualitative method. The justification for its use is the lack of historical data on landslide hazards.

The justifications for the recommendation are as follows:

i. *Data availability*: Fewer data are required by ranking the indicators into several vulnerability classes.
ii. *Combining qualitative and quantitative indicators*: Through the predefined ranking criteria of indicators, both quantitative and qualitative indicators may be ranked and combined into a semi-quantitative vulnerability parameter.
iii. *Analysis in a geographic information system (GIS)*: The vulnerability value for each CI can be easily stored in the GIS database.
iv. *Flexible weighting process:* The weight assigned for each indicator is adjusted based on user experiences.
v. *Data collection process carried out by a non-expert*: Determination of the indicator scores shall be done by the owner of the buildings.

vi. *Involvement of local stakeholders in the IBM method*: This increases the reliability of landslide vulnerability assessment (LVA) and the vulnerability reduction process.

1.4 Guidelines and Existing Acts and Regulations in Malaysia

The *Garis Panduan Pembangunan di Kawasan Tanah Tinggi*, Natural Resources and Environment Department of Malaysia (2005), provides guidelines on physical developments on highlands, 300 meters above mean sea level, as summarized in Table 1.1. These guidelines propose landslide vulnerability assessment for class 3 slopes and above, which may help as an alternative to a sustainable development environment. The existing acts, regulations, and guidelines on development planning in hilly areas are 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)
- Garis Panduan Perancangan Bandar Berdaya Tahan Bencana (2019)

1.5 Limitations

The content of the guidelines is limited to the following:

i. The guidelines only cover physical landslide vulnerability assessment and risk classification.
ii. The landslide vulnerability assessment and risk analysis will only focus on CIs: residential houses/buildings, roads, dams, and utilities (pylon).
iii. The generation of landslide vulnerability and risk maps requires a landslide hazard map. Landslide hazard maps should follow certain criteria required, such as the level of details in both spatial and attribute data. Therefore, the ability to generate these maps will depend on the quality of the landslide hazard map of the study area.
iv. The field-based validation for vulnerability assessment and risk analysis will consider the typical landslides and CIs in the area.
v. The social vulnerability indicator used with respect to landslides is based on a literature review and shall be identified for future studies.

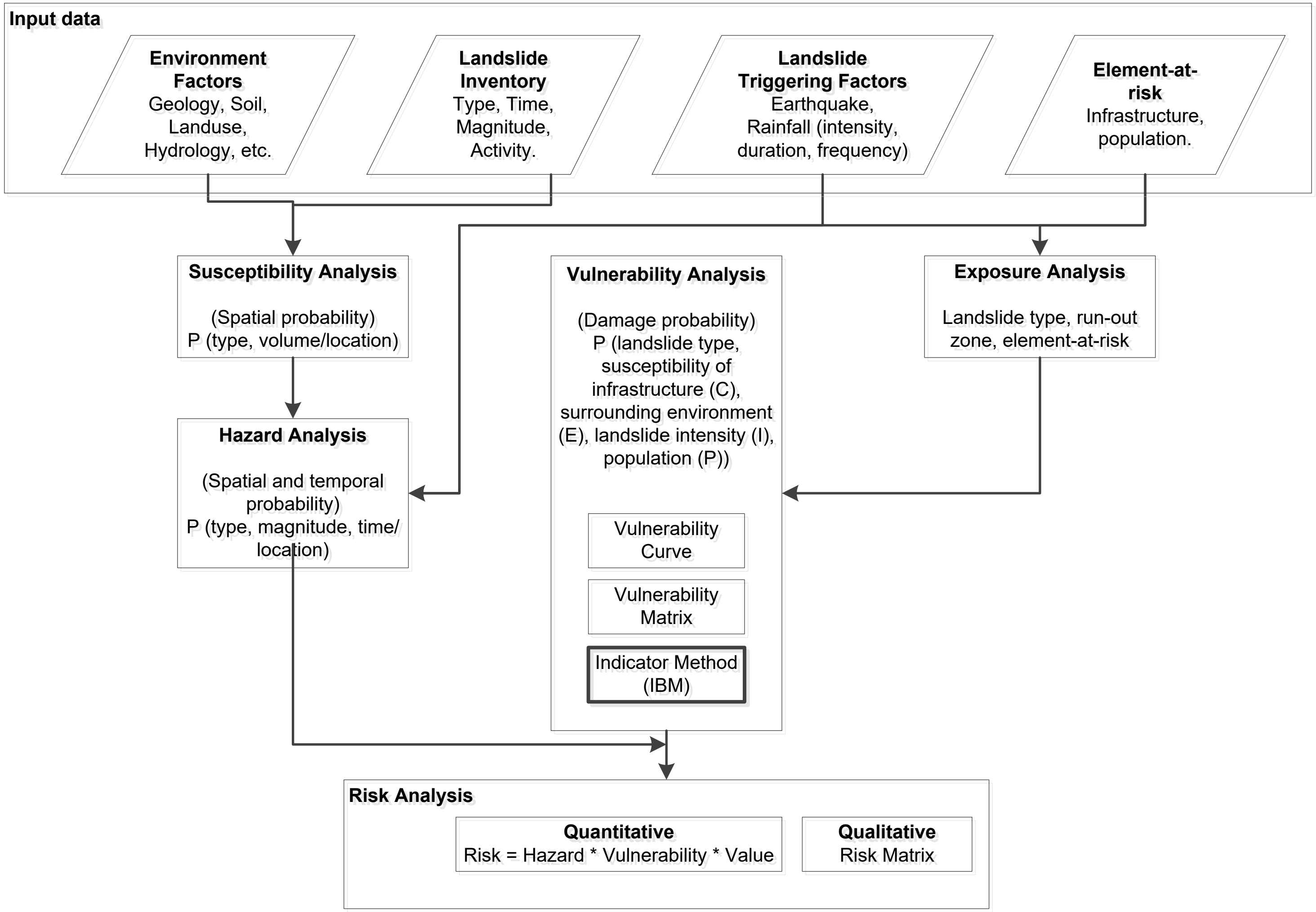


Table 1-1 Flow chart of landslide risk analysis showing the adopted indicator-based method of analysis

Table 1-2 Malaysia Guidelines on hilly terrain physical developments (Ministry of Housing and Local Government [KPKT], 2009)

Slope Gradient (α)	Slope classification for engineering work	Description
Below 15º	Class 1	Compliance with i. Garis Panduan Pembangunan Di kawasan Bukit 1997 (issued by the local government) ii. Garis Panduan Kawalan Hakisan dan Kelodakan, 1996 (issued by the Department of Environment) iii. Manual Saliran Mesra Alam 2000 (issued by the Department of Irrigation and Drainage)
15º–25º	Class 2	
25º–35º	Class 3	Requires an additional environmental impact assessment study Proposes the conduct of landslide vulnerability assessment, which may serve as an alternative tool to establish a sustainable development environment
Above 35º	Class 4	Development projects within this area are not permitted at all, except for road construction, which is inevitable. However, an environment impact assessment study is required. Proposes the conduct of landslide vulnerability assessment, which may serve as an alternative tool to establish a sustainable development environment

2. TERMINOLOGY AND DEFINITION

2.1 Definitions of Keywords

LANDSLIDE

This is a general term used to describe the movement of a mass of rock, earth, or debris down a slope (Cruden, 1991).

LANDSLIDE HAZARD

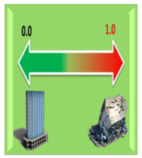
This is the use of available information to estimate the zones where landslides of a particular type, volume, velocity, and runout may occur within a given period of time (Corominas et al., 2014).

LANDSLIDE SUSCEPTIBILITY

This is the relative spatial likelihood for the occurrence of landslides of a particular type and volume (van Westen, 2016).

VULNERABILITY ASSESSMENT

Vulnerability assessment is useful for disaster risk reduction and the promotion of information exchange or improvement of disaster preparedness and loss prevention (Birkmann, 2006).

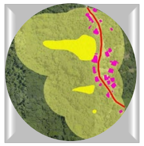


LANDSLIDE VULNERABILITY

This is 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).

ELEMENTS-AT-RISK

These refer to the population, buildings and engineering works, economic activities, public services/utilities, and other infrastructures and environmental values in the area that are potentially affected by the landslide hazard (Fell et al., 2008).



LANDSLIDE EXPOSURE

This is the population, property, systems, or other elements present in landslide hazard zones that are exposed to potential losses (Corominas et al., 2014).

RISK ANALYSIS

This is the use of available information to estimate the risk of the landslide hazard to individuals or the population, property, and the environment (Corominas et al., 2014).

CRITICAL INFRASTRUCTURE

CI includes a range of engineered systems, assets, and facilities that are essential for day-to-day societal functions and for continued economic and societal functioning in the aftermath of a disaster (Bach et al., 2014).

2.2 Landslide Type

Figure 2.1 shows a schematic classification of landslides following the scheme of Varnes (1978) and Cruden and Varnes (1996). An update to Varnes' classification was presented to the landslide community by Hungr et al. (2014).

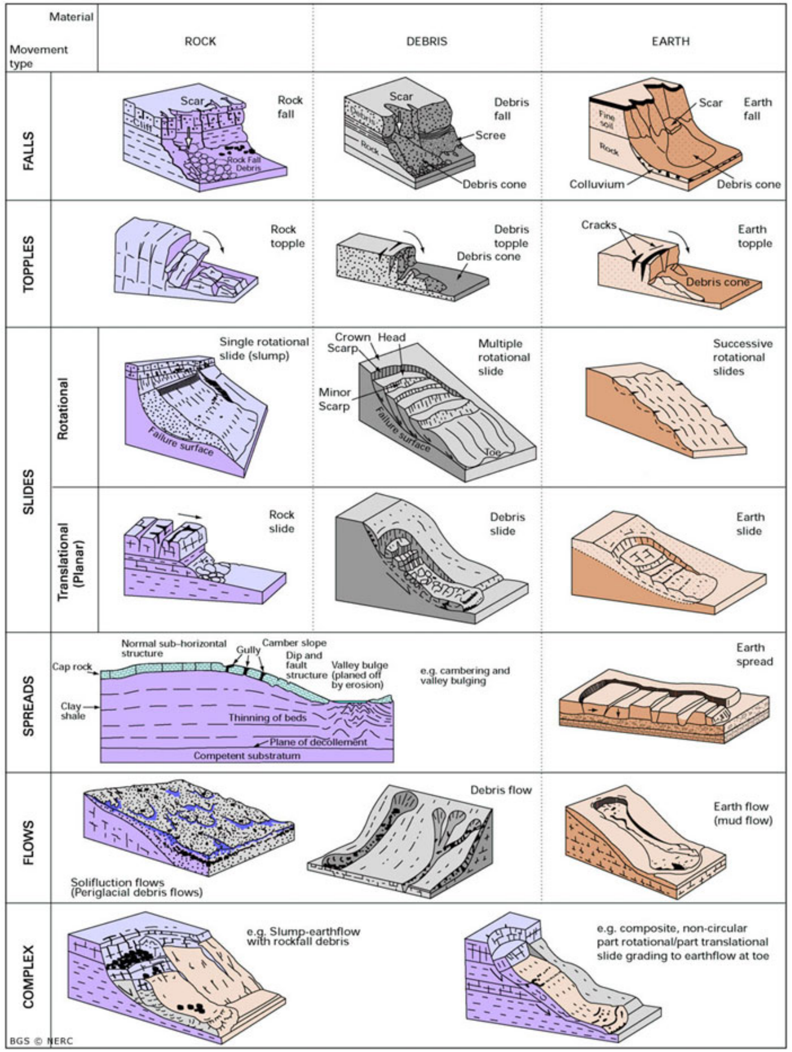


Figure 2-1 Schematic illustration of landslide types (British Geological Survey, 2017)

2.3 Geospatial Approach of Landslide Hazard Mapping

GIS is a tool that enables the digital visualization of geospatial data. In the case of geohazards, GIS can be used to predict potential areas and affected areas of geohazards, such as slope failure and debris flow. The geospatial data for producing a landslide hazard map come from various sources, such as LiDAR and high-resolution satellite images. The landslide hazard map is derived using three inputs: (a) landslide inventory, (b) landslide causal factors, and (c) landslide triggering factors (i.e., rainfall). The triggering factors are related to climate change factors, such as rainfall. Figure 2.2 shows an example of a landslide hazard map; the image uses color coding for five hazard classifications from very low (green) to very high (red). Field verification of landslide inventory should be validated at the site.

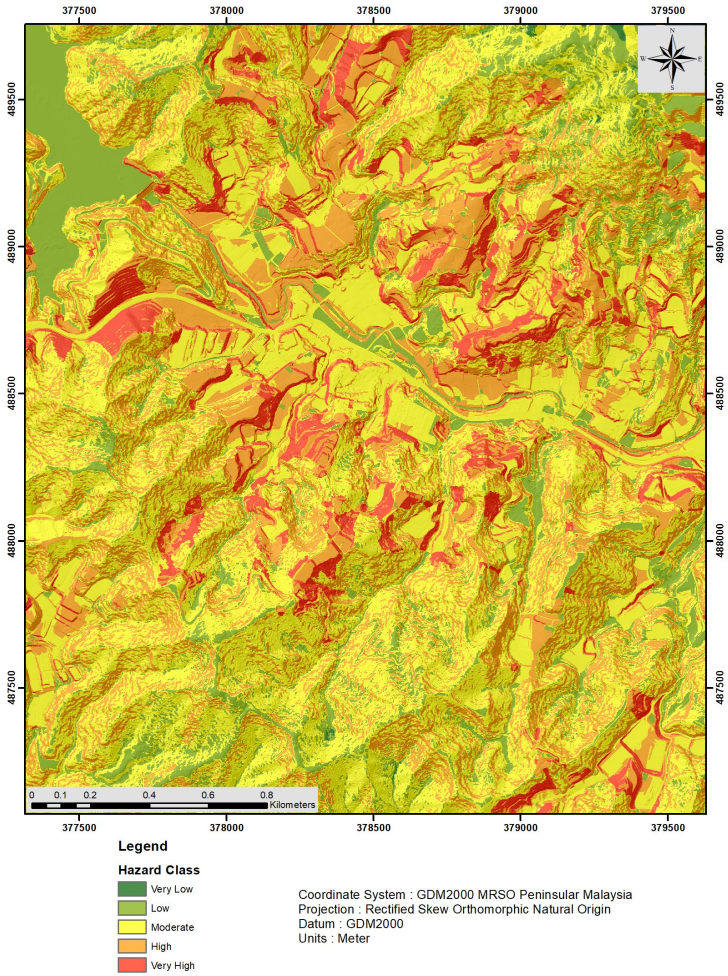


Figure 2-2 Example of a landslide hazard map for Lembah Bertam, Cameron Highlands, Pahang, Malaysia (Mineral and Geoscience Department Malaysia [JMG], 2018)

3. CRITICAL INFRASTRUCTURE

The following are examples of physical vulnerabilities or elements-at-risk in which landslide vulnerability assessment for land use planning will be beneficial:

Table 3-1 Physical vulnerabilities or elements-at-risk for infrastructure assessment

Physical Vulnerability or Element-at-risk	Suggested Infrastructure for Assessment
Residential land development	i. New urban areas ii. Redevelopment of urban areas iii. Subdivision of rural land
Residential development controls in existing urban areas potentially affected by landsliding	i. Within the local government area ii. City wide
Development of important infrastructure	i. Hospitals, schools, fire brigades, and other emergency services ii. Critical communication infrastructure iii. Major lifelines, such as transport, water, and gas pipelines and electricity power lines
Development of new or redevelopment of existing highways, roads, and railways	i. Rural roads ii. Urban main roads iii. Urban subdivision roads
Dam	i. Dam construction to control river flooding and debris flow along the identified potential river channel, with main dams (sabo dams, comb dams) at the upper stream and check dams at the mid-low stream

4. LANDSLIDE RISK ANALYSIS FRAMEWORK AND VULNERABILITY ASSESSMENT

4.1 Landslide Risk Analysis Framework

The landslide risk analysis framework emphasizes landslide vulnerability assessment, derivation of the vulnerability index (VI), and derivation of the risk estimation for the risk classification of physical CIs and elements-at-risk. The derived landslide risk map shows the CIs 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

The descriptions of vulnerability measurement and hazard measurement adopted in this study are based on the classification of Fell et al. (2005), as shown in Tables 4.1 and 4.2.

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 stabilization
2	Major	Extensive damage to most of the structure or damage extending beyond site boundaries, requiring significant stabilization works
3	Medium	Moderate damage to some of the structure or a significant part of the site requires large stabilization works
4	Minor	Limited damage to a part of the structure or a part of the site requires some reinstatement or stabilization works
5	Insignificant	Little damage

Table 4-2 Hazard measurement – qualitative measures of the 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 conditions.
C	Possible	The event could occur under adverse conditions.
D	Unlikely	The event could occur under very adverse conditions.
E	Rare	The event is conceivable but only under exceptional circumstances.
F	Not credible	The event is inconceivable or fanciful.

4.3 Landslide Vulnerability Classes for CI

Figure 4.1 shows the overall landslide risk analysis framework with the landslide vulnerability assessment method and processes. Identification and interpretation of the landslide are done by utilizing both remote sensing and field data to produce a landslide vulnerability, hazard, and risk map.

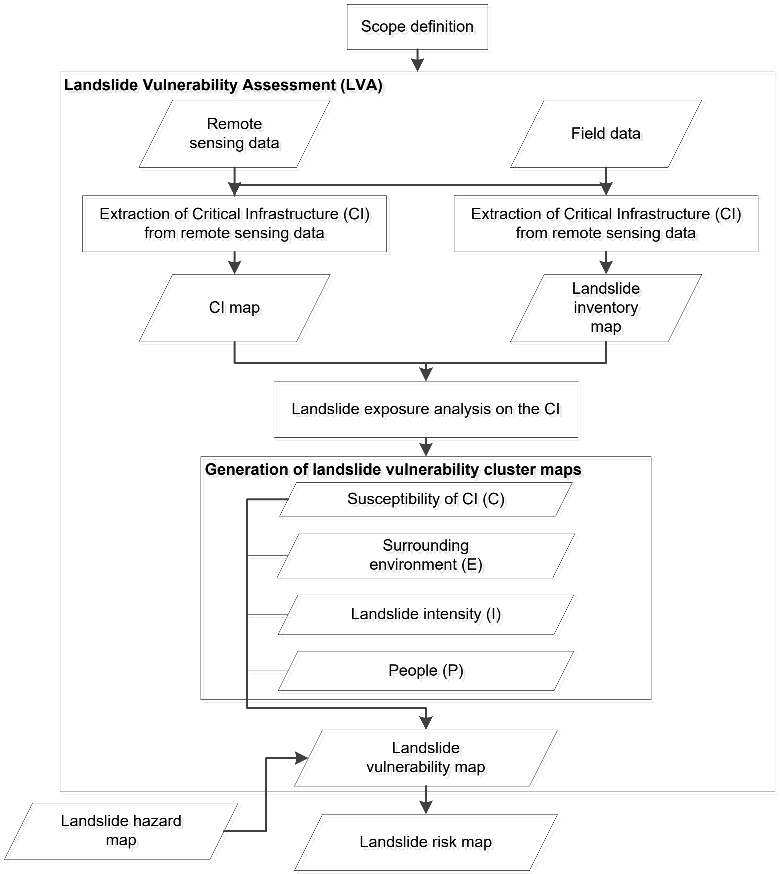


Figure 4-1 Risk analysis framework encompassing the landslide vulnerability assessment approach

4.4 Landslide Risk Classification Matrix

The international risk classification matrix adopted by Ko Ko et al. (1999) is adapted and recommended for use, as shown in Table 4.3. It classifies the likelihood of landslide hazards based on the vulnerability of the CIs or elements-at-risk.

The matrix serves as a useful tool in landslide risk management by facilitating a relative comparison of the risks of different sites and the prioritization of follow-up actions in addressing the risks posed by a large number of sites (Fell et al., 2005).

The risk index is relatively simple and straightforward, so it is ideal for non-experts to use on landslide cases (Corangamite Catchment Management Authority, 2012). It is commonly used when information related to quantitative landslide risk assessment is lacking (Pellicani et al., 2017).

Table 4-3 International standard risk assessment matrix modified from 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, and **VL** – Very low risk.

5. FRAMEWORK OF LANDSLIDE VULNERABILITY ASSESSMENT AND RISK ANALYSIS

The criteria for selecting vulnerability indicators are as follows (Birkmann, 2006):

- Should be relevant and significant
- Should be reproducible and easily measurable
- Has available data and is cost-effective
- Should be sensitive, accurate, and comparable

5.1 Landslide Vulnerability Assessment

The recommended choice of indicators and their weight values are based on a combination of the qualitative (expert assessment on previous records) and quantitative approaches (specific numerical modeling of the impact of landslides). Experts' recommendations should be prioritized if previous landslide damage records are insufficient. The landslide vulnerability indicators, value, and index may vary for different areas of study and types of CIs (residential houses/buildings, roads, dams, and utilities) with respect to landslide type. The indicators for landslide vulnerability and the sub-indicators used in this guideline document are based on a comprehensive literature review, records of landslide occurrences in Malaysia, and rigorous peer review. Their use is further justified by published comparative case studies that present the limitations of information and other constraints related to Malaysian landslide history.

Figure 5.1 shows the vulnerability assessment of a building exposed to translational/rotational landslide. The vulnerability of a residential building to the translational landslide type constitutes four clusters, namely Susceptibility of the CI, the Surrounding Environment, Landslide Intensity, and People (C, E, I, and P, respectively), with their respective indicators, sub-indicators, and weightage. The distribution of weightage value for a cluster should be in sequence from 0.1 (low influence to increased vulnerability) to 1.0 (high influence to increased vulnerability). The summation of the weight values for indicators C, E, I, and P must be equal to 1.0. The VI for CI (V) is defined as

$$V = \sum_{i=1}^{m} w_i \times s_i \,, \qquad (3)$$

where w_i is the i-th weight of m indicators for different clusters, and s_i is the i-th weight of sub-indicators.

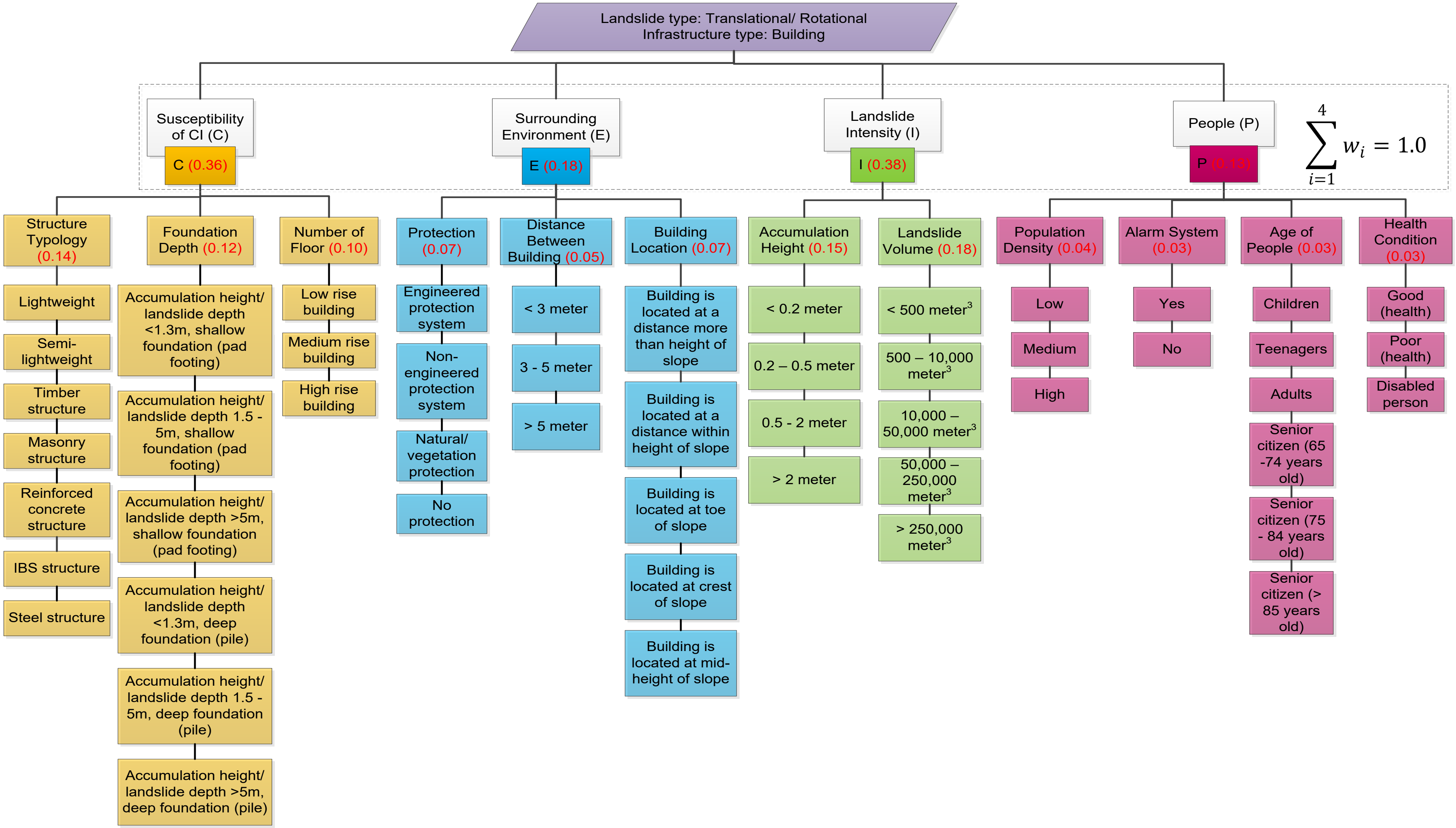


Figure 5-1 Vulnerability assessment of a building exposed to translational/rotational landslide

5.1.1 Data Requirement

Geospatial data shall be utilized to extract and characterize the CIs in the study area with the use of various image processing and spatial analysis methods. Table 5.1 shows the data requisite for vulnerability assessment. The output from the landslide hazard and vulnerability project in the study area will be used to generate a landslide risk map. However, the applicability of the landslide hazard information will rely heavily on the quality of the hazard map and the need for the proposed vulnerability method.

Table 5-1 Data requirement for vulnerability assessment

Type of Data	Source of Data	Data Information
Critical Infrastructure	In-situ drone-surveyed remotely sensed data, such as LiDAR	Geometric features, footprints, height, size, and length of the CI
	Fieldwork inspection	Classification of the slope, geology, condition of the slope face, drainage system, slope distress, slope stabilization, facilities, scale of failure, slope geometry, in-situ vulnerability indicators, and population
Slope information	In-situ drone-surveyed remotely sensed data, such as LiDAR	Slope gradient, slope aspect, plan curvature, stream network, and watershed
Topography map	Survey and Mapping Department, Malaysia (JUPEM)	Slope angle, road, river, contour, and digital elevation model
Aerial photo	Survey and Mapping Department, Malaysia (JUPEM), private sector	Detailed visualization of the study area
Landslide inventory	Mineral and Geoscience Department (JMG)	Type of landslide, initiation or accumulation area, depth of the landslide, volume of the landslide, blocking river, landslide damage, and hazard potential
Landslide hazard map	Mineral and Geoscience Department (JMG)	Hazard classes (i.e. very low, low, medium, high, and very high) for a specific type of landslide

a) Generation of the Landslide Inventory Map

The landslide inventory map (Figure 5.2) should be generated using hillshade from a digital elevation model (DEM) of high-resolution remote sensing data overlaid with contour for visualization (image interpretation) to delineate the area of the landslide, the possible landslide runout, and the 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).

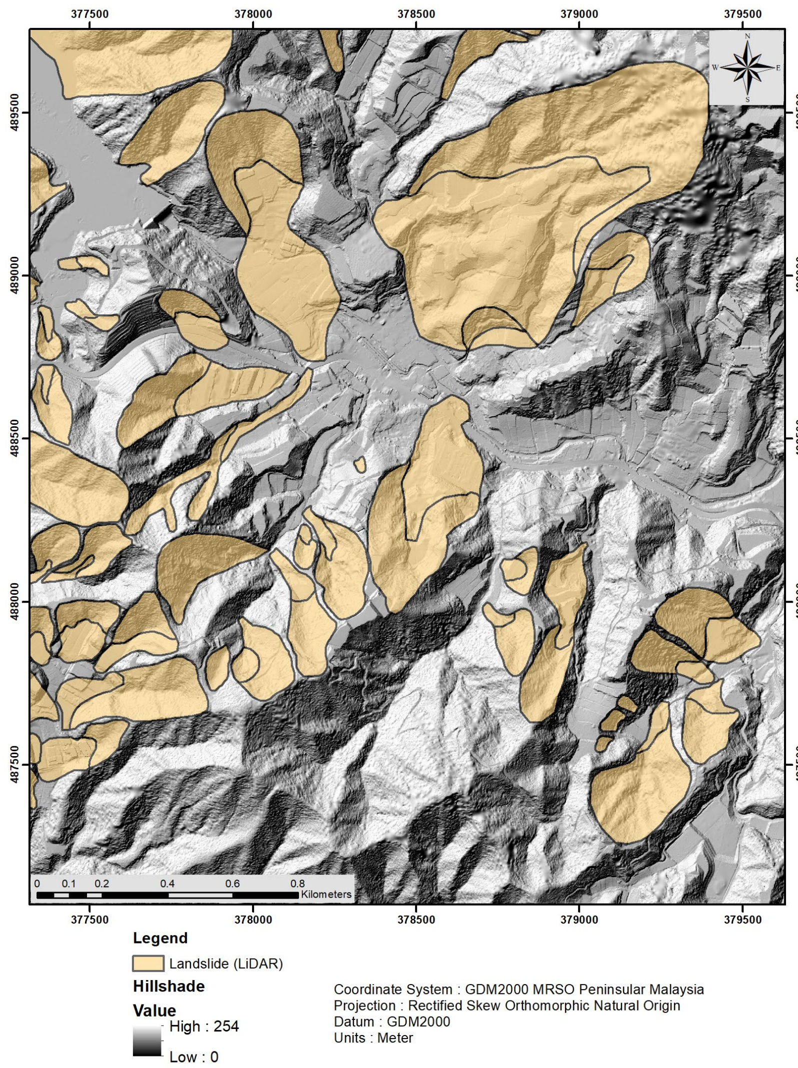


Figure 5-2 Example of a derived landslide inventory map of Lembah Bertam, Cameron Highlands

b) Generation of the CI Map

The generation of CI maps shall 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. The generation of CI maps using a digital image processing approach should be based on the supervised image classification process. Various parametric and non-parametric algorithms, such as maximum likelihood, artificial neural network, and support vector machine, can be used to produce a CI map using high spatial resolution remote sensing data. The classified remote sensing data are in raster format and should be converted into vector format in the next data processing stage. Figure 5.3 shows the CI map of Lembah Bertam, Cameron Highlands.

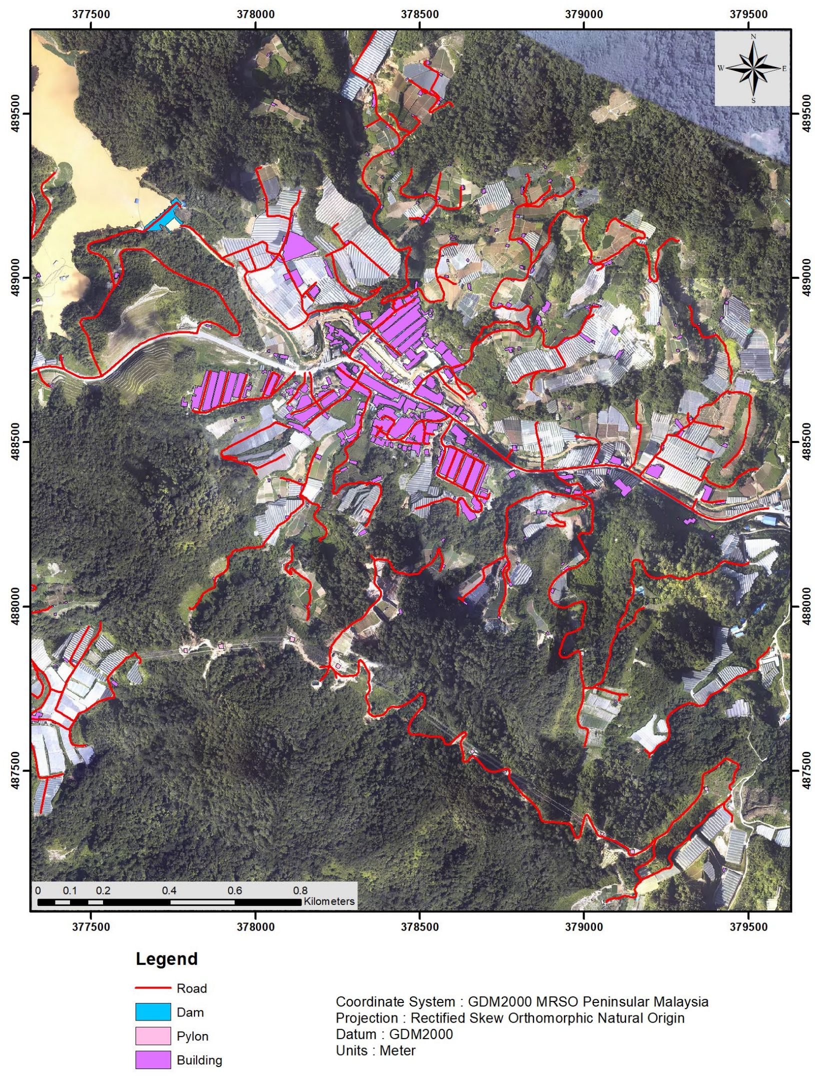


Figure 5-3 CI map of Lembah Bertam, Cameron Highlands

c) Landslide Exposure Analysis of CI

Landslide exposure analysis involves the process of identifying the exposed CI within the landslide and runout zones. The CI map is overlaid with the landslide inventory map (Figure 2.2). Each CI is marked based on its location either within the landslide and runout zones or outside both zones. Figure 5.4 shows the landslide exposure map of Lembah Bertam, Cameron Highlands.

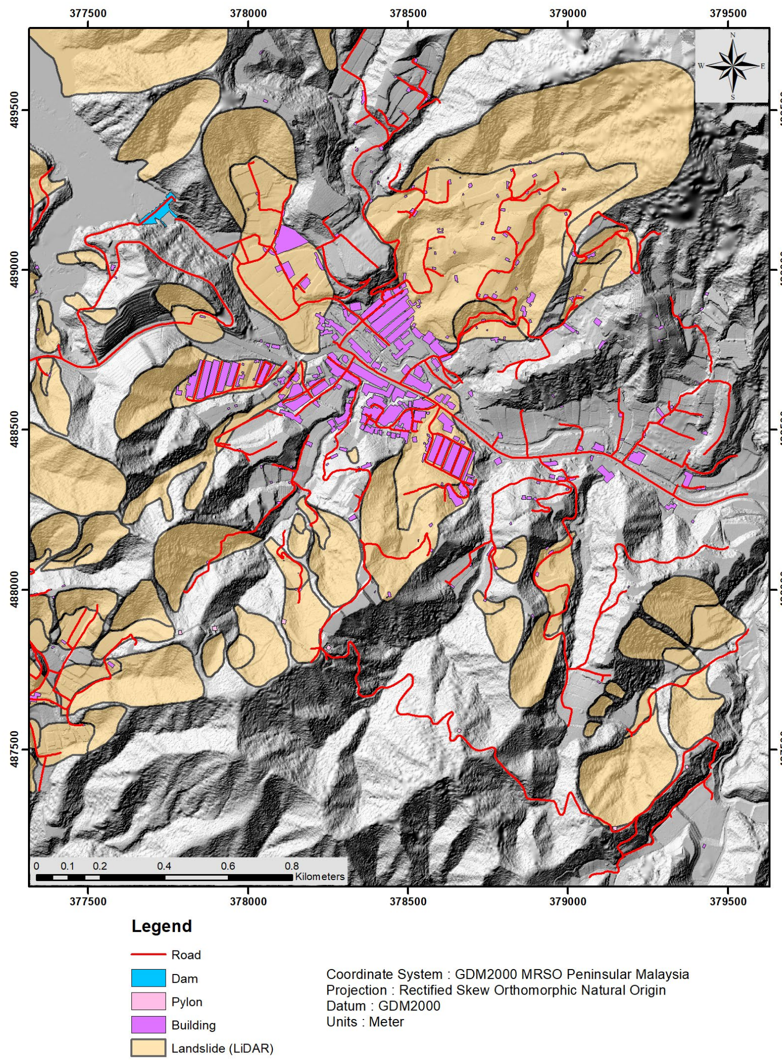


Figure 5-4 Landslide exposure map of Lembah Bertam, Cameron Highlands

5.1.2 Generation of Landslide Vulnerability Cluster Maps

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

a) Generation of the C Map

The generation of the C map aims to characterize the susceptibility of the CI by considering all indicators in the C cluster. The CI map that has information on the location of the CI is required as the main input. The map for cluster C shall be generated for each CI, in which detailed information as required by each indicator and sub-indicator needs to be determined for each polygon of the CI. Finally, the weight value shall be assigned for each indicator and sub-indicator of each polygon of the CI in the map. Figure 5.5 shows the map of cluster C for the respective CI.

b) Generation of the E Map

The E cluster map focuses on characterizing the impact of surrounding land features on the vulnerability of the CI. The impact of the landslide on a specific CI can be increased or reduced by the surrounding environment of the CI. For example, slope mitigation measures will reduce the impact of landslide or the vulnerability of the CI. The 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 the indicator and sub-indicator shall be assigned for each CI polygon of the CI map. Figure 5.6 represents the map of cluster E for the respective CI.

c) Generation of the I Map

The I cluster map shows the landslide intensity that characterizes a landslide body. Landslide intensity is very important to evaluate the vulnerability of elements-at-risk, such as buildings, roads, dams, and utilities. In this case, three indicators are selected for evaluation and identification, which are i) the accumulation height of the landslide, ii) landslide thickness, and iii) landslide volume. Weightage is given to these three indicators and shall be calculated in a sum together with the other indicators, depending on the types of element-at-risk. Figure 5.7 presents the output of the landslide exposure analysis of cluster I for the respective CI in the selected area in Lembah Bertam.

d) Generation of the P Map

The generation of the P cluster map accounts for the impact of damaged or disrupted CI services on the community. The indicators and sub-indicators of the P cluster shall be selected for each CI polygon, in which the suitable weight shall be assigned to each CI polygon. Figure 5.8 presents the map of cluster P for the respective CI.

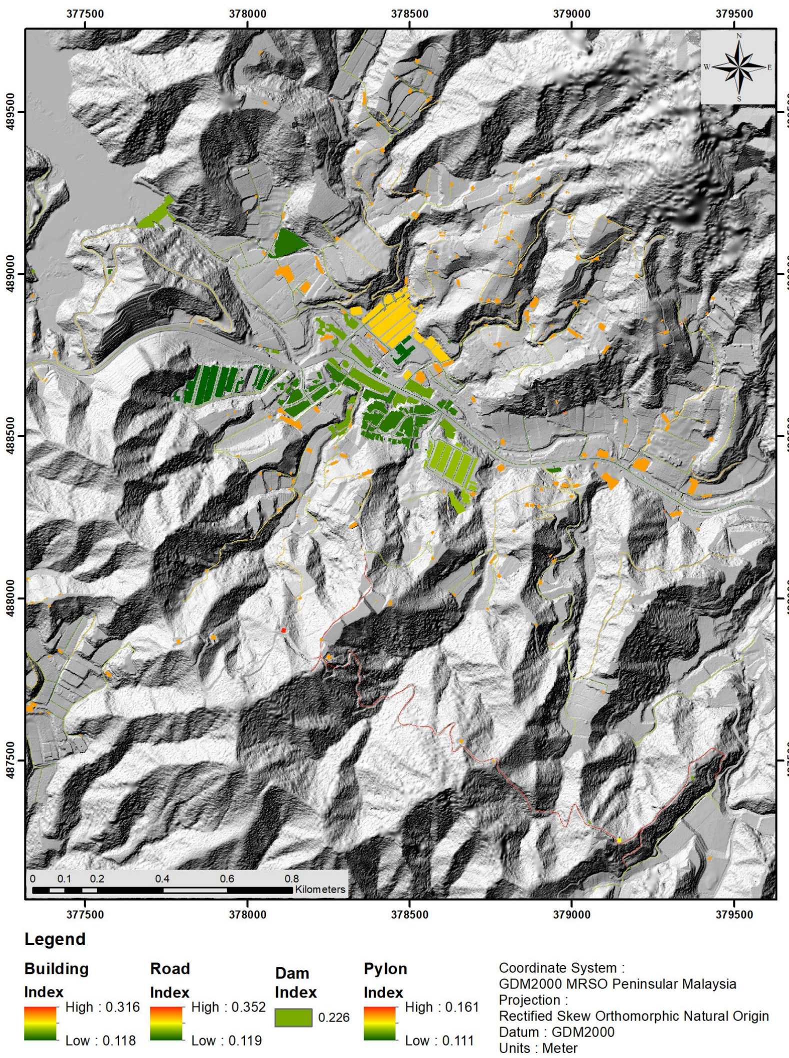


Figure 5-5 Map of cluster C of Lembah Bertam, Cameron Highlands

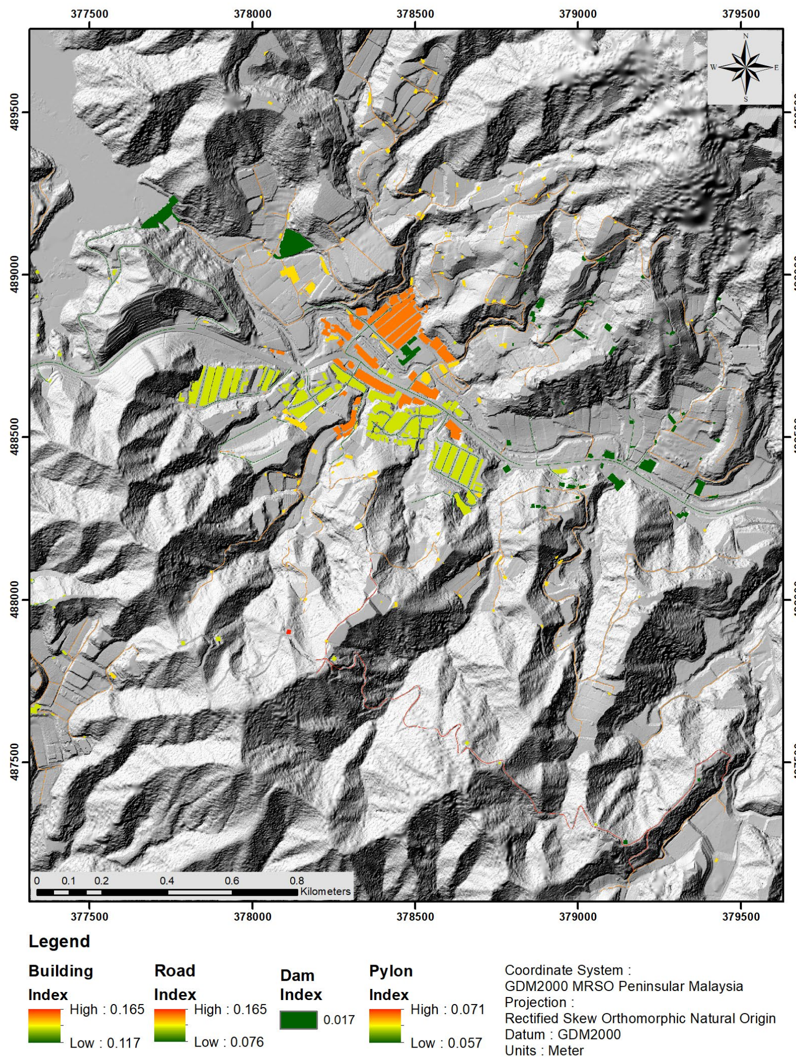


Figure 5-6 : Map of cluster E of Lembah Bertam, Cameron Highlands

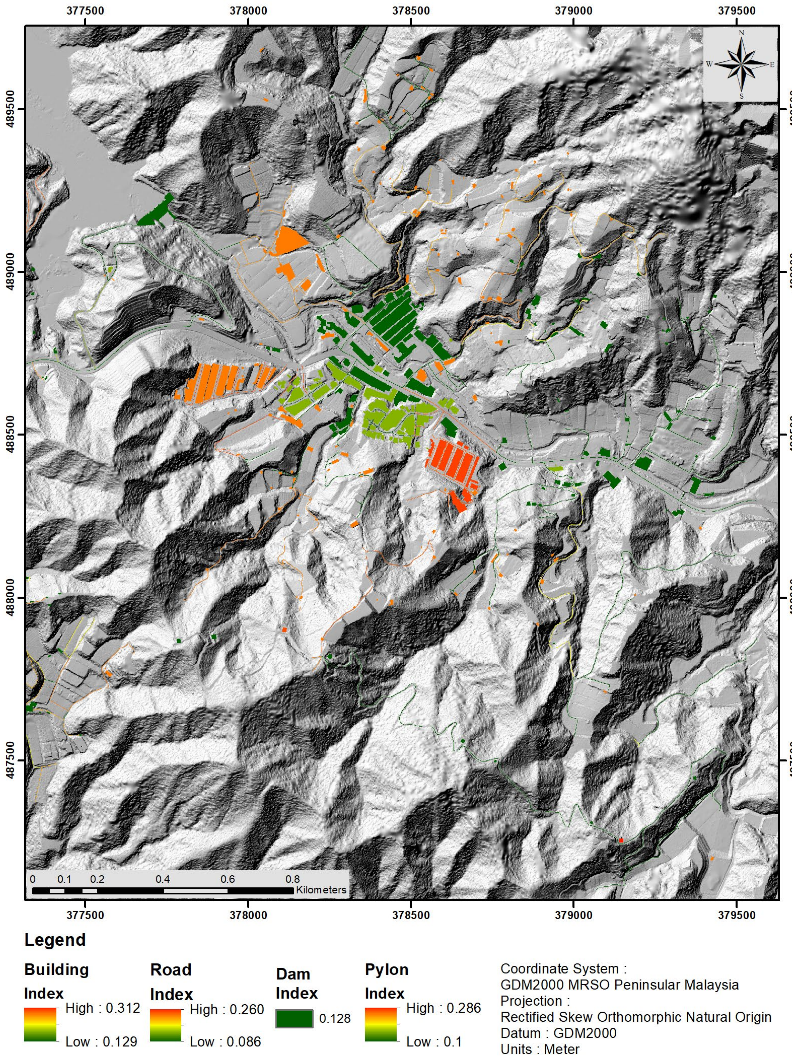


Figure 5-7 Output of cluster I of Lembah Bertam, Cameron Highlands

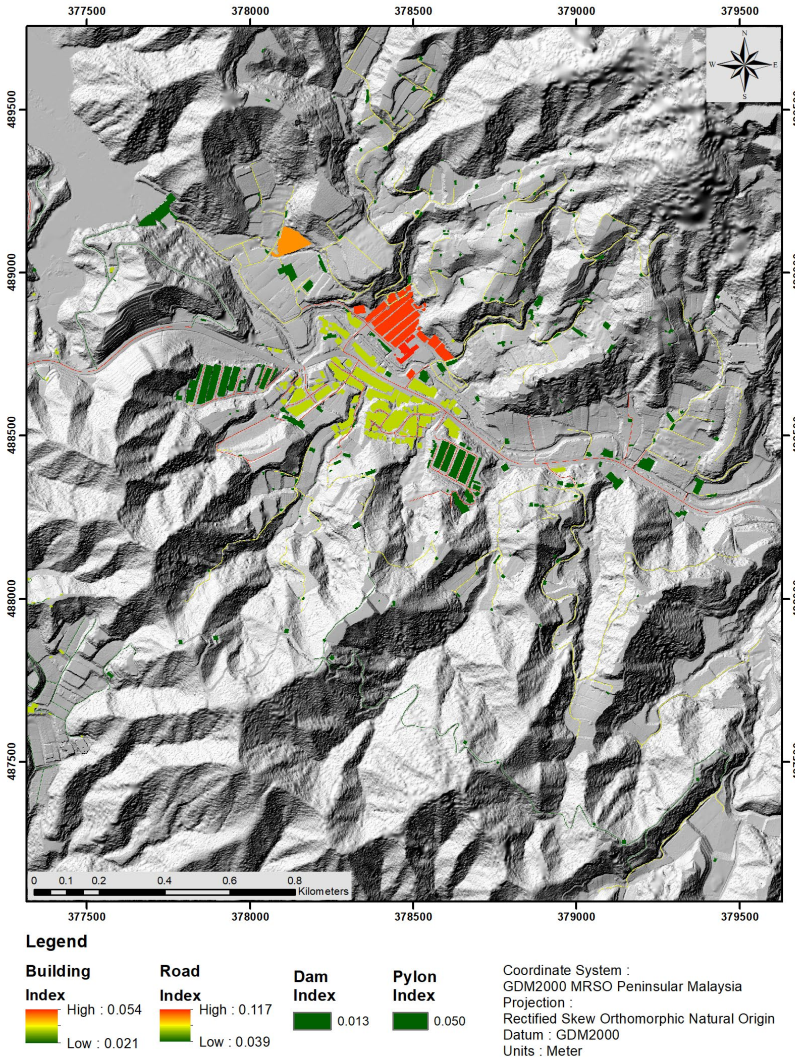


Figure 5-8 Map of cluster P of Lembah Bertam, Cameron Highlands

5.1.3 Generation of the Landslide Vulnerability Map for CI

The landslide vulnerability map for the respective CI is produced by combining cluster maps C, E, I, and P. The resulting landslide VI using Equation 1 is categorized into its specific vulnerability class for each CI, as shown in Table 4.3. Figure 5.9 is a simple schematic explaining the combination of all cluster maps in the previous section. The resulting combination of all cluster maps is shown in Figure 5.10, which is the landslide vulnerability map for the location.

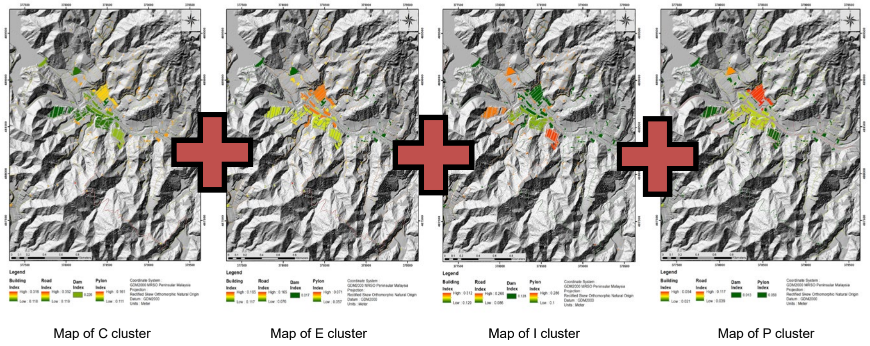


Figure 5-9 Combination of all cluster maps

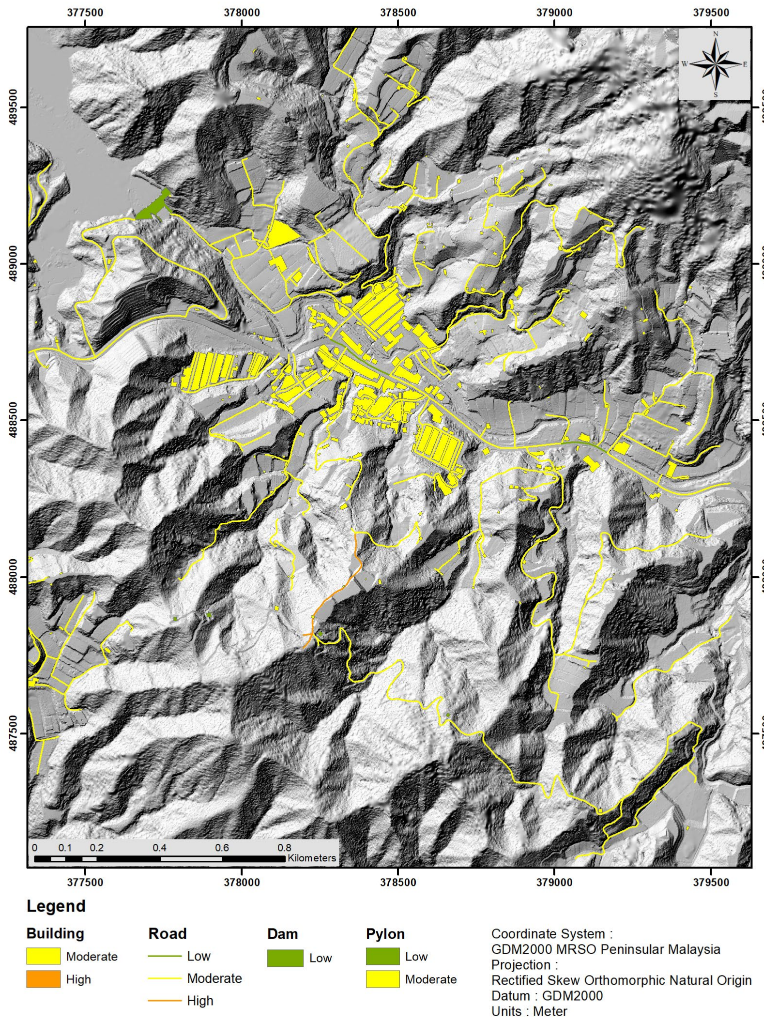


Figure 5-10 Landslide vulnerability map of Lembah Bertam, Cameron Highlands

5.1.4 Generation of the Landslide Risk Map for CI

The landslide risk map is produced through the combination of the landslide hazard map (Figure 2.2) and the landslide vulnerability map (Figure 5.10). A geospatial raster processing combining both maps, called the raster calculator, merges two or more raster layers to produce a single output raster layer. The final landslide risk map of the same area for the respective CI is shown in Figure 5.11. Similar to the vulnerability map, the landslide risk map has only five classifications from very low to very high.

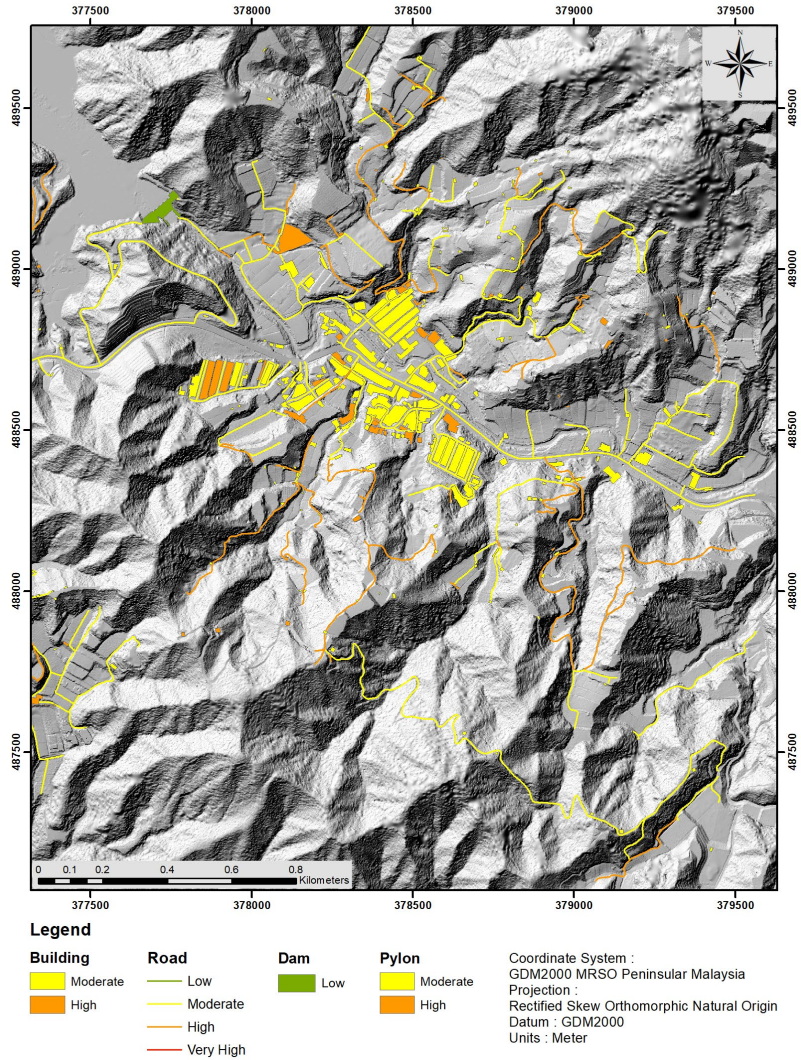


Figure 5-11 Landslide risk map of Lembah Bertam, Cameron Highlands

6. SELECTION OF THE C, E, I, AND P INDICATORS, SUB-INDICATORS, AND WEIGHTAGE

The landslide vulnerability assessment procedure for the CI is shown in Figure 6.1. It begins with the choice of indicators associated with four clusters, C, E, I, and P, until the derivation of the CI level of risk.

Select the indicators that are related to the 4 components
C – Susceptibility of Critical Infrastructure (CI)
E – Effect of surrounding environment or mitigation measures
I – Intensity of landslide hazard
P – Susceptibility of people

↓

Set the weightage value for each indicator (range from 1 To 10)

↓

Define the class for each of the indicator

↓

State the weight for each class of indicator (range from 1 to 10)

↓

Define vulnerability class for each CI

↓

State the description of vulnerability class

↓

Define the risk level and its description

Figure 6-1 Step-by-step instructions to fill out the landslide vulnerability survey forms for each CI and landslide type

6.1 Cluster Indicators and Sub-indicators

Aside from the literature review, the selection and determination of suitable cluster indicators and sub-indicators were done through a series of forums with stakeholders—local authorities, government agencies, and professionals who have vast experience related to Malaysia landslide hazards. The recommended cluster indicators and sub-indicators are as follows:

Table 6-1 Group of cluster indicators (C, E, I, and P) for a building under the translation/rotational landslide type

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)	Accumulation Height< 1.5 Meter, Pad Footing< 3.0 Meter	
	Accumulation Height =1.5 Meter - 5.0 Meter, Pad Footing< 3.0 Meter	
	Accumulation Height>5.0 Meter, Pad Footing< 3.0Meter	
Building Foundation Depth (Landslide Type vs. Deep Foundation Building)	Accumulation Height< 1.5 Meter, Pile > 3.0 Meter	
	Accumulation Height=1.5 Meter - 5.0 Meter, Pile> 3.0Meter	
	Accumulation Height > 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 indicators (C, E, I, and P) for a road under the translation/rotational landslide type

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 indicators (C, E, I, and P) for a dam under the translation/rotational landslide type

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 6-4 Group of cluster indicators (C, E, I, and P) for a pylon under the translation/rotational landslide type

CI-Pylon, 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)

6.2 Cluster Weightage Matrix and Descriptions

The weightage distribution for each cluster's (C, E, I, and P) components must represent the degree of contribution of each component to the development of the VI. The vulnerability of any CI shall exist as a result of two main components: landslide hazards and the CI.

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

i. Landslide hazards (causal factor) and CIs (elements-at-risk) exist.
ii. The weightage value of these two contributing components (I and C) must be of the highest weightage value.
iii. The weightage values of E and P are the lowest, as the presence of these clusters 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 the VI or vulnerability classes from very low to very high, as shown in Table 4.3.

The recommended cluster weightage value matrix is shown in Table 6.5.

Table 6-5 Recommended cluster weightage value matrix

Cluster	Cluster weightage value		
	Option 1	Option 2	Option 3
Landslide 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 the Building **(P)**	0.1	0.2	0.13
Total	**1.0**	**1.0**	**1.0**

The most recommended cluster weightage value matrix is option 3. However, this proposed cluster weightage can further be revised with the availability of new data. An example of scenario-based simulation using the recommended cluster weightage value option to derive the vulnerability class is elaborated in Appendix A.

7. DETERMINATION OF THE VULNERABILITY INDEX AND RISK CLASSIFICATION FOR CRITICAL INFRASTRUCTURE

From the recommended procedure, Figure 7.1 shows 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 the VI of the CI using cluster weightage value matrix option 3.

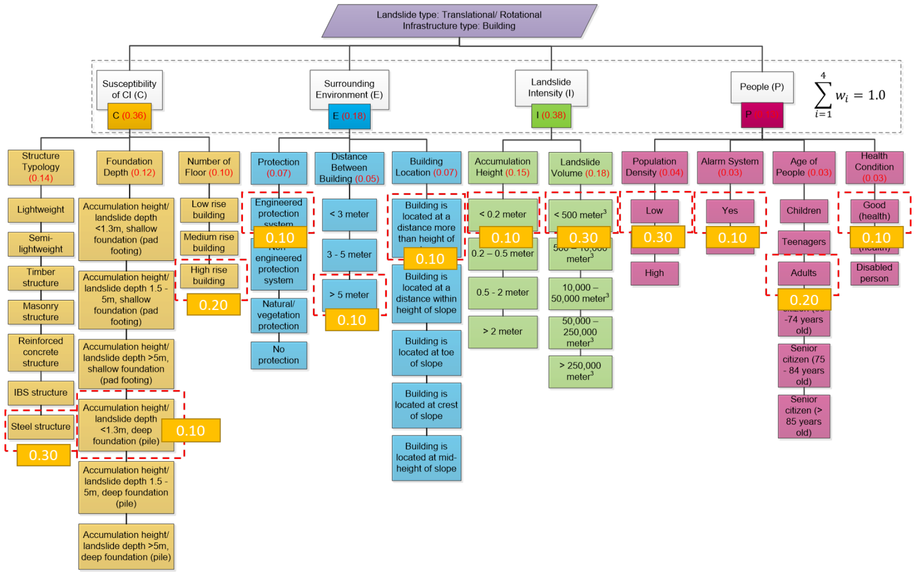


Figure 7-1 Conceptual division of indicators, sub-indicators, and weight values for the landslide vulnerability assessment scenario

7.1 Vulnerability Index for CI

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

An example of scenario 1 (CI: building, landslide type: translational/rotational) is shown in Figure 7.1. The summation of all scores in the yellow box is equivalent to the VI for scenario 1 (Figure 7.2). The index is then referred to the vulnerability classes in Table 4.3, and the possible degree of the severity of damage to the CI is determined.

Landslide Type: Translational/Rotational

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

Susceptibility of the 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 minor injuries of the people in the building

Figure 7-2 The corresponding VI calculation for the building and residential vulnerability scenario as in Figure 7.1

Table 7.1 summarizes the statistical information of the 358 buildings within the study area. The number of buildings is based on hazard classification and vulnerability classes. Ultimately, the risk classification of buildings was determined from the respective maps.

Table 7-1 Building statistics from the hazard, vulnerability, and risk maps at Lembah Bertam

Building at Lembah Bertam	Number of Buildings
Total Buildings	358
Hazard	
Buildings with Low Hazard	13
Building with Medium Hazard	104
Buildings with High Hazard	150
Buildings with Very High Hazard	91
Vulnerability	
Buildings with Moderate Vulnerability	358
Risk	
Buildings with Medium Risk	117
Buildings with High Risk	241

7.2 Risk Classification for CI

A landslide risk map is derived from the cross-over of the vulnerability map of the CI and the landslide hazard map by adopting the concept of qualitative risk. Figure 5.13 in Section 5.2.4 shows an example of a derived landslide risk map (Lembah Bertam). Among all the buildings in this area, 117 were categorized to have medium risk, whereas the rest (241) were identified to have high risk.

8. MAP SCALES FOR LANDSLIDE VULNERABILITY AND RISK

Data acquisition depends on the study area. The area can be divided into three categories: small scale, medium scale, and large scale. A regional study area scale with less than 1:100,000 is commonly used to identify affected residential areas, commercial areas, and roads affected by a landslide.

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

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 zoning to inform policy makers and the general public	> 10,000 km^2
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	1,000–10,000 km^2
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	10–1,000 km^2
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 kilometers

9. RELIABILITY OF LANDSLIDE VULNERABILITY ASSESSMENT AND RISK ANALYSIS

9.1 Potential Sources of Error

a) Landslide Inventories

Landslide inventory maps are prepared using the interpretation of DEM data derived from LiDAR combined with orthophotos from the same source. The creation of landslide inventory maps using this method is known to be subjective and prone to errors, as the accuracy of the maps depends on the experience and skills of the person involved. If the study sites are large and the interpretations are done by different groups of people, there are chances that errors can occur. The data acquisition of landslide inventory maps from previous interpretations or the existing landslide body with the latest set of inventories will most likely produce some inconsistencies in the landslide body and associated landslide intensity sub-indicators. Therefore, it is recommended that inventory maps derived from remotely sensed data be calibrated through field verification in the study area.

b) Estimation of Intensity Values

One of the important components in constructing the VI using the IBM is landslide intensity. High landslide intensity values indicate a vulnerable CI. As there is no specific procedure and standard approach to compute landslide intensity in Malaysia, the computation is based on three parameters (accumulation height of the landslide, landslide thickness, and landslide volume). These parameters were estimated from expert assessment, as no proper record of landslide inventory is available. A proper method to quantitatively measure landslide inventory can improve accuracy and reduce the error of estimating landslide intensity values.

c) Hazard Map

A hazard map is one of the main components of landslide risk mapping and assessment. A landslide hazard map depicts the spatial and temporal probability of landslide occurrence in a specific area. Landslide vulnerability and risk assessments require a hazard map to be produced for different types of landslides. This allows a separate landslide risk estimation process for a different type of landslide and CI. The landslide hazard map should be developed based on the landslide susceptibility map, which considers important local landslide causal and triggering factors. All parameters for landslide susceptibility and hazard mapping should be developed and obtained based on high-resolution remotely sensed data and meteorological data and be supported by ground observation data. The reliability of landslide susceptibility and hazard maps should be validated based on a credible source of landslide inventory map or data.

9.2 Validation of Mapping

a) Peer Review

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

b) Formal Validation

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

9.3 Rationalization of Cluster Weightage Distribution

There is inadequate landslide data inventory in Malaysia, and most of the data are taken only from the literature. Therefore, the rationalization of cluster weightage distribution is needed because of this lack of data inventory. The landslide vulnerability assessment using the IBM was done at Cameron Highlands, where frequent landslide hazards occur. The location was selected not only because of landslide frequency but also because of the availability of a range of CIs in the area. Despite the calculated VI derived from the recommended procedure, the rationalization of cluster weightage value was recommended so that the outcome is logically based on local technical expert experiences.

General Principles:

i. The vulnerability of any CI will be presented if two main components (i.e., causal factor, such as landslide hazard, and effect, such as the element-at-risk [building, etc.]) exist.
ii. The value of the weightage for each component should represent the degree of contribution of each component to the development of the VI.
iii. The value of the two main contributing components (C and I) should be of the highest weightage value.
iv. The value of the VI derived from a selected option of the cluster weightage value must be realistic and able to capture the whole range of vulnerability classes from very low to very high in any case.

10. APPLICATION OF THE LANDSLIDE VULNERABILITY INDEX AND RISK CLASSIFICATION

10.1 Typical Development Controls Applied to Landslides

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

i. When there is a history of landsliding
ii. When there is no history of landsliding but the topography dictates that landsliding may occur
iii. When there is no history of landsliding but geological and geomorphological conditions are such that landsliding is possible
iv. When there are constructed features that, should they fail, may travel rapidly and affect other CIs
v. When there are forestry works and agricultural land clearing in which landsliding may lead to damages to the environment by degrading streams and other receiving water bodies

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

11. ACKNOWLEDGEMENT

The Construction Research Institute of Malaysia (CREAM), through the cooperation and support of various government departments and agencies, and the private sector in Malaysia produced a series of documents, namely interim reports, a guideline document, and a manual on vulnerability assessment and risk analysis for CI in Malaysia. The aim is to develop the capacity and capability of construction industry players related to highland disaster risk reduction agenda through an emphasis on professionalism, innovation, and knowledge in an endeavor to improve the quality of life. This cross-disciplinary research was assigned to a team of geoscience professionals, land surveyors, geotechnical engineers, industry players, and academics.

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APPENDIX A – EXAMPLE OF LANDSLIDE VULNERABILITY ASSESSMENT

Landslide type: Translational/Rotational
CI: Building
Susceptibility of CI (C): • *Structural Typology* ***(0.14)****: Steel structure* ***(0.30)*** • *Foundation Depth* ***(0.12)****: Landslide Type Vs Deep Foundation Building: Accumulation height/landslide depth <1.5 meter, deep foundation (pile)* ***(0.10)*** • *Number of floor* ***(0.10)****: High rise (> 5 storey)* ***(0.20)*** **Surrounding Environment (E)**: • *Presence of protection* ***(0.07)****: Engineered protection system* ***(0.10)*** • *Distance between building* ***(0.05)****: > 5 meter* ***(0.10)*** • *Building location* ***(0.07)****: Building is located at a distance more than height of slope* ***(0.10)*** **Landslide intensity (I)**: • *Accumulation height* ***(0.15)****: Height < 0.2 meter* ***(0.10)*** • *Landslide volume* ***(0.18)****: < 500 meter*^{3} ***(0.30)*** **People inside the building (P)**: • *Population density* ***(0.04)****: Low* ***(0.30)*** • *Evacuation of alarm system* ***(0.03)****: Yes* ***(0.10)*** • *Age of people* ***(0.03)****: Adults* ***(0.20)*** • *Health condition* ***(0.03)****: Health (Good)* ***(0.10)*** **Vulnerability index** = (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) = **0.20** ***Vulnerability index***: 0.20
Class of vulnerability: Low
Vulnerability description: Cracks in the wall, stability not affected, reparation not urgent and slight injuries of people in the building

APPENDIX B – INDICATORS, SUB-INDICATORS AND WEIGHT VALUES OF CI (BUILDING)

CLUSTER	COMPONENT (WEIGHT)	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (WEIGHT)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.36	STRUCTURAL TYPOLOGY / STRUCTURE CONSTRUCTION MATERIALS	0.14	Steel structure	0.30
				IBS structures	0.40
				Reinforced concrete structure	0.40
				Masonry structure	0.50
				Timber structure	0.70
				Semi light weight	0.80
				Light weight	1.00
		BUILDING FOUNDATION DEPTH (LANDSLIDE TYPE VS DEEP FOUNDATION BUILDING)	0.12	Accumulation height/landslide depth <1.5 meter, deep foundation (pile)	0.10
				Accumulation height/landslide depth 1.5 - 5 meter, deep foundation (pile)	0.20
				Accumulation height/landslide depth > 5 meter, deep foundation (pile)	0.40
		BUILDING FOUNDATION DEPTH (LANDSLIDE TYPE VS SHALLOW FOUNDATION BUILDING)		Accumulation height/landslide depth < 1.5 meter, shallow foundation (pad footing)	0.60
				Accumulation height/landslide depth 1.5 - 5 meter, shallow foundation (pad footing)	0.80
				Accumulation height/landslide depth > 5 meter, shallow foundation (pad footing)	1.00
		NUMBER OF FLOOR	0.10	High rise (> 5 storey)	0.20
				Medium rise (2 - 5 storey)	0.50
				Low rise (Single storey)	0.80
SURROUNDING ENVIRONMENT [E]	0.18	PRESENCE OF PROTECTION	0.07	Engineered protection system	0.10
				Non-engineered protection system	0.40
				Natural / Vegetation protection	0.70
				No protection	1.00
		DISTANCE BETWEEN BUILDING	0.05	> 5 meter	0.10
				3 - 5 meter	0.50
				< 3 meter	0.90
		BUILDING LOCATION	0.07	Building is located at a distance more than height of slope	0.10
				Building is located at a distance within height of slope	0.20
				Building is located at the toe of slope	0.60
				Building is located at the crest of slope	0.80
				Building is located at the mid-height of slope	1.00

LANDSLIDE INTENSITY [I]	0.33	ACCUMULATION HEIGHTS	0.15	< 0.2 meter	0.10
				0.2 meter - 0.5 meter	0.40
				0.5 meter - 2.0 meter	0.70
				> 2.0 meter	1.00
		LANDSLIDE VOLUME	0.18	< 500 meter^3	0.30
				500 - 10,000 meter^3	0.50
				10,000 - 50,000 meter^3	0.70
				50,000 - 250,000 meter^3	0.90
				> 250,000 meter^3	1.00
PEOPLE INSIDE BUILDING [P]	0.13	POPULATION DENSITY	0.04	Low	0.30
				Medium	0.60
				High	0.90
		EVACUATION OF ALARM SYSTEM	0.03	Yes	0.10
				No	1.00
		AGE OF PEOPLE	0.03	Adults	0.20
				Teenagers	0.30
				Children	0.50
				Senior citizen (65 - 74 years old)	0.80
				Senior citizen (75 - 84 years old)	0.90
				Senior citizen (> 85 years old)	1.00
		HEALTH CONDITION	0.03	Health (Good)	0.10
				Health (Poor)	0.50
				Disabled person	1.00

APPENDIX C – INDICATORS, SUB-INDICATORS AND WEIGHT VALUES OF CI (ROAD)

CLUSTER	COMPONENT (WEIGHT)	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (WEIGHT)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.38	ROAD CATEGORY (JKR STANDARD DESIGN)	0.09	R6 (expressway)	0.10
				U6 (urban expressway)	0.10
				R5 (highway)	0.40
				U4 / U5 (urban arterial road)	0.40
				R4 / R5 (primary rural road)	0.60
				U3 / U4 (urban collector road)	0.70
				R3 / R4 (secondary rural road)	0.80
				R1 / R1a / R2 (minor rural road)	0.90
				U1 / U1a / U2 / U3 (urban local street)	0.90
		LOCATION OF ROAD	0.10	Road is located at a distance more than height of slope	0.10
				Road is located at a distance within height of slope	0.30
				Road is located at the toe of slope	0.50
				Road is located at the crest of slope	0.70
				Road is located at the mid-height of slope	0.90
		ROAD MATERIAL	0.09	Rigid pavement / Concrete road	0.10
				Flexible pavement / Bituminous road	0.50
				Unpaved road	0.90
		ROAD MAINTENANCE	0.10	Good maintenance	0.10
				Poor maintenance	0.50
				No	1.00
SURROUNDING ENVIRONMENT [E]	0.17	PRESENCE OF PROTECTION	0.06	Engineered protection system	0.10
				Non-engineered protection system	0.40
				Natural / Vegetation protection	0.70
				No protection	1.00
		PRESENCE OF WARNING SYSTEM	0.06	Yes	0.10
				No	1.00
		ROAD DRAINAGE SYSTEM	0.05	Yes	0.20
				No	0.90

LANDSLIDE INTENSITY [I]	0.32	ACCUMULATION HEIGHTS	0.10	< 0.2 meter	0.10
				0.2 - 0.5 meter	0.50
				0.5 - 2.0 meter	0.70
				> 2.0 meter	0.90
		LANDSLIDE THICKNESS	0.10	< 1.5 meter	0.30
				1.5 - 5 meter	0.50
				5 - 20 meter	0.70
				> 20 meter	0.90
		LANDSLIDE VOLUME	0.12	< 500 meter^3	0.30
				500 - 10,000 meter^3	0.50
				10,000 - 50,000 meter^3	0.70
				50,000 - 250,000 meter^3	0.90
				> 250,000 meter^3	1.00
ROAD USER [P]	0.13	TRAFFIC VOLUME	0.13	(R2 / R1 / R1a / U2 / U1/ U1a (less than 1000 ADT)) - Low traffic volume	0.30
				(R3 / U3 - 3000 to 1000 ADT)	0.50
				(R4 / U4 - 10,000 to 3000 ADT)	0.60
				(R5 / U5 - more than 10,000 ADT)	0.80
				(R6 / R5/ U6 - all traffic volume) - High traffic volume	0.90

APPENDIX D – INDICATORS, SUB-INDICATORS AND WEGHT VALUES OF CI (DAM)

CLUSTER	COMPONENT (WEIGHT)	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (WEIGHT)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.38	BASIN / CATCHMENT)	0.06	Very large (> 100 kilometer^2)	0.20
				Large (50 - 100 kilometer^2)	0.40
				Medium (25 - 50 kilometer^2)	0.50
				Small (5 - 25 kilometer^2)	0.60
				Very small (< 5 kilometer^2)	1.00
		RESERVOIR	0.07	Very high (> 30 kilometer^2)	0.20
				High (11 - 30 kilometer^2)	0.30
				Medium (6 - 10 kilometer^2)	0.50
				Low (1 - 5 kilometer^2)	0.60
				Very low (< 1 kilometer^2)	1.00
		DAM DIMENSION (MAIN STRUCTURE - HEIGHT)	0.06	< 5 meter	0.20
				6 - 15 meter	0.30
				16 - 50 meter	0.50
				51 - 99 meter	0.60
				> 100 meter	0.80
		DAM DIMENSION (MAIN STRUCTURE - LENGTH)	0.06	> 300 meter	0.20
				201 - 300 meter	0.30
				101 - 200 meter	0.40
				51 - 100 meter	0.60
				< 50 meter	0.70
		DAM TYPOLOGY/ CATEGORIES	0.06	Sedimentation / Recreational	0.20
				Flood mitigation	0.40
				Irrigation	0.50
				Power generation	0.60
				Water supply	0.80
		DAM CONSTRUCTION MATERIALS	0.06	Reinforced concrete	0.30
				Composite	0.50
				Rockfill	0.60
				Earthfill	0.80
SURROUNDING ENVIRONMENT [E]	0.17	PRESENCE OF PROTECTION	0.09	Fully engineered protection system	0.10
				Partially man-made protection system	0.40
				Natural protection (e.g vegetation)	0.60
				No protection	1.00
		PRESENCE OF WARNING SYSTEM	0.08	Yes	0.10
				No	1.00

LANDSLIDE INTENSITY [I]	0.32	LANDSLIDE VOLUME	0.32	< 500 meter^3	0.20
				500 - 10,000 meter^3	0.40
				10,000 - 50,000 meter^3	0.60
				50,000 - 250,000 meter^3	0.80
				> 250,000 meter^3	1.00
PEOPLE AFFECTED BY DAM OPERATION [P]	0.13	POPULATION DENSITY	0.13	Low (< 25 people per km^2)	0.10
				Medium (25 - 50 people per km^2)	0.50
				High (> 50 people per km^2)	0.70

APPENDIX E – INDICATORS, SUB-INDICATORS AND WEIGHT VALUES OF CI (POWERLINE)

CLUSTER	COMPONENT (WEIGHT)	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (WEIGHT)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.30	TYPOLOGY OF UTILITIES	0.07	Telco tower	0.20
				Substation 33KV	0.30
				PMU	0.50
				GRID 132KV (Height 29 meter) (Width 5.7 meter)	0.70
				Hybrid tower (Combination of KV)	0.80
				GRID 500KV (Height 46 - 67 meter) (Width 10.5 - 19 meter)	0.80
				GRID 275KV (Height 34 meter) (Width 7.5 meter)	0.90
		TOWER AND TOWER COMPONENT MATERIAL	0.06	Composite	0.30
				Steel	0.50
				Wood	0.80
		BUILDING STRUCTURE FOUNDATION (TELCO, PMU, SUBSTATION 33KV)	0.04	For surficial landslide, < 1.5 meter	0.20
				For shallow landslide, 1.5 - 5 meter	0.30
				For deep seated landslide, 5 - 20 meter	0.60
				For very deep seated landslide, > 20 meter	0.90
		TOWER STRUCTURE FOUNDATION (132KV, 275KV, 500KV, HYBRID)	0.07	For surficial landslide, < 1.5 meter	0.10
				For shallow landslide, 1.5 - 5 meter	0.30
				For deep seated landslide, 5 - 20 meter	0.60
				For very deep seated landslide, > 20 meter	0.90
		LOCATION OF TOWER	0.06	Toe of slope	0.30
				Top of slope	0.50
				Face of slope	0.90
SURROUNDING ENVIRONMENT [E]	0.15	PRESENCE OF PROTECTION	0.03	Engineered protection system	0.10
				Non-engineered protection system	0.40
				Natural / Vegetation protection	0.70
				No protection (Including Encroachment & ROW)	1.00
		SLOPE MORPHOLOGY (SHAPE)	0.03	Straight	0.30
				Convex	0.50
				Concave	0.90
		PRESENCE OF WARNING SYSTEM	0.02	Yes	0.10
				No	1.00
		DISTANCE OF TOWER FROM THE RIVER	0.03	> 50 meter	0.10
				25 - 50 meter	0.40
				10 - 25 meter	0.70
				< 10 meter	0.90
		PRESENCE OF EROSION	0.04	No erosion	0.10
				Sheet	0.30
				Rill	0.70
				Gully	0.90

LANDSLIDE INTENSITY [I]	0.45	ACCUMULATION HEIGHTS	0.14	< 0.2 meter	0.10
				0.2 - 0.5 meter	0.50
				0.5 - 2.0 meter	0.70
				> 2.0 meter	0.90
		LANDSLIDE THICKNESS	0.16	Surficial deposit, < 1.5 meter	0.10
				Shallow landslide, 1.5 - 5 meter	0.30
				Deep seated landslide, 5 - 20 meter	0.60
				Very deep seated landslide, > 20 meter	0.90
		LANDSLIDE VOLUME	0.14	< 50 meter^3	0.10
				50 - 500 meter^3	0.20
				500 - 10,000 meter^3	0.50
				10,000 - 50,000 meter^3	0.80
				50,000 - 250,000 meter^3	0.90
				> 250,000 meter^3	1.00
PEOPLE AFFECTED BY TNB POWERLINE OPERATION [P]	0.10	POPULATION DENSITY	0.10	Low (< 25 people per km^2)	0.10
				Medium (25 - 50 people per km^2)	0.50
				High (> 50 people per km^2)	0.70

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