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

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EXECUTIVE SUMMARY

The first interim report was focused on the completion of 1st and 2nd objectives of the project i.e. 1) to identify issues related to vulnerability assessments and risk index for critical infrastructures and 2) to review the best practices of vulnerability assessments in other countries (Japan, Hong Kong, Taiwan, etc.) and provide benchmarking/ comparative analysis to Malaysia. This second interim report focuses on the 3rd objective i.e. to assess and develop the parameters/indicators of landslide vulnerability assessment and risk index of critical infrastructures and assigning level for each parameter. The completion of objective begins with the proposed landslide vulnerability and risk assessment methods, initial landslide vulnerability clusters, indicators, sub-indicators, weight values, vulnerability class and risk class as reported in the first interim report. This initial information is improved based on series of focus group discussion (FGD) with different stakeholders and internal experts of the consultant team members. The results from the FGDs were analysed based on the consistency inputs from stakeholders, sensitivity of each indicator and cluster, and simulation of different landslide vulnerability scenarios (worst, medium and best case scenarios). The improvement process is continuously done until the simulated scenarios suit the class and description of landslide vulnerability for each CI.

The final landslide vulnerability clusters, indicators, sub-indicators, weight values, vulnerability class and risk class were produced based on the improvements made by the internal experts based on the initial weights assigned by the stakeholders and literature review. Furthermore, the landslide vulnerability method was tested in the specific area at Ringlet and Lembah Bertam in Cameron Highlands. The landslide validation process involves several major activities including intensive field work for field data acquisition, generation of element-at-risk maps for each critical infrastructure (CI) i.e. buildings, road, dam and Tenaga Nasional Berhad (TNB) powerline, generation of landslide vulnerability and risk maps. The generation of CI maps include intensive tasks in development of several maps on the susceptibility of critical infrastructure (C), effect of surrounding or mitigation measures (E), susceptibility of people (P) and intensity of landslide hazard (I). The entire maps were produced from processing and analysis of remotely sensed data and other ancillary geospatial data collected during the field work. In addition, the landslide vulnerability assessment was

evaluated based on the previous landslide disaster at Taman Bukit Mewah, Bukit Antarabangsa, Hulu Kelang on 6 December 2008.

Detailed analysis on the results shows that the entire weight values assigned for the indicator are consistent among the panels. However, the weight values assigned for the sub-indicators are not consistent, which implies strong deviation on the experience and understanding of the landslide vulnerability concept for CI among the participants. Therefore, the cluster, indicators, sub-indicators and weight values should be improved by the internal experts. In addition, the results show that the weight values assigned by the internal experts are more sensitive to the variations of vulnerability value compared to the weight assigned by the stakeholders. In addition, the sensitivity of each indicator and cluster is highly dependent on the weight assigned for the clusters or indicators and the weight variation of the sub-indicators (0.1 to 1.0). More sensitive cluster/indicator can be achieved by assigning high weight value for cluster and indicator with good variation or distribution of weight of sub-indicator (0.1 to 1.0). Based on the best, medium and worst case landslide vulnerability scenarios, the set of weight assigned by the internal experts has produced more reasonable value expected for very low, moderate and very high vulnerability classes compared to the weights obtained from the stakeholders.

To conclude with, the final landslide cluster, indicators, sub-indicators and weight values obtained from the internal experts have successfully improved the initial data. The key approach towards development of a reliable and practical landslide vulnerability assessment is to use the easily identified, measurable and most significant indicators. These were proven scientifically from the analysis of sensitivity of indicators and sub-indicators for the particular critical infrastructure. The estimated landslide vulnerability for building at Taman Bukit Mewah was 0.74 (High vulnerability) “Structural breaks, partly desructed, reconstruction of destructed parts, death is highly likely (severe injury) and evacuation necessary”. The results show good agreement with the reports of the landslide produced by the Slope Engineering Division (CKC), Public Works Department (JKR).

1.0 INTRODUCTION

The Landslide Vulnerability Assessment (LVA) is certainly useful for Disaster Risk Reduction (DRR) program in the promoting an exchange of information, or for improving disaster preparedness and preventing losses, as aims by the Hotspots Project by creating indicators regarding the frequency of the hazards and the foreseeable economic or human impacts at a global scale (Cardona, 2005; Birkmann, 2007; Léone, 2007). Ideally, it should also assist policy makers in identifying investments priorities (e.g. prevention and mitigation measures) to reduce risk, to identify national risk-management capacities and to evaluate the effects of policies and investments on risk management, and to gauge a country's relative position and follow its evolution over time (Birkmann, 2007).

Some global approaches aim to compare disaster risk between countries exposed to selected natural hazards, as it is the case of the Disaster Risk Index (DRI), which measures the mortality by assessing the relative vulnerability, which is the ratio of the number of persons killed by the number of exposed persons (UNDP/BCPR, 2004; Birkmann, 2007). The DRI was used to identify the countries which most need prevention and development (Peduzzi et al., 2009). Another index of structural vulnerability to climate change was developed to assess the environmental vulnerability of the least developed countries which are facing environmental shocks resulting from climate change, in order to allocate adaptation funds (Guillaumont & Simonet, 2011).

Vulnerability can be measured either on a metric scale or a non-numerical scale (Glade, 2003) and is represented by different ways. One of them is the elaboration of an index which combine various indicators. The index elaboration is usually used to assess social vulnerability (e.g. Social Vulnerability Index (SoVI) which was established by Cutter et al. (2003)), economic vulnerability (e.g. Economic Vulnerability Index (EVI), established by Guillaumont (2009)), human vulnerability (e.g. Disaster Risk Index (DRI), established by UNDP/BCPR (2004)) or environmental vulnerability (e.g. Index of Structural Vulnerability to Climate Change, established by Guillaumont & Simonet (2011)).

Physical vulnerability is more often expressed through vulnerability functions (e.g. Fuchs et al., 2007) which represent the interactions between the damaging event and the elements at risk through curves expressing the possible resistance of the elements to an impact (Li et al., 2010; Puissant et al., 2013). In the case of the landslide vulnerability, the vulnerability functions are usually used for detailed assessments (1:5000-1:10000) (Puissant et al., 2013). An example of application is the study of Papathoma-Köhle et al. (2012), who measured the degree of loss of buildings in function of the debris flow intensity, represented by the height of the debris deposit.

Disaster risk is considered to be a function of hazard, exposure and vulnerability, expressed as the probability of loss of life, injury, and destroyed or damaged capital stock in a given period of time (Bono & Mora, 2014). A comprehensive risk assessment and analysis is required for a better risk management. It must be evaluated with reference to a particular return period. Maps showing the areas that may be affected by landslides are a common tool used by authorities and decision makers to interact with the public and local community. Given the importance of addressing slope hazard and associated risks in the tropics, this project consortium has taken a significant move and looks forward for the best methodological framework and operational need to holistically manage the disaster risk in a changing environment.

One of the most critical steps towards landslide risk analysis is the determination of landslides vulnerability. Vulnerability identifies the element at risk as well as the evaluation of their relationships with the hazard. The relationships relate the landslide potential damages over a specific element at risk. Vulnerability can be defined as the degree of loss to a given element at risk or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage).

For this report, the third objective of the project which is “to assess and develop the parameters/indicators of landslide vulnerability assessment and risk index of critical infrastructures (CI) and assigning level for each parameter” is addressed. While at the same time, the first scope of work which is addressed in this report is to develop landslide vulnerability indicators, sub-indicators and its corresponding weights through Focus Group Discussion (FGD). The second scope emphasises the testing of the proposed landslide vulnerability and risk method in Cameron Highland.

2.0 GENERAL METHODOLOGY

The overall methodology of assessing and developing the parameters/indicators of landslide vulnerability assessment and risk index of critical infrastructures can be divided into 4 main stages namely 1) data acquisition and pre-processing of geospatial data, 2) improvements of landslide vulnerability cluster, indicators, sub-indicators and weight values, 3) landslide vulnerability and risk mapping in Cameron Highlands and 4) evaluation of the landslide vulnerability and risk assessment method (Figure 2.1). The first stage focuses on the data acquisition that includes geospatial and non-geospatial data. The geospatial data includes acquisition of high resolution aerial photos at Ringlet and Lembah Bertam, Cameron Highlands. The aerial photos were processed to produce digital terrain model (DTM), digital surface model (DSM) and orthophotos of the study areas. In addition, several other ancillary data were also obtained from different agencies for example landslide hazard map, high resolution DTM and orthophotos from Mineral and Geoscience Department (JMG). Finally, the input information of the proposed landslide vulnerability and risk assessment with initial information on the clusters (C, E, I, and P), indicators, sub-indicators and weights were obtained from intensive literature reviews.

The second stage focuses on improvements of landslide vulnerability clusters, indicators, sub-indicators and weight values. Several focus group discussions (FGDs) have been conducted with stakeholders and internal experts to improve the landslide vulnerability and risk assessment methods. The first FGD was conducted with different stakeholders. The FGD involved detailed explanation on the concept of landslide vulnerability and risk assessment which includes step-by-step explanation on the procedure in determining the clusters, indicators, sub-indicators and the weight values. Each participant is required to fill a specially designed survey form for landslide vulnerability and risk assessments. The outcomes from this FGD was further improved with specific FGDs with a group for dam and TNB powerline. Finally, all the input for landslide vulnerability and risk assessment of each CI and landslide type was evaluated and finalized by the internal experts of the consultant group members. Several analyses have been carried out to determine the consistency inputs from stakeholders, the sensitivity of each indicator and cluster and reliability of the vulnerability index based simulation of different landslide vulnerability scenarios (worst, medium and best case scenarios). The consistency analysis aims at analyzing the consistency of weight values assigned by the stakeholders for the indicators and sub-indicators through the analysis of standard deviation value of weight between participants. The sensitivity analysis focuses on analyzing the sensitivity of each indicator and sub-indicator towards the estimation of landslide vulnerability value (index) based on the one-at-a-time (OAT) method. The simulation on the other hand analyze the reliability of weight values given by the stakeholders and internal experts (for each CI and landslide type). The best case landslide scenario is expected to produce the lowest vulnerability value that can be classified as “very low vulnerability” class. Medium case landslide scenario is expected to produce the medium vulnerability value that can be classified as “moderate vulnerability” class. Finally, the worst case landslide scenario is expected to produce the highest vulnerability value that can be classified as “very high vulnerability” class. The landslide vulnerability and risk have been grouped into 5 classes namely, very high, high, moderate, low and very low.

In the third stage, the method and final information for landslide vulnerability and risk assessments is evaluated at two study sites, namely Ringlet and Lembah Bertam, Cameron Highlands. The process involves generation of various geospatial maps for different clusters of landslide vulnerability assessment i.e. susceptibility of critical infrastructure (C), effect of surrounding or mitigation measures (E), susceptibility of people (P) and intensity of landslide hazard (I). The C cluster map is generated based on interpretation and classification of high resolution orthophoto and intensive fieldwork in the study area. Each CI should be characterized based on the indicators and sub-indicators in this cluster. The map for cluster E accounts the surrounding environment that might increase and decrease the impact of landslide hazard. The CI characterization process of both maps involved interpretation and image classification of high resolution orthophoto and airborne LiDAR data. The P map considers the impact of CI’s vulnerability on the people. For example, the P map for building consists of density residents for each building. The I map reflects the intensity of landslide hazard estimated based on the landslide characteristics obtained from the landslide inventory map. The landslide inventory map has been produced based on the expert interpretation of high density airbone LiDAR data and orthophoto. Exposure map is developed by delineating possible run-out area for each landslide body and each zone (i.e. landslide body and run-out zones) has different value of landslide hazard intensity. The exposed CI is determined by overlaying the exposure map with the CI in the study area. The maps for each cluster should be developed for each CI. Finally, the C, E, I and P maps for each CI have been used to produce landslide vulnerability map.

The landslide vulnerability map is classified into 5 classes, i.e. very high, high, moderate, low and very low. The landslide risk map is produced based on the matrix combination of landslide vulnerability and hazard classes. The landslide hazard map of the study area is obtained from the Department of Mineral and Geoscience, which was produced using high resolution remote sensing and geospatial modelling approaches. The landslide map was already classified to similar classes. Finally, the risk map is produced by crossing both vulnerability and hazard maps and classified into 5 classes, i.e. very high, high, moderate, low and very low landslide risk areas.

Evaluation of the landslide vulnerability and risk assessment method is carried out over areas with detailed records on landslide disaster. The records are used to parameterize each indicator and sub-indicator in the landslide vulnerability. The estimated landslide vulnerability value and class for building are compared with the damage records and damage description in the report.

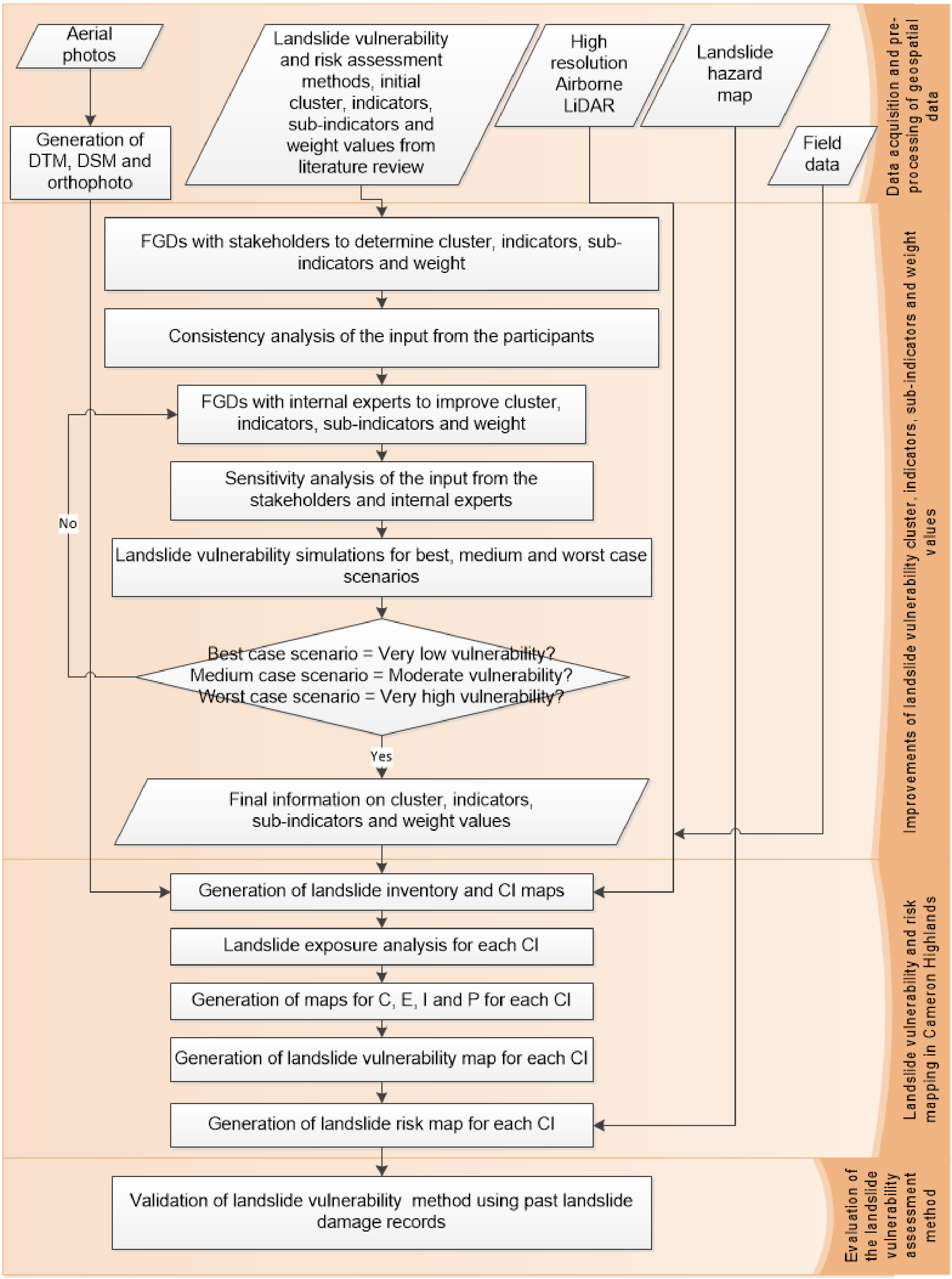

Figure 2.1: General methodology.

3.0 LANDSLIDE VULNERABILITY AND RISK ASSESSMENT METHODS

3.1 Landslide Vulnerability Assessment

Based on previous study, the proposed landslide vulnerability assessment is based on the semi-quantitative approach indicator-based vulnerability assessment (IBM) introduced by Papathoma-Köhle (2016) and and Uzielli et al. (2008). The previous method however did not clearly consider the intensity of landslide hazard in the IBM method. Therefore in this project the hazard intensity will be clearly integrated as part of the indicators in the IBM as it was strongly suggested by Papathoma-Köhle (2016). Uzielli et al. (2008) on the other hand considered the susceptibility of people inside the building but did not consider surrounding environment or mitigation measure in the vulnerability estimation. In the proposed method the vulnerability indicators are grouped into 4 clusters i.e. susceptibility of CI (*C*), effect of surrounding environment or mitigation measures (*E*), susceptibility of people affected by the damaged CI (*P*) and intensity of landslide hazard (*I*) (Equation 1).

$$V = f(C, E, P, I) \tag{1}$$

Therefore, the vulnerability index for CI (*V*) is defined as in Equation 2.

$$V = \sum_{i=1}^{m} w_i \times s_i \tag{2}$$

Where wi is the i-th weight of m indicators under different clusters (in this case m = 4 for Figure 3.1) and S_i is i-th weight for a specific sub-indicator. The weight for each indicator ranges from 0.1 (low influence to increase vulnerability) to 1.0 (high influence to increase vulnerability). The total weight value must be equal to 1.0. The weight value for each sub-indicator also ranges from 0.1 (low influence to increase vulnerability) to 1.0 (high influence to increase vulnerability). Figure 3.1 shows the overall concept of the proposed landslide vulnerability estimation method.

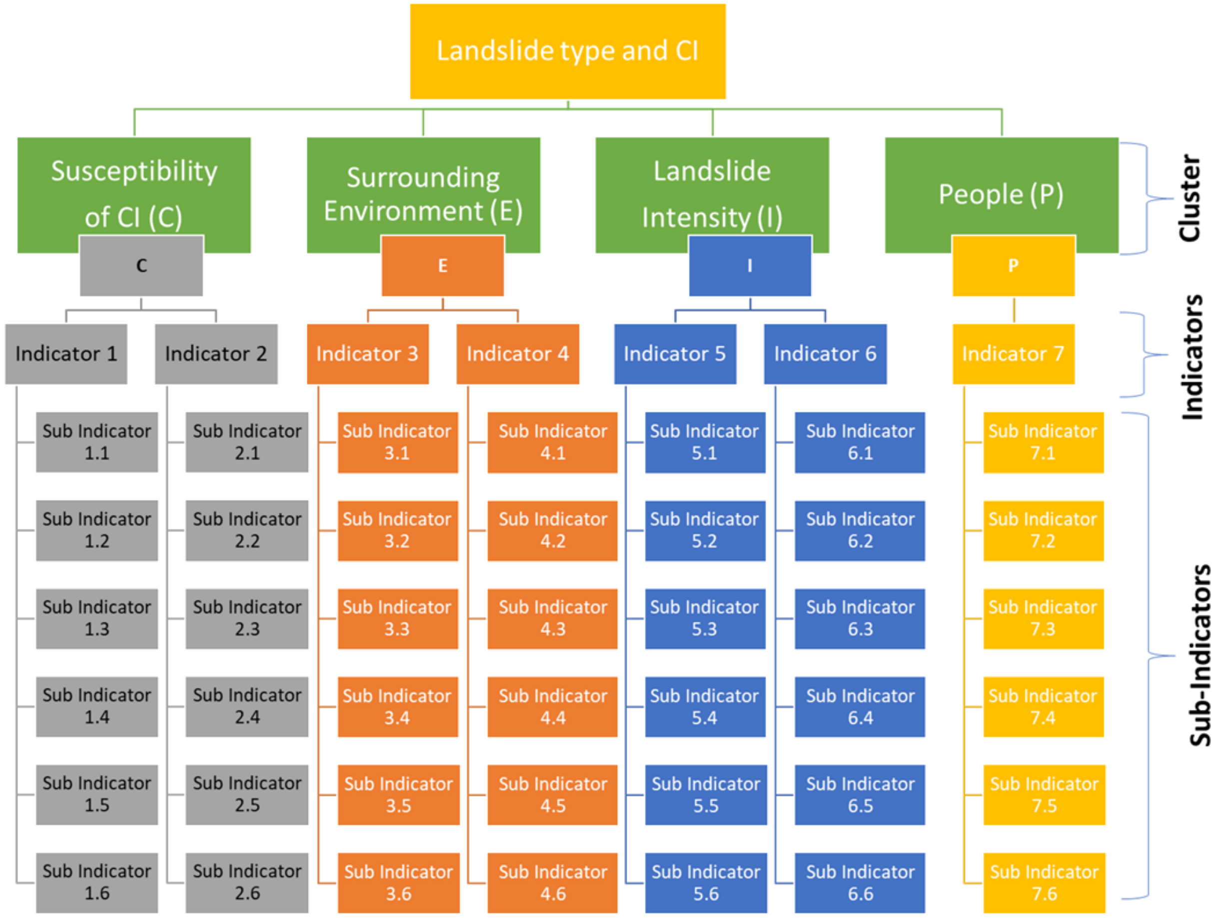

Figure 3.1: The concept of the proposed IBM's method after Kappes et al. (2012).

The CI susceptibility cluster indicates the susceptibility of the CI towards specific landslide hazard intensity that accounts the physical characteristics. The surrounding environment or mitigation measures cluster will take into account the role of existing mitigation measures and surrounding elements in reducing or increasing the impact of landslide on the CI. The intensity of landslide hazard is the final cluster that will indicate the intensity of landslide hazard on a specific CI. People affected by the damaged CI will take into account the impact on the people inside the building/residential, road user, people living downstream area in relation with the location of the dam and people affected by the disrupted functions of utility services.

The final vulnerability value is a weighted and aggregated value explained by Equation 2. In this method, the weighting is not static and varies depending on the needs of the users. The method allows the user to set their own priorities and change the weighting accordingly. Kappes et al. (2012) suggested that the main advantage of the model is the flexibility. In addition, they also consider that the method is not hazard-intensity specific to be an advantage, in which the method can still be used in absence of the intensity or the process characteristics.

The reasons for using a semi-quantitative model based on a scoring system are:

a) **Data availability**: The ranking of indicators into several vulnerability classes requires less data than assessing a quantitative value to each indicator. The quantitative approach of vulnerability assessment certainly required huge amount of past records for landslide damages. However, in this project gathering such data is very challenging and till now the recorded data of landslide damages do not fit with the requirements of the quantitative method.
b) **The possibility for combining qualitative and quantitative indicators**: Through predefined ranking criteria for 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 flexibility in the GIS database. This allows effective analysis on the vulnerability data for example adjustment of the weight and indicators for re-evaluation of vulnerability based on updated landslide records. The GIS system allows spatial analysis for “what if” scenario on the vulnerability data for example that aims at reducing vulnerability and risk by applying specific mitigation measures.
d) **The weighting process is flexible**: The weight assigned for each indicator can be adjusted based on the needs of the users.
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. This will save money and time for data collection.
f) **The IBM methods encourages the involvement of local community**: Local and individual building owners involves in data collection and vulnerability reduction process.

The selection of indicators and their weight values will be based on combination of qualitative (expert judgment on previous records) and quantitative approach (specific numerical modelling on the impact of landslides). However, the former approach (expert judgement) will be the main input since we have lack of previous landslide damage records and validated numerical modelling for landslide impacts in Malaysia. Determination of weight and scores will be made through detailed interviews and workshops with related agencies and experts.

Determination of landslide vulnerability cluster, indicators, sub-indicators, weight values, vulnerability and risk class will be made for different areas (urban, sub-urban, urban highland and rural), CI (residential, building, road, dam, pipeline and tele-communication tower) and typical landslide type in Malaysia. Each vulnerability index for a specific CI will be given together with detailed description on the damages and the process that causes the damage. The damages will be ranked into a specific level for example low, medium, high and very high based on the requirement and vulnerability perception of the related authorities, agencies and experts.

3.2 Landslide Risk Assessment

Unlike the suggested semi-quantitative method for landslide vulnerability assessment, it is proposed that a qualitative method for landslide risk assessment via risk assessment matrix is used in this project (Anbalagan and Singh, 1996). Primarily, this suggestion is made given that the majority of literatures and practice for landslide risk assessment is based on a qualitative method, therefore the method is proven to be effective and convenient (Glade, n.d.). For this to happen, Equation (3) is adjusted to only accommodate two elements of qualitative risk assessment matrix which are hazard and vulnerability, as below.

$$R = H \times V \quad (3)$$

In Equation (3), R = risk, H = hazard and V = vulnerability. To execute this, the challenge is to define the scale of the risk index, however, much earlier, the qualitative measurement of hazard and vulnerability needs to be established. That said, either to straightaway use the already existing qualitative hazard and vulnerability measurement or to modify the quantitative measurement to qualitative. It is proposed that the measurement used is adopted from the Australian Geomechanic Society's *Qualitative Measures of Likelihood of Landsliding* (Hazard Measurement) and *Qualitative Measures of Consequences to Property* (Vulnerability Measurement) as shown in Table 3.1 and Table 3.2 (Fell, 2000).

Table 3.1: Qualitative Measures of Likelihood of Landsliding (Hazard Measurement) (Fell, 2000).

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

Table 3.2: Qualitative Measures of Consequences to Property (Vulnerability Measurement) (Fell, 2000).

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

The combination of Table 3.1 and 3.2 translates into Table 3.3 which is an international standard risk assessment matrix (Ko Ko et al., 1999). Combining likelihood with consequence results in a risk assessment matrix divided into 5 classes of risk index from very low risk (VL) to very high risk (VH). Although the risk index seems straightforward, the measurement of hazard and vulnerability is ideally done by experts to avoid spurious outcomes and for it to be value-adding (Fell, 2000).

Table 3.3: International Standard Risk Assessment Matrix (Ko Ko et al., 1999).

Likelihood (hazard)	Consequences to property (Vulnerability)				
	Catastrophic	Major	Medium	Minor	Insignificant
Almost certain	VH	VH	H	H	M
Likely	VH	H	H	M	L-M
Possible	H	H	M	L-M	VL-L
Unlikely	M-H	M	L-M	VL-L	VL
Rare	M-L	L-M	VL-L	VL	VL
Not credible	VL	VL	VL	VL	VL

Legend:

VH	=	Very high risk
H	=	High risk
M	=	Moderate risk
L	=	Low risk
VL	=	Very low risk

The other reasons for using a qualitative risk assessment via risk assessment matrix are:

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, 2000).
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)
d. In reference to Table 3.4 against the semi-quantitative method of indicator approach suggested for vulnerability assessment executed via direct mapping, the ideal landslide risk assessment technique is qualitative risk.

Table 3.1: Suitability of Risk Approach Compared Against Hazard Approach.

Hazard Approach	Risk Approach		
	Qualitative	Semi-quantitative	Quantitative
Inventory-based probabilistic	2	2	2
Heuristic/geomorphological/direct mapping/expert-based	3	3	0
Statistical (bivariate or multivariate)	3	2	2
Deterministic and dynamic modelling	0	1	3

4.0 INDICATORS AND SUB-INDICATORS FOR LANDSLIDE VULNERABILITY ASSESSMENT

4.1 Initial Indicators and Sub-Indicators for Landslide Vulnerability Assessment

The proposed landslide vulnerability assessment requires determination of 4 clusters i.e. susceptibility of CI (C), effect of surrounding environment or mitigation measures (E), susceptibility of people inside the residential building (P) and intensity of landslide hazard (I) (Equation 1). Initially, in this project each cluster is treated equally, in which all the group of indicators has the same influence towards the vulnerability value. In this case each group is given with 25% (or 0.25) weight value. The weight value will be given equally among the indicators under each cluster or differently based on their level of importance in vulnerability estimation. The weight for each indicator will be assigned based on intensive discussion with the stakeholder and internal experts. Different sets of indicators, sub-indicators and weight values will be determined for different types of typical landslides in Malaysia i.e. rotational landslide, translational landslide, rockfall and debris flow. However, in this project based on the literature review we have proposed suitable initial information on the cluster, indicators, sub-indicators, weight values, vulnerability and risk classes for different types of landslides and CI.

Table 4.1 shows the initial landslide indicators for building. The indicators that represents the susceptibility of building and residential area consists of structural typology of the building, foundation depth, number of floors, and special. Each indicator has specific sub-indicators, in which specific weight value (between 0.1 and 1.0) should be assigned to each class for example as given in Table 4.8. The low the weight value implies low contribution to the increase in total vulnerability value. The higher the weight value will increase the total vulnerability value of the CI. Other indicators representing surrounding environment/mitigation measures, landslide intensity and people inside the building are divided shown in Table 4.1.

Tables 4.2 to 4.5 show the initial landslide vulnerability indicators for residential, road, dam and utilities. Table 4.6 highlighted the initial sub-indicators for building and residential from several literatures.

Table 4.1: Initial landslide vulnerability cluster and indicators for building.

No	Vulnerability Indicators	Type of Landslide			Weightage
		Rotational & Translational	Rock fall	Debris Flow	
	Building Characteristic				0.25
1	Structural typology/ Structure construction materials	x	x	x	
2	Foundation depth	x	x	x	
3	Number of floor	x	x	x	
4	Building categories	x	x	x	
	Surrounding Environment/ Mitigation Measures				0.25
1	Presence of protection	x	x	x	
2	Surrounding wall			x	
3	Surrounding vegetation	x	x	x	
4	Row of building from the river			x	
5	Distance between building			x	
	Landslide Intensity				0.25
1	Accumulation heights	x	x	x	
2	Flow depths			x	
3	Landslide thickness	x		x	
4	Landslide area				
5	Landslide volume	x	x	x	
6	Volume/ kinetic energy		x	x	
7	Block volume/size		x		
8	Debris volume	x		x	
9	Runout distance	x	x	x	
10	Landslide velocity	x	x	x	
	People Inside Building				0.25
1	Population density	x	x	x	
2	Age of people	x	x	x	
3	Presence of warning systems	x	x	x	
Total					**1.00**

Table 4.2: Initial landslide vulnerability cluster and indicators for residential.

No	Vulnerability Indicators	Type of Landslide			Weightage
		Rotational & Translational	Rock fall	Debris Flow	
	Building Characteristic				0.25
1	Structural typology/ Structure construction materials	x	x	x	
2	Foundation depth	x	x	x	
3	Number of floor	x	x	x	
4	Building categories	x	x	x	
	Surrounding Environment/ Mitigation Measures				0.25
1	Presence of protection	x	x	x	
2	Surrounding wall	x	x	x	
3	Surrounding vegetation			x	
4	Row of building from the river			x	
5	Distance between building			x	
	Landslide Intensity				0.25
1	Accumulation heights	x	x	x	
2	Flow depths			x	
3	Landslide thickness	x		x	
4	Landslide area	x	x	x	
5	Landslide volume	x	x	x	
6	Volume/ kinetic energy		x	x	
7	Block volume/size		x		
8	Debris volume	x		x	
9	Runout distance	x	x	x	
10	Landslide velocity	x	x	x	
	People Inside Building				0.25
1	Population density	x	x	x	
2	Age of people	x	x	x	
3	Presence of warning systems	x	x	x	
Total					**1.00**

Table 4.3: Initial landslide vulnerability cluster and indicators for roads.

No	Vulnerability Indicators	Type of Landslide			Weightage
		Rotational & Translational	Rock fall	Debris Flow	
	Roads Characteristic				0.25
1	Level of serviceability	x	x	x	
2	Type of road	x	x	x	
3	Width	x	x	x	
	Surrounding Environment/ Mitigation Measures				0.25
1	Presence of protection	x	x	x	
2	Presence of warning systems	x	x	x	
2	Surrounding wall			x	
3	Surrounding vegetation			x	
4	Row of building from the river			x	
5	Distance between building	x	x	x	
	Landslide Intensity				0.25
1	Accumulation heights	x	x	x	
2	Flow depths			x	
3	Landslide thickness	x		x	
4	Landslide area	x	x	x	
5	Landslide volume	x	x	x	
6	Volume/ kinetic energy		x	x	
7	Block volume/size		x		
8	Debris volume	x		x	
9	Runout distance	x	x	x	
10	Landslide velocity	x	x	x	
	Road User				0.25
1	Traffic volume	x	x	x	
Total					**1.00**

Table 4.4: Initial landslide vulnerability cluster and indicators for dam.

No	Vulnerability Indicators	Type of Landslide			Weightage
		Rotational & Translational	Rock fall	Debris Flow	
	Dam Characteristic				0.25
1	Size of catchment	x	x	x	
2	Dam typology	x	x	x	
3	Foundation depth	x	x	x	
4	Dam height	x	x	x	
5	Dam construction materials	x	x	x	
	Surrounding Environment/ Mitigation Measures				0.25
1	Presence of protection	x	x	x	
2	Presence of warning systems	x	x	x	
2	Surrounding wall			x	
3	Surrounding vegetation			x	
	Landslide Intensity				0.25
1	Accumulation heights	x	x	x	
2	Flow depths				
3	Landslide thickness	x	x	x	
4	Landslide area			x	
5	Landslide volume	x		x	
6	Volume/ kinetic energy	x	x	x	
7	Block volume/size	x	x	x	
8	Debris volume		x	x	
9	Runout distance		x		
10	Landslide velocity	x		x	
	Population Living Downstream Area				0.25
1	Population density	x	x	x	
Total					**1.00**

Table 4.5: Initial landslide vulnerability cluster and indicators for utilities (i.e. pipeline, power line and telecommunication tower)

No	Vulnerability Indicators	Type of Landslide			Weightage
		Rotational & Translational	Rock fall	Debris Flow	
	Utilities Characteristic				0.25
1	Maintenance of utilities	x	x	x	
2	Typology of utilities	x	x	x	
	Surrounding Environment/ Mitigation Measures				0.25
1	Presence of protection	x	x	x	
2	Presence of warning systems	x	x	x	
2	Surrounding wall			x	
3	Surrounding vegetation			x	
4	Row of building from the river				
5	Distance between building	x	x	x	
	Landslide Intensity				0.25
1	Accumulation heights	x	x	x	
2	Flow depths			x	
3	Landslide thickness	x		x	
4	Landslide area	x	x	x	
5	Landslide volume	x	x	x	
6	Volume/ kinetic energy		x	x	
7	Block volume/size		x		
8	Debris volume	x		x	
9	Runout distance	x	x	x	
10	Landslide velocity	x	x	x	
	Users of Utilities				0.25
1	Population density	x	x	x	
Total					**1.00**

Table 4.6: Intial sub-indicators for building and residential.

No	Vulnerability Indicators	Classifications	Reference
	Building Characteristic		
1	Structural typology / Structure construction materials	1. Lightest, simple structures 2. Light structures 3. Rock masonry, concrete and timber 4. Rock masonry, concrete structures 5. Reinforced concrete structures 6. Reinforced structures	(Li, Nadim, Huang, Uzielli, & Lacasse, 2010; Uzielli, Nadim, Lacasse, & Kaynia, 2008)
2	Foundation depth	1. For landslide depth <2 meter a. ≤2 meter b. >2 meter 2. For landslide depth 2 – 10 meter a. Less than a landslide depth b. 10 – 13 meter c. >13 meter 3. For landslide depth >10 meter a. Any depth of building foundation	(Li et al., 2010)
3	Number of floor	1. Single storey (1 storey) 2. Low rise building (2 storey) 3. Medium rise building (3,4,5 storey) 4. High rise building (+6 storey)	(Li et al., 2010)
4	Building categories (combination of number of floor, structure materials,)	1. Four storey or higher reinforced concrete building with pile foundation. 2. Three storey or lower reinforced concrete building with shallow foundation. 3. Single storey reinforced concrete building with shallow foundation.	Civil consultant engineer (2018)

		4. Building with combination of bricks/timber/zinc materials. 5. Temporary structure and timber houses.	
		1. Poor traditional masonry buildings. 2. Poor adobe stone or taipa buildings 3. Poor other resistant elements (wood, metallic) buildings 4. Usual traditional masonry buildings 5. Usual reinforced concrete buildings 6. Luxurious reinforced concrete buildings 7. Heritage traditional mansory	(Zêzere, Garcia, Oliveira, & Reis, 2008)
	Surrounding Environment		
6	Presence of protection	1. No protection 2. Bad 3. Medium 4. Strong	(Li et al., 2010)
7	Surrounding wall	1. Wall >1.5 meter 2. Wall <1.5 meter	(Papathoma-Köhle, 2016)
		1. Concrete wall >0.7 meter 2. Concrete wall <0.7 meter 3. Concrete foundation closed 4. Concrete foundation open 5. Stoned wall 6. Earth-filled dam 7. Lattice fencing	(Fuchs, Heiss, & Hübl, 2007)
8	Surrounding vegetation	1. Vegetation (trees) 2. Vegetation (bushes)	(Papathoma-Köhle, 2016)

9	Row of building from the river	1. First 2. Second 3. >Third	(Papathoma-Köhle, 2016)
10	Distance between building	NA	NA
	Landslide Intensity		
11	Accumulation heights	1. Height <0.5 meter 2. 0.5 meter < height < 2 meter 3. Height > 2 meter	(Roxana, Dagmar, & Thomas, 2013)
12	Flow depths	NA	NA
13	Landslide thickness	NA	NA
14	Landslide area	NA	NA
16	Landslide volume	Estimated volume in (m^3) 1. <0.001 2. <0.5 3. >0.5 4. <500 5. 500 – 10,000 6. 10,000 – 50,000 7. >500,000 8. >>500,000	(Cardinali et al., 2002)
17	Volume/ kinetic Energy	NA	NA
18	Block volume/size	NA	NA
19	Debris volume	NA	NA
20	Runout distance	NA	NA
21	Landslide Velocity	1 – Extremely slow (16mm/year) 2 – Very slow (16mm/year) 3 – Slow (1.6m/year) 4 – Moderate (3m/week) 5 – Rapid (1.8m/hour) 6 – Very rapid (3m/min)	(Cardinali et al., 2002; Cruden & Couture, 2011)

		7 – Extremely rapid (5m/sec)	
	People Inside Building		
22	Population Density	NA	NA
23	Age	0 – 5 5 – 10 10 – 15 15 – 20 20 – 50 50 – 55 55 – 60 60 – 65 65 – 70 70 – 75 ≥ 75	(Isaza-Restrepo, Martínez Carvajal, & Hidalgo Montoya, 2016; Kaynia et al., 2008; Uzielli et al., 2008)
24	Gender	Male Female	NA
25	Presence of warning systems	NA	NA

4.2 Final Indicators and Sub-Indicators for Landslide Vulnerability Assessment

Table 4.7 to Table 4.18 show the final set of landslide vulnerability indicators, sub-indicators and their weights based on the output of the FGD's discussion for building, road, dam and utility (TNB powerline). In the meanwhile, Table 4.19 shows justification of each initial indicators. The final vulnerability value for each CI as calculated using Equation 1 (ranges between 0.1 and 1.0) will be classified into different classes of vulnerability index as shown in Table 4.20.

Table 4.7: Indicators, sub-indicators and weight values of CI (building) with landslide type (translational/rotational).

COMPONENT	WEIGHT	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (WEIGHT)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.36	STRUCTURAL TYPOLOGY / STRUCTURE CONSTRUCTION MATERIALS	0.13	Light weight	1.00
				Semi light weight	0.80
				Timber Structure	0.70
				Masonry structure	0.50
				Reinforced concrete structure	0.40
				IBS structures	0.40
				Steel structure	0.30
		BUILDING FOUNDATION DEPTH (LANDSLIDE TYPE VS SHALLOW FOUNDATION BUILDING)	0.12	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

		BUILDING FOUNDATION DEPTH (LANDSLIDE TYPE VS DEEP FOUNDATION BUILDING)		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
		NUMBER OF FLOOR	0.10	Low rise (Single storey)	0.80
				Medium rise (2 - 5 storey)	0.50
				High rise (> 5 storey)	0.20
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	< 3 meter	0.90
				3 - 5 meter	0.50
				> 5 meter	0.10
		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 – 0.5 meter	0.50
				0.5 – 2.0 meter	0.70
				> 2.0 meter	0.90
		LANDSLIDE VOLUME	0.18	Very small, < 500 meter3	0.30
				Small, 500 - 10,000 meter3	0.50
				Medium, 10,000 - 50,000 meter3	0.70
				Large, 50,000 - 250,000 meter3	0.90
				Very large, > 250,000 meter3	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	Children	0.50
				Teenagers	0.30
				Adults	0.20

				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

Table 4.8: Indicators, sub-indicators and weight values of CI (road) with landslide type (translational/rotational).

COMPONENT	WEIGHT	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (SCORE)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.38	ROAD CATEGORY (JKR STANDARD DESIGN)	0.09	R1 / R1a / R2 (minor rural road)	0.90
				R3 / R4 (secondary rural road)	0.80
				R4 / R5 (primary rural road)	0.60
				R5 (highway)	0.40
				R6 (expressway)	0.10
				U1 / U1a / U2 / U3 (urban local street)	0.90
				U3 / U4 (urban collector road)	0.70
				U4 / U5 (urban arterial road)	0.40
				U6 (urban expressway)	0.10
		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	Flexible pavement / Bituminous road	0.50
				Rigid pavement / Concrete road	0.10
				Unpaved road	0.90
		ROAD MAINTENANCE	0.10	No	1.00
				Good maintenance	0.10
				Poor maintenance	0.50
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 meter - 0.5 meter	0.50
				0.5 meter - 2.0 meter	0.70
				> 2.0 meter	0.90
			0.10	< 1.5 meter	0.30

		LANDSLIDE THICKNESS		1.5 meter - 5 meter	0.50
				5 meter - 20 meter	0.70
				> 20 meter	0.90
		LANDSLIDE VOLUME	0.12	Very small, < 500 meter3	0.30
				Small, 500 - 10,000 meter3	0.50
				Medium, 10,000 - 50,000 meter3	0.70
				Large, 50,000 - 250,000 meter3	0.90
				Very large, > 250,000 meter3	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

Table 4.9: Indicators, sub-indicators and weight values of CI (dam) with landslide type (translational/rotational).

COMPONENT	WEIGHT	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (SCORE)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.38	BASIN / CATCHMENT)	0.06	Very large (> 100 kilometer2)	0.20
				Large (50 - 100 kilometer2)	0.40
				Medium (25 - 50 kilometer2)	0.50
				Small (5 - 25 kilometer2)	0.60
				Very small (< 5 kilometer2)	1.00
		RESERVOIR	0.07	Very high (> 30 kilometer2)	0.20
				High (11 - 30 kilometer2)	0.30
				Medium (6 - 10 kilometer2)	0.50
				Low (1 - 5 kilometer2)	0.60
				Very low (< 1 kilometer2)	1.00
		DAM DIMENSION (MAIN STRUCTURE - HEIGHT)	0.06	> 100 meter	0.80
				51 - 99 meter	0.60
				16 - 50 meter	0.50
				6 - 15 meter	0.30
				< 5 meter	0.20
		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	Water supply	0.80
				Power generation	0.60
				Irrigation	0.50
				Flood mitigation	0.40
				Sedimentation / Recreational	0.20
		DAM CONSTRUCTION MATERIALS	0.06	Earthfill	0.80
				Rockfill	0.60
				Reinforced concrete	0.30
				Composite	0.50
SURROUNDING ENVIRONMENT [E]	0.17	PRESENCE OF PROTECTION	0.09	No protection	1.00
				Natural protection (e.g vegetation)	0.60
				Partially man-made protection system	0.40
				Fully engineered protection system	0.10
		PRESENCE OF WARNING SYSTEM	0.076	Yes	0.10
				No	1.00

LANDSLIDE INTENSITY [I]	0.32	LANDSLIDE VOLUME	0.32	Very small, < 500 meter3	0.20
				Small, 500 - 10,000 meter3	0.40
				Medium, 10,000 - 50,000 meter3	0.60
				Large, 50,000 - 250,000 meter3	0.80
				Very large, > 250,000 meter3	1.00
PEOPLE AFFECTED BY DAM OPERATION [P]	0.13	POPULATION DENSITY	0.13	Low (0)	0.10
				Medium (1 - 10)	0.40
				High (11 - 100)	0.60
				Very High (> 100)	1.00

Table 4.10: Indicators, sub-indicators and weight values of CI (TNB powerline) with landslide type (translational/rotational).

COMPONENT	WEIGHT	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (SCORE)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.30	TYPOLOGY OF UTILITIES	0.07	GRID 500KV (Height 46 - 67 meter) (Width 10.5 - 19 meter)	0.80
				GRID 275KV (Height 34 meter) (Width 7.5 meter)	0.90
				GRID 132KV (Height 29 meter) (Width 5.7 meter)	0.70
				Hybrid Tower (Combination of KV)	0.80
				Substation 33KV	0.30
				PMU	0.50
				Telco Tower	0.20
		TOWER AND TOWER COMPONENT MATERIAL	0.06	Wood	0.80
				Steel	0.50
				Composite	0.30
		BUILDING STRUCTURE FOUNDATION (TELCO,	0.04	For surficial landslide, < 1.5 meter	0.20
				For shallow landslide, 1.5 - 5 meter	0.30

		PMU, SUBSTATION 33KV)		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	Top of slope	0.50
				Face of slope	0.90
				Toe of slope	0.30
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	Concave	0.90
				Convex	0.50

				Straight	0.30
		PRESENCE OF WARNING SYSTEM	0.02	Yes	0.10
				No	1.00
		DISTANCE OF TOWER FROM THE RIVER	0.03	< 10 meter	0.90
				10 - 25 meter	0.70
				25 - 50 meter	0.40
				> 50 meter	0.10
		PRESENCE OF EROSION	0.04	Gully	0.90
				Rill	0.70
				Sheet	0.30
				No Erosion	0.10
LANDSLIDE INTENSITY [I]	0.45	ACCUMULATION HEIGHTS	0.14	< 0.2 meter	0.1
				0.2 – 0.5 meter	0.5
				0.5 – 2.0 meter	0.7
				> 2.0 meter	0.9
		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 meter3	0.10
				50 - 500 meter3	0.20
				500 - 10,000 meter3	0.50
				10,000 - 50,000 meter3	0.80
				50,000 - 250,000 meter3	0.90
				> 250,000 meter3	1.00
PEOPLE AFFECTED BY TNB POWERLINE OPERATION [P]	0.10	POPULATION DENSITY	0.10	Low (<25 people per km2)	0.10
				Medium (25 - 50 people per km2)	0.50
				High (> 50 people per km2)	0.70

Table 4.11: Indicators, sub-indicators and weight values of CI (building) with landslide type (debris flow).

COMPONENT	WEIGHT	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (SCORE)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.36	STRUCTURAL TYPOLOGY / STRUCTURE CONSTRUCTION MATERIALS	0.13	Light weight	1.00
				Semi light weight	0.80
				Timber Structure	0.70
				Masonry structure	0.50
				Reinforced concrete structure	0.40
				IBS structures	0.40
				Steel structure	0.30
		BUILDING FOUNDATION DEPTH (LANDSLIDE TYPE VS SHALLOW FOUNDATION BUILDING)	0.12	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

		BUILDING FOUNDATION DEPTH (LANDSLIDE TYPE VS DEEP FOUNDATION BUILDING)		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
		NUMBER OF FLOOR	0.10	Low rise (Single storey)	0.80
				Medium rise (2 - 5 storey)	0.50
				High rise (> 5 storey)	0.20
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	< 3 meter	0.90
				3 - 5 meter	0.50
				> 5 meter	0.10
		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	LANDSLIDE VELOCITY	0.10	Extremely rapid (5 meter/second)	1.00
				Very rapid (3 meter/minute)	0.90
				Rapid (1.8 meter/hour)	0.70
				Moderate (13 meter/month)	0.50
				Slow (1.6 meter/year)	0.40
				Very slow (16 millimeter/year)	0.20
				Extremely slow (16 millimeter/year)	0.10
		ACCUMULATION HEIGHTS	0.08	< 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	0.06	Surficial landslide, 1.5 meter	0.20
				Shallow landslide, 1.5 - 5 meter	0.40
				Deep seated landslide, 5 - 20 meter	0.60
				Very deep seated landslide, > 20 meter	0.80
		LANDSLIDE VOLUME	0.09	Very small, < 500 meter3	0.30

				Small, 500 - 10,000 meter3	0.50
				Medium, 10,000 - 50,000 meter3	0.70
				Large, 50,000 - 250,000 meter3	0.90
				Very large, > 250,000 meter3	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	Children	0.50
				Teenagers	0.30
				Adults	0.20
				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

Table 4.12: Indicators, sub-indicators and weight values of CI (road) with landslide type (debris flow).

COMPONENT	WEIGHT	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (SCORE)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.38	ROAD CATEGORY (JKR STANDARD DESIGN)	0.09	R1 / R1a / R2 (minor rural road)	0.90
				R3 / R4 (secondary rural road)	0.80
				R4 / R5 (primary rural road)	0.60
				R5 (highway)	0.40
				R6 (expressway)	0.10
				U1 / U1a / U2 / U3 (urban local street)	0.90
				U3 / U4 (urban collector road)	0.70
				U4 / U5 (urban arterial road)	0.40
				U6 (urban expressway)	0.10
		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	Flexible pavement / Bituminous road	0.50
				Rigid pavement / Concrete road	0.10
				Unpaved road	0.90
		ROAD MAINTENANCE	0.10	No	1.00
				Good maintenance	0.10
				Poor maintenance	0.50
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	LANDSLIDE VELOCITY	0.08	Extremely Rapid (5 meter/second)	1.00
				Very Rapid (3 meter/minute)	0.90
				Rapid (1.8 meter/hour)	0.70
				Moderate (13 meter/month)	0.50
				Slow (1.6 meter/year)	0.40
				Very Slow (16 millimeter/year)	0.20
				Extremely Slow (16 millimeter/year)	0.10
		ACCUMULATION HEIGHTS	0.08	< 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	0.08	< 1.5 meter	0.30
				1.5 meter - 5 meter	0.50
				5 meter - 20 meter	0.70
				> 20 meter	0.90
		LANDSLIDE VOLUME	0.08	Very small, < 500 meter3	0.30
				Small, 500 - 10,000 meter3	0.50
				Medium, 10,000 - 50,000 meter3	0.70
				Large, 50,000 - 250,000 meter3	0.90

				Very large, > 250,000 meter3	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

Table 4.13: Indicators, sub-indicators and weight values of CI (dam) with landslide type (debris flow).

COMPONENT	WEIGHT	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (SCORE)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.38	BASIN / CATCHMENT)	0.06	Very large (> 100 kilometer2)	0.20
				Large (50 - 100 kilometer2)	0.40
				Medium (25 - 50 kilometer2)	0.50
				Small (5 - 25 kilometer2)	0.60
				Very small (< 5 kilometer2)	1.00
		RESERVOIR	0.07	Very high (> 30 kilometer2)	0.20
				High (11 - 30 kilometer2)	0.30
				Medium (6 - 10 kilometer2)	0.50
				Low (1 - 5 kilometer2)	0.60
				Very low (< 1 kilometer2)	1.00
		DAM DIMENSION (MAIN STRUCTURE - HEIGHT)	0.06	> 100 meter	0.80
				51 - 99 meter	0.60
				16 - 50 meter	0.50
				6 - 15 meter	0.30
				< 5 meter	0.20

		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	Water supply	0.80
				Power generation	0.60
				Irrigation	0.50
				Flood mitigation	0.40
				Sedimentation / Recreational	0.20
		DAM CONSTRUCTION MATERIALS	0.06	Earthfill	0.80
				Rockfill	0.60
				Reinforced concrete	0.30
				Composite	0.50
SURROUNDING ENVIRONMENT [E]	0.17	PRESENCE OF PROTECTION	0.09	No protection	1.00
				Natural protection (e.g vegetation)	0.60
				Partially man-made protection system	0.40

				Fully engineered protection system	0.10
		PRESENCE OF WARNING SYSTEM	0.08	Yes	0.10
				No	1.00
LANDSLIDE INTENSITY [I]	0.32	LANDSLIDE VELOCITY	0.17	Extremely rapid (5 meter/second)	1.00
				Very rapid (3 meter/minute)	0.90
				Rapid (1.8 meter/hour)	0.70
				Moderate (13 meter/month)	0.50
				Slow (1.6 meter/year)	0.40
				Very slow (16 millimeter/year)	0.20
				Extremely slow (16 millimeter/year)	0.10
		LANDSLIDE VOLUME	0.15	Very Small, < 500 meter3	0.20
				Small, 500 - 10,000 meter3	0.40
				Medium, 10,000 - 50,000 meter3	0.60

				Large, 50,000 - 250,000 meter3	0.80
				Very Large, > 250,000 meter3	1.00
PEOPLE AFFECTED BY DAM OPERATION [P]	0.13	POPULATION DENSITY	0.13	Low (0)	0.10
				Medium (1 - 10)	0.40
				High (11 - 100)	0.60
				Very High (> 100)	1.00

Table 4.14: Indicators, sub-indicators and weight values of CI (TNB powerline) with landslide type (debris flow).

COMPONENT	WEIGHT	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (SCORE)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.30	TYPOLOGY OF UTILITIES	0.07	GRID 500KV (Height 46 - 67 meter) (Width 10.5 - 19 meter)	0.80
				GRID 275KV (Height 34 meter) (Width 7.5 meter)	0.90
				GRID 132KV (Height 29 meter) (Width 5.7 meter)	0.70
				Hybrid Tower (Combination of KV)	0.80
				Substation 33KV	0.30
				PMU	0.50
				Telco Tower	0.20
		TOWER AND TOWER COMPONENT MATERIAL	0.06	Wood	0.80
				Steel	0.50
				Composite	0.30
		BUILDING STRUCTURE FOUNDATION (TELCO,	0.04	For surficial landslide, < 1.5 meter	0.20
				For shallow landslide, 1.5 - 5 meter	0.30

		PMU, SUBSTATION 33KV)		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	Top of slope	0.50
				Face of slope	0.90
				Toe of slope	0.30
SURROUNDING ENVIRONMENT [E]	0.15	PRESENCE OF PROTECTION	0.04	Engineered protection system	0.10
				Non-engineered protection system	0.40
				Natural / Vegetation protection	0.70
				No protection (Including Encroachment & ROW)	1.00
			0.04	Concave	0.90

		SLOPE MORPHOLOGY (SHAPE)		Convex	0.50
				Straight	0.30
		PRESENCE OF WARNING SYSTEM	0.03	Yes	0.10
				No	1.00
		DISTANCE OF TOWER FROM THE RIVER	0.04	< 10 meter	0.90
				10 - 25 meter	0.70
				25 - 50 meter	0.40
				> 50 meter	0.10
		PRESENCE OF EROSION	0.05	Gully	0.90
				Rill	0.70
				Sheet	0.30
				No Erosion	0.10
LANDSLIDE INTENSITY [I]	0.45	LANDSLIDE VELOCITY	0.13	Extremely Rapid (5 meter/second)	1.00
				Very Rapid (3 meter/minute)	0.90
				Rapid (1.8 meter/hour)	0.70
				Moderate (13 meter/month)	0.50
				Slow (1.6 meter/year)	0.40
				Very Slow (16 millimeter/year)	0.20
				Extremely Slow (16 millimeter/year)	0.10

		ACCUMULATION HEIGHTS	0.10	Height < 0.5 meter	0.20
				0.5 meter < Height < 2 meter	0.50
				> 2 meter	0.90
		LANDSLIDE THICKNESS	0.13	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	0.10	<50 meter3	0.10
				50 - 500 meter3	0.20
				500 - 10,000 meter3	0.50
				10,000 - 50,000 meter3	0.80
				50,000 - 250,000 meter3	0.90
				> 250,000 meter3	1.00
PEOPLE AFFECTED BY TNB POWERLINE OPERATION [P]	0.10	POPULATION DENSITY	0.10	Low (<25 people per km2)	0.10
				Medium (25 - 50 people per km2)	0.50
				High (> 50 people per km2)	0.70

Table 4.15: Indicators, sub-indicators and weight values of CI (building) with landslide type (rock fall).

COMPONENT	WEIGHT	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (SCORE)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.36	STRUCTURAL TYPOLOGY / STRUCTURE CONSTRUCTION MATERIALS	0.14	Light weight	1.00
				Semi light weight	0.80
				Timber Structure	0.70
				Masonry structure	0.50
				Reinforced concrete structure	0.40
				IBS structures	0.40
				Steel structure	0.30
		BUILDING FOUNDATION DEPTH (LANDSLIDE TYPE VS SHALLOW FOUNDATION BUILDING)	0.12	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

		BUILDING FOUNDATION DEPTH (LANDSLIDE TYPE VS DEEP FOUNDATION BUILDING)		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
		NUMBER OF FLOOR	0.10	Low rise (Single storey)	0.80
				Medium rise (2 - 5 storey)	0.50
				High rise (> 5 storey)	0.20
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	< 3 meter	0.90
				3 - 5 meter	0.50
				> 5 meter	0.10
		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	LANDSLIDE VELOCITY	0.11	Extremely rapid (5 meter/second)	1.00
				Very rapid (3 meter/minute)	0.90
				Rapid (1.8 meter/hour)	0.70
				Moderate (13 meter/month)	0.50
				Slow (1.6 meter/year)	0.40
				Very slow (16 millimeter/year)	0.20
				Extremely slow (16 millimeter/year)	0.10
		SIZE OF BOULDER / BLOCK	0.11	0.3 meter	0.40
				0.3 - 0.6 meter	0.60
				0.6 - 1.0 meter	0.80
				> 1.0 meter	1.00
		LANDSLIDE VOLUME	0.10	Very small, < 500 meter3	0.30
				Small, 500 - 10,000 meter3	0.50
				Medium, 10,000 - 50,000 meter3	0.70
				Large, 50,000 - 250,000 meter3	0.90

				Very large, > 250,000 meter3	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	Children	0.50
				Teenagers	0.30
				Adults	0.20
				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

Table 4.16: Indicators, sub-indicators and weight values of CI (road) with landslide type (rock fall).

COMPONENT	WEIGHT	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (SCORE)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.38	ROAD CATEGORY (JKR STANDARD DESIGN)	0.09	R1 / R1a / R2 (minor rural road)	0.90
				R3 / R4 (secondary rural road)	0.80
				R4 / R5 (primary rural road)	0.60
				R5 (highway)	0.40
				R6 (expressway)	0.10
				U1 / U1a / U2 / U3 (urban local street)	0.90
				U3 / U4 (urban collector road)	0.70
				U4 / U5 (urban arterial road)	0.40
				U6 (urban expressway)	0.10
		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	Flexible pavement / Bituminous road	0.50
				Rigid pavement / Concrete road	0.10
				Unpaved road	0.90
		ROAD MAINTENANCE	0.10	No	1.00
				Good maintenance	0.10
				Poor maintenance	0.50
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	LANDSLIDE VELOCITY	0.08	Extremely rapid (5 meter/second)	1.00
				Very rapid (3 meter/minute)	0.90
				Rapid (1.8 meter/hour)	0.70
				Moderate (13 meter/month)	0.50
				Slow (1.6 meter/year)	0.40
				Very slow (16 millimeter/year)	0.20
				Extremely slow (16 millimeter/year)	0.10

		SIZE OF BOULDER / BLOCK	0.11	0.3 meter	0.50
				0.3 - 0.6 meter	0.70
				0.6 - 1.0 meter	0.80
				> 1.0 meter	1.00
		LANDSLIDE VOLUME	0.11	Very small, < 500 meter3	0.30
				Small, 500 - 10,000 meter3	0.50
				Medium, 10,000 - 50,000 meter3	0.70
				Large, 50,000 - 250,000 meter3	0.90
				Very large, > 250,000 meter3	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

Table 4.17: Indicators, sub-indicators and weight values of CI (dam) with landslide type (rock fall).

COMPONENT	WEIGHT	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (SCORE)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.38	BASIN / CATCHMENT)	0.06	Very large (> 100 kilometer2)	0.20
				Large (50 - 100 kilometer2)	0.40
				Medium (25 - 50 kilometer2)	0.50
				Small (5 - 25 kilometer2)	0.60
				Very small (< 5 kilometer2)	1.00
		RESERVOIR	0.07	Very high (> 30 kilometer2)	0.20
				High (11 - 30 kilometer2)	0.30
				Medium (6 - 10 kilometer2)	0.50
				Low (1 - 5 kilometer2)	0.60
				Very low (< 1 kilometer2)	1.00
		DAM DIMENSION (MAIN STRUCTURE - HEIGHT)	0.06	> 100 meter	0.80
				51 - 99 meter	0.60
				16 - 50 meter	0.50
				6 - 15 meter	0.30
				< 5 meter	0.20

		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	Water supply	0.80
				Power generation	0.60
				Irrigation	0.50
				Flood mitigation	0.40
				Sedimentation / Recreational	0.20
		DAM CONSTRUCTION MATERIALS	0.06	Earthfill	0.80
				Rockfill	0.60
				Reinforced concrete	0.30
				Composite	0.50
SURROUNDING ENVIRONMENT [E]	0.17	PRESENCE OF PROTECTION	0.09	No protection	1.00
				Natural protection (e.g vegetation)	0.60
				Partially man-made protection system	0.40

				Fully engineered protection system	0.10
		PRESENCE OF WARNING SYSTEM	0.08	Yes	0.10
				No	1.00
LANDSLIDE INTENSITY [I]	0.32	LANDSLIDE VELOCITY	0.11	Extremely rapid (5 meter/second)	1.00
				Very rapid (3 meter/minute)	0.90
				Rapid (1.8 meter/hour)	0.70
				Moderate (13 meter/month)	0.50
				Slow (1.6 meter/year)	0.40
				Very slow (16 millimeter/year)	0.20
				Extremely slow (16 millimeter/year)	0.10
		SIZE OF BOULDER / BLOCK	0.11	< 0.3 meter	0.20
				0.3 - 0.6 meter	0.40
				0.6 - 1.0 meter	0.60
				> 1.0 meter	0.80
		LANDSLIDE VOLUME	0.09	Very small, < 500 meter3	0.20

				Small, 500 - 10,000 meter3	0.40
				Medium, 10,000 - 50,000 meter3	0.60
				Large, 50,000 - 250,000 meter3	0.80
				Very large, > 250,000 meter3	1.00
PEOPLE AFFECTED BY DAM OPERATION [P]	0.13	POPULATION DENSITY	0.13	Low (0)	0.10
				Medium (1 - 10)	0.40
				High (11 - 100)	0.60
				Very High (> 100)	1.00

Table 4.18: Indicators, sub-indicators and weight values of CI (TNB powerline) with landslide type (rock fall).

COMPONENT	WEIGHT	INDICATOR	INDICATOR (WEIGHT)	SUB-INDICATOR	SUB-INDICATOR (SCORE)
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	0.30	TYPOLOGY OF UTILITIES	0.07	GRID 500KV (Height 46 - 67 meter) (Width 10.5 - 19 meter)	0.80
				GRID 275KV (Height 34 meter) (Width 7.5 meter)	0.90
				GRID 132KV (Height 29 meter) (Width 5.7 meter)	0.70
				Hybrid tower (Combination of KV)	0.80
				Substation 33KV	0.30
				PMU	0.50
				Telco tower	0.20
		TOWER AND TOWER COMPONENT MATERIAL	0.06	Wood	0.80
				Steel	0.50
				Composite	0.30
		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	Top of slope	0.50
				Face of slope	0.90
				Toe of slope	0.30
SURROUNDING ENVIRONMENT [E]	0.15	PRESENCE OF PROTECTION	0.04	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)	0.04	Concave	0.90
				Convex	0.50
				Straight	0.30
		PRESENCE OF WARNING SYSTEM	0.03	Yes	0.10
				No	1.00
		DISTANCE OF TOWER FROM THE RIVER	0.04	< 10 meter	0.90
				10 - 25 meter	0.70
				25 - 50 meter	0.40
				> 50 meter	0.10
		PRESENCE OF EROSION	0.05	Gully	0.90
				Rill	0.70
				Sheet	0.30
				No erosion	0.10
LANDSLIDE INTENSITY [I]	0.45	LANDSLIDE VELOCITY	0.17	Extremely rapid (5 meter/second)	1.00
				Very rapid (3 meter/minute)	0.90
				Rapid (1.8 meter/hour)	0.70
				Moderate (13 meter/month)	0.50
				Slow (1.6 meter/year)	0.40
				Very slow (16 millimeter/year)	0.20
				Extremely slow (16 millimeter/year)	0.10

		SIZE OF BOULDER / BLOCK	0.15	< 0.3 meter	0.60
				0.3 - 0.6 meter	0.70
				0.6 - 1.0 meter	0.80
				> 1.0 meter	1.00
		LANDSLIDE VOLUME	0.13	Very small, <50 meter3	0.40
				Very small, 50 - 500 meter3	0.60
				Small, 500 - 10,000 meter3	0.70
				Medium, 10,000 - 50,000 meter3	0.80
				Large, 50,000 - 250,000 meter3	1.00
				Very large, > 250,000 meter3	1.00
PEOPLE AFFECTED BY TNB POWERLINE OPERATION [P]	0.10	POPULATION DENSITY	0.10	Low (0)	0.30
				Medium (1 - 10)	0.50
				High (11 - 100)	0.70

Table 4.19: Justification of indicators in estimating landslide vulnerability.

Type of Critical Infrastructure	Indicators	Description/Justification
All CIs	Structure materials	The scores may vary according to the case study and it is clear that each material type reacts in a different way to the impact of a debris flow
Building/ Residential/Dam	Height of the building or structure	The height of the building or structure directly influences the degree of loss. The higher the building the lower the degree of loss.
Building/Residential	Number of floors	Building height is significant for its response to sliding debris. Additionally, multi-storey buildings offer opportunities for vertical evacuation. A one-floor high building does not necessarily offer this possibility.
Road	Level of serviceability	The limit state design of structures includes factors such as durability, overall stability, cracking resistance and excessive vibration.
Road	Type of road	Different types of road may have different structural designs that might reduce the impact of landslide
Road	Width of road	Different width of road may have different structural designs that might reduce the impact of landslide
All CIs	Surrounding wall	Surrounding wall has a protection effect for the building according to its height and material
All CIs	Surrounding vegetation	Surrounding vegetation reduces the intensity of the process on the building to a lesser degree than a surrounding wall does.
Building/ Residential/Dam	Depth of foundation	An appropriate foundation may prevent the collapse of buildings and other structure
All CIs	Row of building from the river	Other buildings may act as protection to other buildings.

All CIs	Distance between buildings	The back shield effect of surrounding buildings has been recognised in many studies as a factor that reduces the vulnerability of a building to debris flow
All CIs	Presence of protection or mitigation measures	Local protection measures (such as extra window protection, no windows from the slope side, basement with elevated entrance etc.), when present, may significantly reduce the vulnerability of the building.
All CIs	Accumulation heights	The height of the displaced material, which lies above the original ground surface. The height of accumulation has been used by previous studies in estimating landslide damages depending on the height of the structure.
All CIs	Flow depths	Involve the depth of fluid of materials down slope movement. The height of accumulation has been used by previous studies in estimating landslide damages.
All CIs	Landslide thickness	The most striking difference between the two types of landslides is in thickness. Thin landslides, less than 2 m thick, occupy the upper parts of hillslopes where the colluvium is thin. Thick landslides, more than 2 m thick, occupy the lower parts of the slopes.
All CIs	Landslide area	The area of the landslide within which the displaced material lies above the original ground surface. The impact of landslide on a specific structure was also determined by the location of the structure in relation with the landslide area for example building inside the landslide area might have different impact compared to building outside the landslide area.
All CIs	Landslide volume	Volumes of landslides are recorded in the scientific literature using cubic kilometres (km3) for the largest and millions of cubic metres. The volume of landslide has a significant impact on the structure.

All CIs	Volume/kinetic energy	Potential to kinetic energy transfer is especially important in understanding the evolution of landforms. Potential to kinetic energy transfer is the driving force behind wind and water movement leading to erosion and weathering.
All CIs	Block volume/size	The volume of overlying material moves as a single, little-deformed mass.
All CIs	Debris volume	Large fraction of the debris flow is water. As the flow comes to rest, the water and fine-grained sediments segregate, forming a hyperconcentrated flow that can continue for great distances.
All CIs	Runout distance	Used for the depositional part or terminal flow path downstream of a defined point.
All CIs	Landslide velocity	A velocity range is connected to the different type of landslides, on the basis of observation of case history or site observations.
All CIs	Population density	Population density is the number of people per unit of area, usually quoted per square kilometer or square mile. The higher the density of people in the building resulting higher risk of human casualties.
All CIs	Age of people	This would exclude specific ages, but the groupings could be of any scope from 10-20 year-olds, 30-40 year-olds, etc. Old people might have difficulties in responding towards hazard thus increase the risk of casualties.
All CIs	Gender	The range of characteristics differentiating between masculinity and femininity.
All CIs	Presence of warning systems	Any system of biological or technical nature deployed by an individual or group to inform of a future danger. This might have a positive impact towards vulnerability since it increases the chance of the resident survival during the landslide event.

Road	Traffic volume	The number of vehicles crossing a section of road per unit time at any selected period. Road with high traffic volume will have high risk of human casualties during the landslide event.

Table 4.20: Landslide vulnerability classes for each CI.

Element-at-Risk	Vulnerability class	Type of Damage	Vulnerability (0-1)
Building and residential	Very low	Slight non-structural damage, stability not affected, furnishing or fitting damaged and no human casualty expected	0.01-0.19
	Low	Cracks in the wall, stability not affected, reparation not urgent and slight injuries of people in the building	0.20-0.39
	Moderate	Strong deformations, huge holes in wall, cracks in supporting structures, stability affected, doors and windows unusable, severe injuries and evacuation necessary	0.40-0.69
	High	Structural breaks, partly destructed, reconstruction of destructed parts, death is highly likely (severe injury) and evacuation necessary	0.70-0.89
	Very High	Severely damaged stucture or totally destructed, evacuation necessary, complete reconstruction and death is almost certain	0.90-1.00
Road	Very low	Slight damage of road and does not affect any traffic problem	0.01-0.19

	Low	No structural damage with minor repairable damage and slightly affect traffic	0.20-0.39
	Moderate	No structural damage, major damage requiring major repair work and severe effect on road traffic	0.40-0.69
	High	Structural damage that can affect the stability and functionality of the road, partly unusable road and requires road diversion	0.70-0.89
	Very high	Heavy damage seriously compromising the structural integrity: partial or total collapse of the road, totally unusable road and immediate road diversion is required	0.90-1.00
Dam	Very low	Slight damage of dam and does not affect any problem to the community	0.01-0.19
	Low	No structural damage – minor repairable damage and slightly affect the dam operation	0.20-0.39
	Moderate	No structural damage –major damage requiring major repair work and severe effect on the dam operation	0.40-0.69
	High	Structural damage that can affect the stability and functionality of the dam and partly disrupted dam operation	0.70-0.89
	Very high	Heavy damage seriously compromising the structural integrity: partial or total collapse of the dam, totally disrupted dam operation and	0.90-1.00

		immediate evacuation is required for the community living downstream	
Utility	Very low	Slight damage of utility and does not affect its operation	0.01-0.19
	Low	No structural damage – minor repairable damage and slightly affect the operation	0.20-0.39
	Moderate	No structural damage –major damage requiring major repair work and severely affect the operations of such utility	0.40-0.69
	High	Structural damage that can affect the stability and functionality of the utility. The operation of the utility infrastructure is highly interrupted and requires backup or alternative	0.70-0.89
	Very high	Heavy damage seriously compromising the structural integrity: partial or total collapse of the road, total collapse of utility operation and immediate backup operation is highly required	0.90-1.00

Subsequently, Table 4.21 is a revised version of Table 3.3 since only five classes of hazard classification are used rather than the original six classes. The classes name for hazard and vulnerability are also modified using the common scale of very low until very high to introduce convenience for locals when assessing risk within their geographical jurisdiction. Notice that, the lowest row from Table 3.3 is completely removed.

Table 4.21: Improvised International Standard Risk Assessment Matrix.

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	L-M
Medium	H	H	M	L-M	VL-L
Low	M-H	M	L-M	VL-L	VL
Very Low	M-L	L-M	VL-L	VL	VL

Legend:

VH	=	Very high risk
H	=	High risk
M	=	Moderate risk
L	=	Low risk
VL	=	Very low risk

The other reasons for using a qualitative risk assessment via risk assessment matrix are:

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, 2000).
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).

5.0 FOCUS GROUP DISCUSSION (FGD) FOR LANDSLIDE VULNERABILITY AND RISK ASSESSMENTS

5.1 Development of Survey Instruments for Expert Input Focus Group Discussion

5.1.1 Landslide Vulnerability Form

This survey was sponsored and funded by Construction Research Institute of Malaysia (CREAM) and conducted by Geomapping Technology Sdn Bhd. The survey was conducted on 18th October 2018 and 8th November 2018. Vulnerability Form Survey was used and to be assessed by 23 respondents consist of technical expert from local government agencies and non-government agencies. The experts were carefully selected according to their field and background of studies. English terminologies were used in order to have the same understanding regarding the indicator on different critical infrastructure (CI). In this survey forms, only suitable indicators for different types of landslides and CI were used. The respondents were grouped according to critical infrastructure (CI) and each group was facilitate by one expert/facilitator of the field.

The survey forms were divided according to the following sets:

Critical Infrastructure: Building / Residential (BR)
Landslide Type : Rotational / Translational (LA)
: Rockfall (LB)
: Debris Flow (LC)

Critical Infrastructure: Road (RD)
Landslide Type : Rotational / Translational (LA)
: Rockfall (LB)
: Debris Flow (LC)

Critical Infrastructure: Dam (DM)
Landslide Type : Rotational / Translational (LA)
: Rockfall (LB)
: Debris Flow (LC)

Critical Infrastructure: Utilities (UT)

Landslide Type : Rotational / Translational (LA)

: Rockfall (LB)

: Debris Flow (LC)

A total of 23 survey forms were completed. Respondents were instructed to complete the survey form and determine the weightage value for each indicators and sub-indicators depending on the critical infrastructure given. The landslide vulnerability form consists of 4 cluster of indicators i.e. susceptibility of critical infrastructure (C), effect of surrounding environment or mitigation measures (E), susceptibility of people inside the residential building (P) and intensity of landslide hazard (I). The weight value was given differently among the indicators under each cluster based on their level of importance in vulnerability estimation. The weight for each indicator has been assigned based on intensive discussion with the group facilitator.

The indicators that represents the susceptibility of building and residential area consists of structural typology of the building, foundation depth, building categories, function of building and height of building. Each indicator has specific sub-indicators, in which specific weight value (between 0.1 and 1.0) has been assigned to each class. The low the weight value implies low contribution to the increase in total vulnerability value. The higher the weight value will increase the total vulnerability value of the CI. Other indicators representing surrounding environment/mitigation measures, landslide intensity and people inside the building are shown in the Appendix A (Survey Form).

5.1.2 Drone Survey

To assist the process of developing Landslide Vulnerability form, a few geospatial tools have been used mainly for landslide verification and identification stage. These tools include the use of Unmanned Aerial Vehicle (UAV) and handheld GPS. UAV was used to construct orthophoto of the areas while GPS provide accurate geo-referenced location of the landslides.

5.1.2.1 DJI Phantom 4 – UAV Model

The surveyor has been using the model as shown in Figure 5.1 which comes with complete system for aerial survey mapping. This model comes with 12 Megapixel camera resolution, Global Positioning System (GPS), Obstacle Avoidance system, and gyro system. All the specifications for this model are listed in Table 5.1.

Figure 5.1: DJI Phantom 4.

Table 5.1: Technical Specification of the DJI Phantom 4.

TECHNICAL SPECIFICATION	DETAIL
AIRCRAFT	
Weight (Including Battery)	1380g
Max Ascent Speed	6 m/s (Sport Mode)
Max Descent Speed	4 m/s (Sport Mode)
Max Service Ceiling Above Sea Level	19685ft (6000m)

Max Flight Time	Approx. 28 min
Max Speed	20 m/s (Sport Mode)
Operating Temperature Range	32° to 104° F (0° to 40° C)
Satellite Systems	GPS / GLONASS
OBSTACLE SENSING SYSTEM	
Obstacle Sensory Range	2 - 49 feet (0.7 - 15 m)
Operating Environment	Surface with clear pattern and adequate lighting (lux > 15)
CAMERA	
Sensor	1/2.3" Effective pixels:12 Mpixel
Lens	FOV (Field Of View) 94° 20 mm (35 mm format equivalent) f/2.8 focus at ∞
ISO Range	100 - 3200 (video) 100 - 1600 (photo)
Electronic Shutter Speed	8 s to 1/8000 s
Max Image Size	4000×3000
Still Photography Modes	Single shot Burst shooting: 3 / 5 / 7 frames Auto Exposure Bracketing (AEB): 3 / 5 bracketed frames at 0.7 EV Bias Time-lapse HDR
Video Recording Modes	UHD: 4096×2160 (4K) 24 / 25p 3840×2160 (4K) 24 / 25 / 30p 2704×1520 (2.7K) 24 / 25 / 30p FHD: 1920×1080 24 / 25 / 30 / 48 / 50 / 60 / 120p HD: 1280×720 24 / 25 / 30 / 48 / 50 / 60p
Max Video Bitrate	60 Mbps

Supported File Systems	FAT32 (≤ 32 GB); exFAT (> 32 GB)
Photo	JPEG, DNG (RAW)
Video	MP4 / MOV (MPEG – 4 AVC / H.264)
Supported SD Cards	Micro SD, Max capacity: 64GB. Class 10 or UHS-1 rating required
Operating Temperature	32° to 104° F (0° to 40° C)
CHARGER	
Voltage	17.4 V
Rated Power	100 W
GIMBAL	
Controllable Range	Pitch: -90° to +30°
VISION POSITIONING SYSTEM	
Velocity Range	≤10 m/s (2 m above ground)
Altitude Range	0 - 33 feet (0 - 10 m)
Operating Range	0 - 33 feet (0 - 10 m)
Operating Environment	Surfaces with a clear pattern and adequate lighting (lux > 15)
REMOTE CONTROLLER	
Operating Frequency	2.400 GHz to 2.483 GHz
Max Transmission Distance	FCC Compliant: 3.1 mi (5 km);
CE Compliant: 2.2 mi (3.5 km) (Unobstructed, free of interference)	
Operating Temperature	32° to 104° F (0° to 40° C)
Battery	6000 mAh LiPo 2S
Transmitter Power (EIRP)	FCC: 23 dBm; CE: 17 dBm
Operating Voltage	7.4V @ 1.2A
INTELLIGENT FLIGHT BATTERY	
Capacity	5350 mAh
Voltage	15.2 V
Battery Type	LiPo 4S

Energy	81.3 Wh
Net Weight	462 g
Operating Temperature	14° to 104° F (-10° to 40° C)
Max Charging Power	100 W

5.1.2.2 Flying Height and Area Covered

To obtain the optimum UAV altitude, it is depending on the quality of the camera. For 12-megapixel camera, the suggested altitude is around 60 meter to 110 meter, meanwhile for 20-megapixel camera, the suggested area is about 80 meter to 150 meter. Therefore, the optimum UAV altitude for ensuring the accuracy of this survey is about 60 meters to 150 meters. The areas covered by the UAV are Lembah Bertam, Ringlet and Habu with flying height of 150 meters.

5.1.2.3 Orthophoto

Orthophoto is a photograph showing images of objects in their true orthographic position where its view is orthogonal and there is no distortion. It gives advantages of displaying actual cultural and land features besides representing the features as cartographic representation such as symbol and line. Orthophoto is an aerial photograph that has gone through orthorectifying process. Through this process, the tilt and relief displacement has been removed to make the aerial photograph geometrically corrected. (Rabiu & Waziri, 2014) stated that orthophoto is the process of transforming a vertical photograph into the traditional maps. After going through the orthorectifying process, Orthophoto can be used as map for making direct measurements of distance, angle, position, and area without making correction to the image. Figure 5.2 illustrates the orthophoto of the interested area in Ringlet, Cameron Highland.

Figure 5.2: Orthophoto Map by UAV images at Ringlet, Cameron Highland.

5.1.3 Handheld GPS

A handheld GPS is a device that uses the Global Positioning System, combining modern geographic technology with a portable, user-friendly device for everyday use. Introduced in the late 1990s, the handheld GPS has many functions, including navigation assistance and land-survey data. Features on some models may also provide information on geographic locations like national and historic landmarks.

The uses of Handheld GPS are very important at site during landslides verification. The interpretation of landslides morphology (body and scarp) were conducted during desktop study by using all available information and data such as google earth image, IFSAR data, LiDAR data and aerial photograph. Handheld GPS used to locate all observation point which are usually in or near to the landslides body. It's also important to mark and locate all element at risk within the hazard zone such as building, roads, dam and utilities.

Based on fieldwork that was conducted, it is suggested that Handheld GPS of Garmin GPSMAP 62ST (Figure 5.3) used as it is easy to carry and very useful and accurate. It is Waterproof navigator with 2.6 inch, sunlight readable, color display and 160 x 240 pixel resolution, 3 axis tilt compensated electronic compass and barometric altimeter. Suggested coordinate system that is easy and high accuracy that have been used is UTM WGS 47N. It is easy to use this coordinate as it is same with google earth coordinates system. We can insert the observation point that was pickup in GPS to google earth application. From this technique, we can estimate the accuracy of the location we previously visited.

Figure 5.3: Handheld GPSMAP 62ST.

All observation point that were pick up using this GPS can be save in the system and we can check this point later once we need it. Usually, after coordinates of observation have been pick up using GPS, photograph of landslide and element at risk will be taken to see any features of recent landslide movement or any evidence of effects towards element at risk such as cracks and subsidence. Four (4) sided photograph of observation point will help to understand the surrounding terrain and morphology of selective landslide point.

5.2 Focus Group Discussion

5.2.1 Introduction

In this project, qualitative method, focus group discussion (FGD) is used for assessing expert input of landslide vulnerability and determination of risk index for critical infrastructures to assist the Construction Research Institute of Malaysia (CREAM). Combination of remotely sensed data, field data and expert input can provide crucial input for development of method assess and estimate vulnerability index for the critical infrastructure.

On 18th October and 8th November 2018, Geomapping Technology Sdn Bhd undertook a series of focus group discussions (FGDs) with technical agencies of Malaysia on the Landslide Vulnerability Assessment and Development of Risk Index for Critical Infrastructure (CI) in Malaysia.

This report summarizes the key findings of the focus group discussion (FGD) conducted with eleven (11) technical agencies from government and non-government sector who experts on each critical infrastructure (CI). They are appointed based on expertise in a field that is relevant to the critical infrastructure chosen. The discussion revealed an information and facts through primary and secondary data collection as well as identifying perceptions of users, departments and technical agencies through surveys.

5.2.2 Objective

Focus group discussions (FGD) were undertaken to consult the experts to determine the weight for indicators and sub-indicators for each critical infrastructure (1); to review and finalize indicator and sub-indicator for each critical infrastructure (2); and to get expert crucial input for developing method assess and estimate vulnerability index for critical infrastructure (3).

The results of the FGD will be used to determine the vulnerability index for each critical infrastructure of the selected study area i.e. Cameron Highland. Furthermore, the result of this vulnerability index will be used to generate a risk map in Malaysia and to be used as an important guideline for drafting risk index.

5.2.3 Methodology

Focus group discussions (FGDs) were conducted with 23 experts from 11 agencies and departments (stakeholders) to explore their views, including second FGD held in Construction Research Institute of Malaysia (CREAM) on 8th November 2018 that focus on one critical infrastructure only. The discussion was held separately for each critical infrastructure groups; Building, Residential and Road, Dam & Water Treatment and Utility to obtain information of each category's specific needs. The groups are as below (Table 5.2). In addition, specific FGD for dam has been made on 8th November 2018 at Construction Research Institute of Malaysia (CREAM). The results of this specific FGD has been used to improve the previous FGD. Further initiatives have been made to discuss the results of the FGD that involved internal experts from different fields to improve the indicators and the weight values for landslide vulnerability assessment.

The FGD begins with several briefings on the concept of landslide vulnerability and risk assessments. The experts were given a clear step by step instruction to fill out the landslide vulnerability survey forms for each CI and landslide type (Figure 5.4). In the first step, the panel is required to select type of landslide and CI. Based on the selected landslide type and CI, the panels were required to define the related indicators for each cluster i.e. C, E, I and P. In this study the C, E, I and P factors are treated equally strong in landslide vulnerability estimation and each factor carries 25% of the total weight. In the third stage panels are required to determine the score value for each indicator scales from 1 to 10. Indicator with score close to 1 has less important level in the landslide vulnerability compared to indicator score close to 10 which is more important in the vulnerability assessment. In this study, the score value for each indicator will be converted to the weight value based on the Equation 4.

$$W_i = \left(\frac{S_i}{\sum_{i=1}^{n} S_i}\right) \tag{4}$$

Where W is the weight of the *i*th indicator, *S* is the score of the *i*th indicator, and *n* is the total indicator in a specific cluster (C, E, I and P). The next step requires the panels to define the sub-indicators for each indicator. In the form we have listed several indicators and relevant sub-indicators for each landslide type and CI based on the intensive literature review and internal discussion with the experts. For each sub-indicators the panels are also required to define the score value from 1 to 10. Score value close to 1 indicates lower contribution towards the vulnerability of CI and score value close to 10 indicates higher contribution of sub-indicator towards the vulnerability. The score value will be converted to the weight scale from 0.1 to 1.0 using Equation 5.

$$W_j = S_j * 0.1 \tag{5}$$

The final estimated vulnerability value for each CI and type of landslide will be classified into several classes. In this study, we have proposed the vulnerability class for each CI as listed in Table 4.20. The panel is required to revise the proposed classes and add any suggestion for improvement.

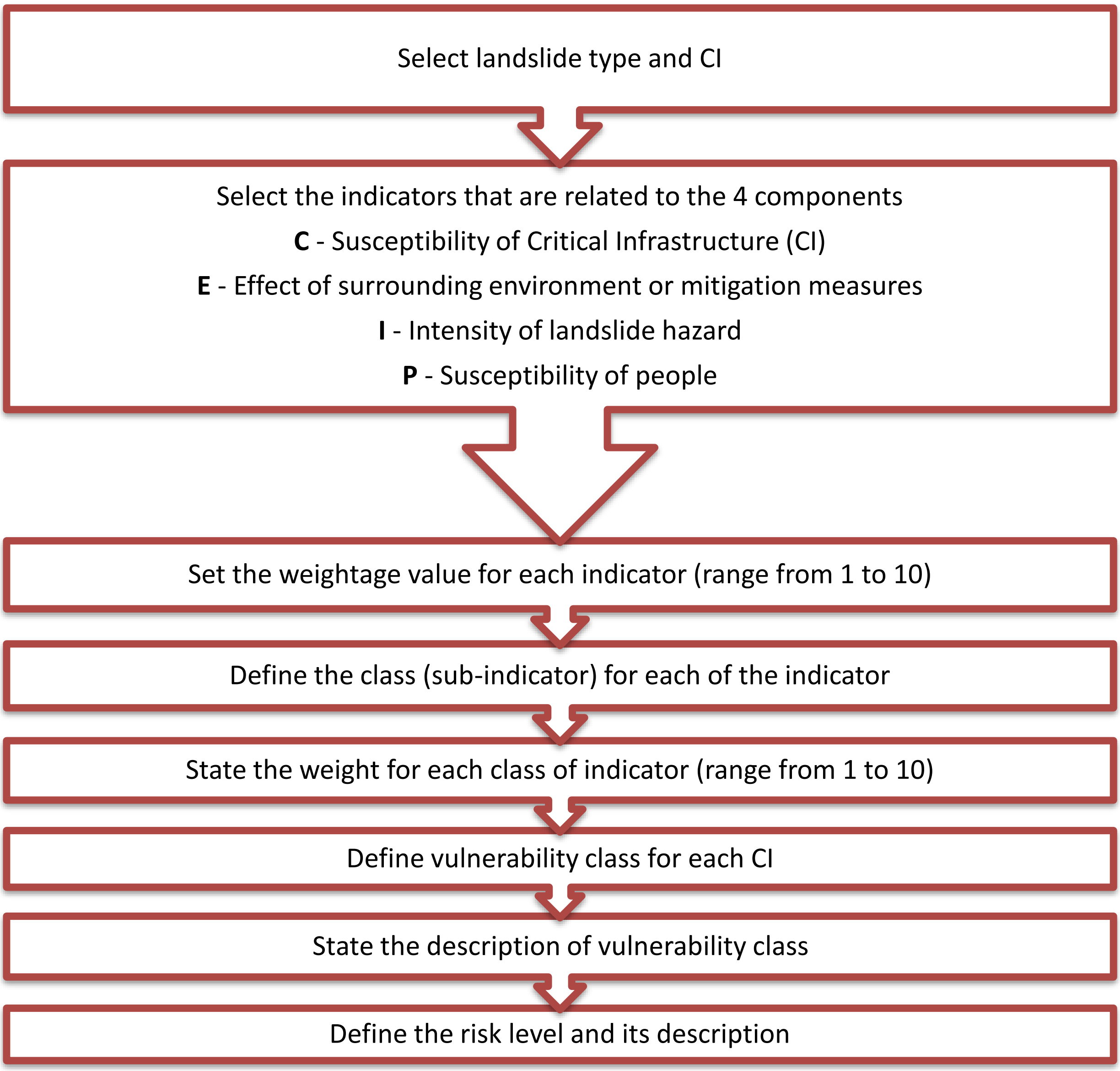

Figure 5.4: Step by step instruction to fill out the landslide vulnerability survey forms for each CI and landslide type.

Table 5.2: Focus Group Discussion groups.

GROUP 1 Building, Residential & Road Aspect	**GROUP 2** Dam & Water Treatment Aspect	**GROUP 3** Utility: Powerline & Telecommunication Aspect
FACILITATOR Prof. Datin. Ir. Dr Zainab Mohamed Dr. Muhammad Zulkarnain Abdul Rahman	**FACILITATOR** Dato' Ir Rozlan ahmad Zainuddin Dr Mohd Faisal Abdul Khanan	**FACILITATOR** Prof.Madya Dr Tajul Anuar Jamaluddin Dr Rodeano Roslee
GROUP MEMBERS Department/Agency : • Majlis Perbandaran Ampang Jaya • JKR Caw.Jalan Malaysia • Jab. Kej. Awam & Pengangkutan Awam • Cawangan Jalan • Jab. Kaw. Bangunan DBKL	**GROUP MEMBERS** Department/Agency : • JPS [Rekabentuk & Empangan] • Pengurusan Aset Air Berhad • Lembaga Urus Air Selangor • JBA Kementerian Air • Uniten	**GROUP MEMBERS** Department/Agency : • Uniten • TNB Research Sdn Bhd

Figure 5.5: Focus Group Discussion (FGD) Session at Puri Pujangga Hotel, UKM.

5.2.4 Key Findings

The main findings data generated by the focus group discussions are summarized in the table 5.3 to table 5.6 below;

Table 5.3: The results of FGD on Building and Residential aspect according to expert judgements.

Building & Residential Aspect	
a) Critical Infrastructure (Building & Residential) i. Propose the depth of shallow foundation that less or equal to 3 under various landslide depth of 1.5 - 10 meter. ii. Assign the constant depth of deep foundation to be more than the depth of shallow foundation (3m) but under various landslide depth. iii. Certified and uncertified building status influence the vulnerability index. iv. The location of the extended building may located close to the slope structure. (which may not get approval from the authorities). v. Replace the Building Structure parameter with Function of Building.	iii. The distance of building between each other can influence the vulnerability index. (Must follow the regulation of spacing of building especially in residential area.) iv. The location of the building structure within the vicinity of the slope structure. v. The locations of the building structure at the crest and mid-height of the slope tend to induced higher driving forces for landslide occurrence. c) Landslide Intensity i. 'Deposit' thickness. (correct use of word) to replace landslide thickness. ii. Change of low value of deposit thickness from 500mm to 1500 mm. (unreasonable value of thickness for low indicator)

vi. Different function of building tends to has different vulnerability index. vii. Certain building like factory which may runs 24 working hours may develops high vulnerability index compare to other types of buildings such as schools and office. viii. DBKL stated that new regulation which indicated that 3-storey house is considered low rise house. b) Surrounding Environment i. Engineered and non-engineered terms are used. ii. Presence of water channel must be considered especially beneath the slope body may causes landslide.	iii. Increase the run-out distance by adding maximum value of 120m. d) People Inside Building i. Replace warning system parameter with evacuation alarm system which more logical for building structure. ii. The sub-parameters for *Age of People* are based on National Registration Department. iii. Range of age influences the vulnerability index. iv. Addition of day during weekend or weekday influences the vulnerability index as different time phase related to different number of personnel.

Table 5.4: The results of FGD on Road aspect according to expert judgements.

<table>
<tr><th colspan="2">Road Aspect</th></tr>
<tr><td>a) Critical Infrastructure (Road)
i. The location of the road structure at the crest and slope body tends to develop high implication of landslide (successive landslide).
ii. State the location of the road structure within the vicinity of the slope structure.
iii. Add unpaved road parameter.

b) Surrounding Environment
i. Parameter of surrounding vegetation is replaced by road drainage system as this structure plays vital role in controlling the flow of the water.
ii. State the condition of the protection only.</td><td>c) Landslide Intensity
i. Landslide Thickness/Depth (Body of Landslide) parameter is replaced by deposit thickness.
ii. Only measure the after-occurrence of landslide.
iii. Reduce the landslide area sub-indicators into three different classes.
iv. Only assign for different velocities of landslide; very slow, slow, moderate and rapid.

d) Road User
i. Traffic volume sub-indicators approved by JKR Road Department.</td></tr>
</table>

Table 5.5: The results of FGD on Dam and Water Treatment aspect according to expert judgements.

Dam & Water Treatment Aspect	
a) Critical Infrastructure i. Size of basin/catchment, reservoir, main structure is added in order to calculate the accumulation and runout distance of the landslide. • Big basin/catchment give high vulnerability (natural slope) • Reservoir (cm^3) with smaller size is more vulnerable. • Slope angle and slope height beneath the reservoir is also important. Eventhough the reservoir is small. Example, Viont Dam (Small reservoir, Slope height) that gave catastrophic. ii. Dam typology is divided to five types (Water Supply, Power Generation, Flood Mitigation and Sedimentation /Recreational) • If landslide happen which functionality is badly affected.	iii. Foundation Depth and Dam Height are not applicable as parameter because of no direct impact from the landslide. iv. Proposed new parameters of dam construction materials such as Earthfill, Rockfill, Composite and Concrete. b) Surrounding Environment i. Moderately man-made protection system is not applicable in the presence of protection parameter. c) Landslide Intensity i. Landslide velocity parameter is following Cruden Varnes (1996) ii. Impact on dam operation occurs if there is a slope failure on a large scale. d) Population Living Downstream Area i. Population Density parameter is given by JPS based on their standard guidelines.

Table 5.6: The results of FGD on Utility; TNB Powerline aspect according to expert judgements.

Utility: TNB Powerline	
a) Critical Infrastructure i. Parameters in utility aspect is given by TNB based on their own vulnerability formula in tree-branch format. ii. Tower location generally based on slope (Top, Face, Toe) iii. Typology of Utilities is given by grid. • Grid 500 KV • Grid 275 KV • Grid 132 KV • Grid 33 KV • PMU • TELCO tower b) Surrounding Environment i. The vulnerability of utilities tower is based on the environment and location of tower (toe,face,top) itself. ii. Slope Morphology (Shape) • Concave • Convex • Straight	c) Landslide Intensity i. Accumulation height run out distance and landslide thickness weightage highly dependent on tower location and slope morphology. ii. Landslide type is hard to be weight as tower usually seated at variable slope morpohology. d) User of Utilities i. Area of high population density is more vulnerable when landslide happen.

5.2.5 Recommendation of FGDs

The Focus Group Discussions identified important key challenges and best practices in implementing the landslide vulnerability and determination of risk index for critical infrastructures, as well as recommended ways to improve implementation going forward. The recommendations as below;

i. Guideline should be accompanied by a dictionary definition of the terms used in the writing.

ii. Guidelines must come out with figure explanation for user to have a better understanding.

iii. Other Focus Group Discussion needs to be held to ensure that all the weightage given is relevant.

5.2.6 Focus Group Discussion with Internal Experts

FGD with internal experts aims at improving the indicators and their corresponding weight values based on the literature reviews and input from the FGD by the stakeholders. The FGD involved 8 different experts with vast experience with the background of construction, landslide hazard, geospatial technology, geologist and etc. In the previous FGD with the stakeholders, the weight value for each indicator cluster (*C*, *E*, *I* and *P*) is treated equally strong with 0.25 for each cluster. For the internal experts FGD the indicator cluster is treated differently which is based on the assumption the target vulnerability assessment aims at supporting CREAM in determining the risk of physical CI towards landslide hazard. In this case, the susceptibility of CI (*C*) is given the highest priority, followed by the intensity of the landslide (*I*), the effect of surrounding environment (*E*) and the impact on people (*P*).

6.0 ANALYSIS OF LANDSLIDE VULNERABILITY INDICATORS AND WEIGHTS FROM EXPERTS (FGD)

The landslide vulnerability cluster, indicators (*C*, *E*, *I* and *P*) and its specific sub-indicators (or classes) should be assigned with suitable weight values. In this study, the weight is obtained based on the expert input. Before the weight value is assigned for each cluster, indicator and sub-indicator the weight values obtained from series of FGD will be analysed as follows:

1. The consistency of weight given by the experts for each cluster, indicators and indicators. The analysis is done for the first FGD with different stakeholders. In the FGD the discussion was only covered on the vulnerability of rotational and translation landslides.
2. Sensitivity analysis on each cluster and indicators for FGD with stakeholders and internal experts.
3. Simulation for best, medium and worst-case scenario of landslide vulnerability for each CI. The simulation is done for FGD with stakeholders and internal experts. In this report we only consider the impact of rotational/translational landslides on buildings/residential area.
4. Generation of the final landslide vulnerability cluster, indicators, sub-indicators and weight values for different types of landslides and CI. The final set of this information is obtained from the results of intensive discussion with the internal experts.

The final weight values obtained from the experts will be combined either using simple averaging or based on the weighted averaged approach. The first approach relies on the fact that the obtained weight values are consistent among the experts and the final weight can be calculated by a simple averaging process. On the other hand, if the weight values are not consistent, the final weight should be calculated based on weighted average approach. The approach gives higher weight to the more reliable experts based on their experiences and knowledge on landslide hazard and its associate damage to different CI. In this study, the consistency level of weight values is determined based on the standard deviation value. Each weight value given for each indicator and its corresponding class will be analysed and the standard deviation value exceeding 0.05 will be marked as inconstant.

The aim of the sensitivity analysis is to determine the sensitivity of each cluster, indicators and sub-indicators towards the final value of landslide vulnerability for each CI. The sensitivity analysis is carried out based on *one-at-a-time* (OAT) method by varying the value of a specific indicators and sub-indicators (*V*) while the rest of sub-indicators remains unchanged (Equation 5). The Sen_{Ind} defines the sensitivity of estimated vulnerability value with the weight changes of sub-indicators (Equation 6). Sen_{Ind} is estimated by the standard deviation of the estimated vulnerability value produced by the simulation (*a*). Higher Sen_{Ind} value indicates more sensitive indicator compared to indicator with lower index value. The sensitivity index for the cluster (Sen_{Clus}) determines the sensitivity of the estimated value with the changes of weight in the indicators (Equation 7). Sen_{Clus} is estimated by the average of the Sen_{Ind} for indicators that belong to a specific cluster. Higher Sen_{Clus} value indicates more sensitive cluster compared to other cluster with lower index value.

$$V = \{a_1, a_2, a_3, a_4 \ldots . a_n\} \tag{5}$$

where *V* is the set of specific vulnerability value (*a*) estimated for each indicator by varying the indicators and sub-indicator values and *n* is the number of possible vulnerability scenarios or simulations.

$$Sen_{Ind} = \sqrt{\frac{\sum_{i=1}^{n}(a_i - mean(a))^2}{n}} \tag{6}$$

$$Sen_{Clus} = \frac{\sum_{i=1}^{m} Sen_{Ind_i}}{m} \tag{7}$$

where m is the number of indicators for each cluster.

The final weight for each indicator and its sub-indicator will be used to estimate the landslide vulnerability for each CI based on three different landslide scenarios. The first scenario takes into account the best case, in which very low landslide vulnerability value is expected. The second scenario focuses on simulating landslide vulnerability based on the intermediate landslide vulnerability case, in which medium value of landslide vulnerability is expected. Finally, the highest vulnerability value is expected for the worst-case scenario of landslide vulnerability. In the first and second FGD sessions the discussions were only focussed on the rotational and translational landslides. Thorough discussion during the FGD session allowed substantial improvement and modifications of the proposed indicator, sub-indicator as well as their corresponding weight values.

The final set of clusters, indicators, sub-indicators and their weights is generated based on the output of the FDG with the internal experts. This data will be tested in Cameron Highlands with supports from various remotely sensed data, field data and other ancillary geospatial data.

6.1 Consistency Analysis of Landslide Vulnerability Indicators and Weight for Building and Residential

Table 6.1 and Figure 6.1 shows the standard deviation value for weight assigned to each indicator for building and residential respectively.

Table 6.1: Standard deviation value of the weight assigned to the indicators

COMPONENT	INDICATOR	STANDARD DEVIATION
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	STRUCTURAL TYPOLOGY / STRUCTURE CONSTRUCTION MATERIALS	0.01
	BUILDING FOUNDATION DEPTH	0.00
	BUILDING CATEGORIES	0.01
	FUNCTION OF BUILDING	0.00
	NUMBER OF FLOOR	0.00
SURROUNDING ENVIRONMENT [E]	PRESENCE OF PROTECTION	0.01
	PRESENCE OF WATER CHANNEL	0.02
	BUILDING ORIENTATION FROM THE RIVER	0.01
	DISTANCE BETWEEN BUILDING	0.01
	BUILDING LOCATION	0.01
LANDSLIDE INTENSITY [I]	ACCUMULATION HEIGHTS	0.05
	DEPOSIT THICKNESS	0.03
	LANDSLIDE VOLUME	0.02
PEOPLE INSIDE BUILDING [P]	POPULATION DENSITY	0.01
	EVACUATION OF ALARM SYSTEM	0.00
	AGE OF PEOPLE	0.00
	HEALTH CONDITION	0.01
	TIMES OF DAY	0.01
	DAY	0.01

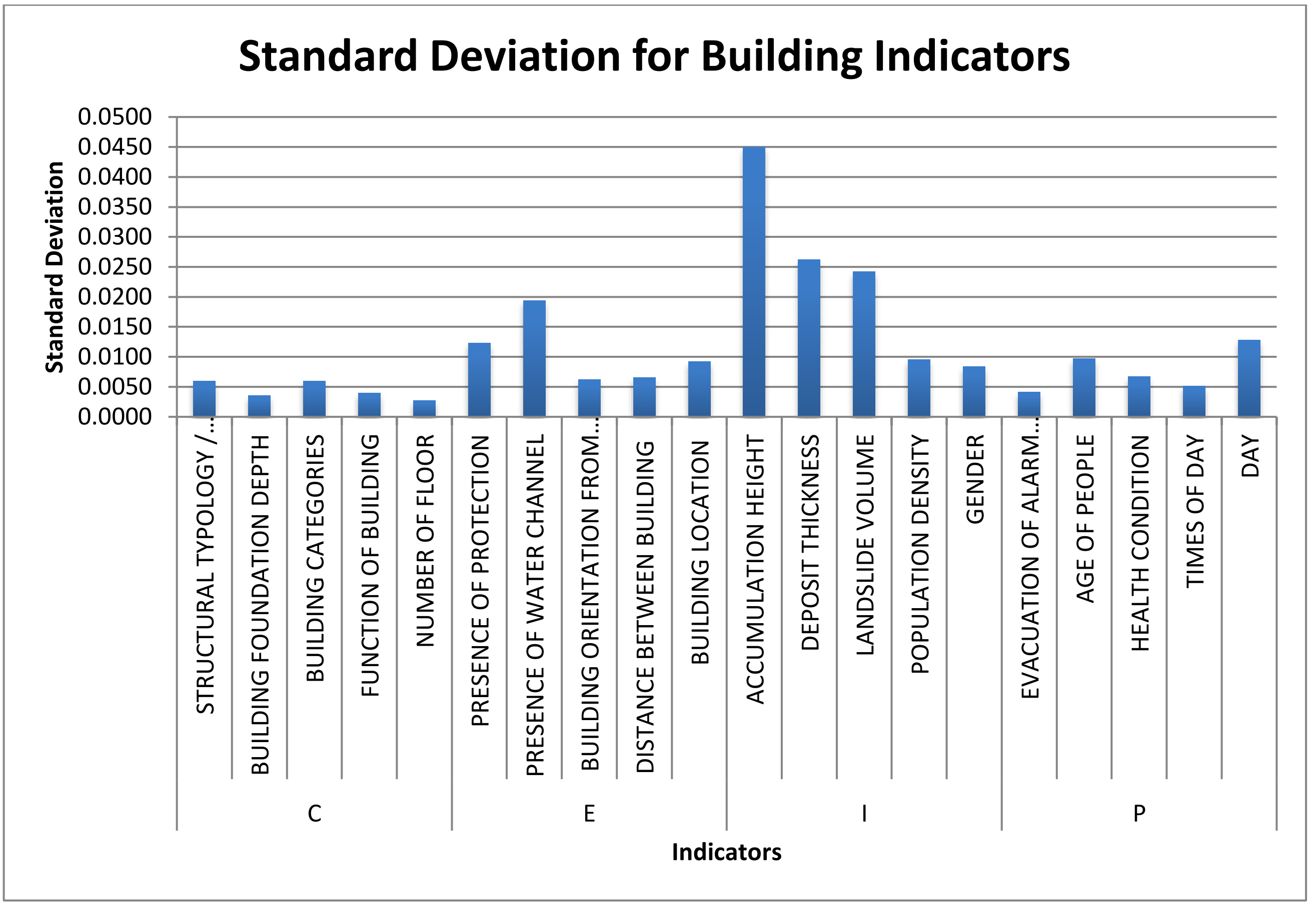

Figure 6.1: Standard deviation value of the weight assigned to the indicators.

Table 6.2: Percentage of standard deviation values exceeding 0.05 thresholds for the indicators (Building).

INDICATOR
Percentage of standard deviation (>0.05)
0.00 % (low variation)

Table 6.2, Figure 6.2 to Figure 6.5 show the standard deviation value for weight value assigned to each sub-indicator for building and residential.

Table 6.3: Standard deviation value of the weight assigned to the sub-indicators.

COMPONENT	INDICATOR	SUB-INDICATOR	STANDARD DEVIATION
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	STRUCTURAL TYPOLOGY / STRUCTURE CONSTRUCTION MATERIALS	Light weight	0.26
		Semi light weight	0.21
		Timber Structure	0.13
		Masonry structure	0.13
		Reinforced concrete structure	0.18
		IBS structures	0.23
		Steel structure	0.26
	BUILDING FOUNDATION DEPTH (LANDSLIDE TYPE VS SHALLOW FOUNDATION BUILDING)	For landslide depth <1.5 meter, depth of building foundation ≤3 meter	0.27
		For landslide depth 1.5 - 5 meter, depth of building foundation ≤3 meter	0.11
		For landslide depth 5 - 10 meter, depth of building foundation ≤3 meter	0.15
		For landslide depth > 10 meter, depth of building foundation ≤3 meter	0.24
	BUILDING FOUNDATION DEPTH (LANDSLIDE	For landslide depth <1.5 meter, depth of building foundation >3 meter	0.24

	TYPE VS DEEP FOUNDATION BUILDING)	For landslide depth 1.5 - 5 meter, depth of building foundation >3 meter	0.19
		For landslide depth 5 - 10 meter, depth of building foundation >3 meter	0.17
		For landslide depth 10 - 20 meter, depth of building foundation >3 meter	0.29
		For landslide depth >20 meter, depth of building foundation >3 meter	0.37
	BUILDING CATEGORIES	Original building	0.22
		Original building with certified extension	0.24
		Original building with non certified extension	0.22
	FUNCTION OF BUILDING	Commercial building (factory)	0.13
		Commercial building (malls)	0.09
		Commercial building (office)	0.09
		Hospitals	0.19
		Schools	0.15
		Residential	0.09
	NUMBER OF FLOOR	Low rise (<3 storey)	0.19
		Medium rise (4 to 5 storey)	0.05

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		High rise (>6 storey)	0.15
SURROUNDING ENVIRONMENT [E]	PRESENCE OF PROTECTION	Engineered protection system	0.21
		Non- engineered protection system	0.13
		Natural /vegetation protection	0.22
		No protection	0.27
	PRESENCE OF WATER CHANNEL	Exist	0.17
		Non-Exist	0.13
	BUILDING ORIENTATION FROM THE RIVER	First row from the river	0.14
		Second row from the river	0.15
		Third row and above from the river	0.08
	DISTANCE BETWEEN BUILDING	<3 meter	0.19
		3- 5 meter	0.15
		>5 meter	0.18
	BUILDING LOCATION	Building is located at a distance more than height of slope	0.24
		Building is located at a distance within height of slope	0.16
		Building is located at the toe of slope	0.13
		Building is located at the crest of slope	0.00
		Building is located at the mid-height of slope	0.06
		Height <0.5 meter	0.10

LANDSLIDE INTENSITY [I]	ACCUMULATION HEIGHTS	0.5 meter < height < 2 meter	0.05
		Height > 2 meter	0.08
	DEPOSIT THICKNESS	< 1.5 meter	0.09
		1.5 meter - 5 meter	0.08
		5 meter - 20 meter	0.05
		>20 meter	0.05
	LANDSLIDE VOLUME	Very Small, <0.001 - 0.5 meter3	0.09
		Very Small , <500 meter3	0.07
		Small, 500 - 10, 000 meter3	0.09
		Medium, 10,000 - 50,000 meter3	0.13
		Large, >500,000 meter3	0.09
		Very Large, >>500,000 meter3	0.06
PEOPLE INSIDE BUILDING [P]	POPULATION DENSITY	Low rise (<3 storey)	0.06
		Medium	0.05
		High	0.09
	EVACUATION OF ALARM SYSTEM	Yes	0.11
		No	0.19
	AGE OF PEOPLE	Children	0.15
		Teenagers	0.16
		Adults	0.20
		Senior Citizen (Tua-muda - 65-74 tahun)	0.07
		Senior Citizen (Tua-tua – 75-84 tahun)	0.09

		Senior Citizen (Paling tua-tua - >85 tahun)	0.11
	HEALTH CONDITION	Health (Good)	0.22
		Health (Poor)	0.16
		Disabled person	0.10
	TIMES OF DAY	Peak hour	0.05
		Non- peak hour	0.22
	DAY	Weekend/ Public holiday	0.19
		Weekdays	0.07

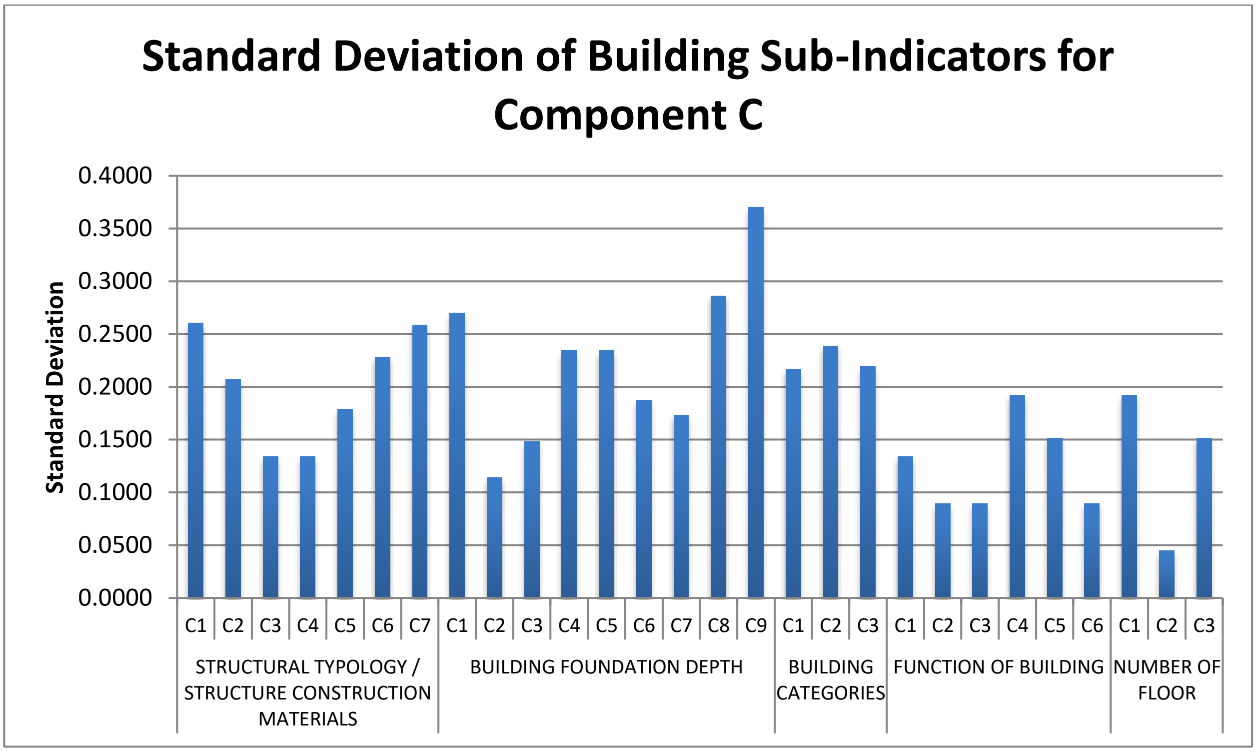


Figure 6.2: Standard deviation value of the weight assigned to the sub-indicators in component C (i.e. susceptibility of CI).

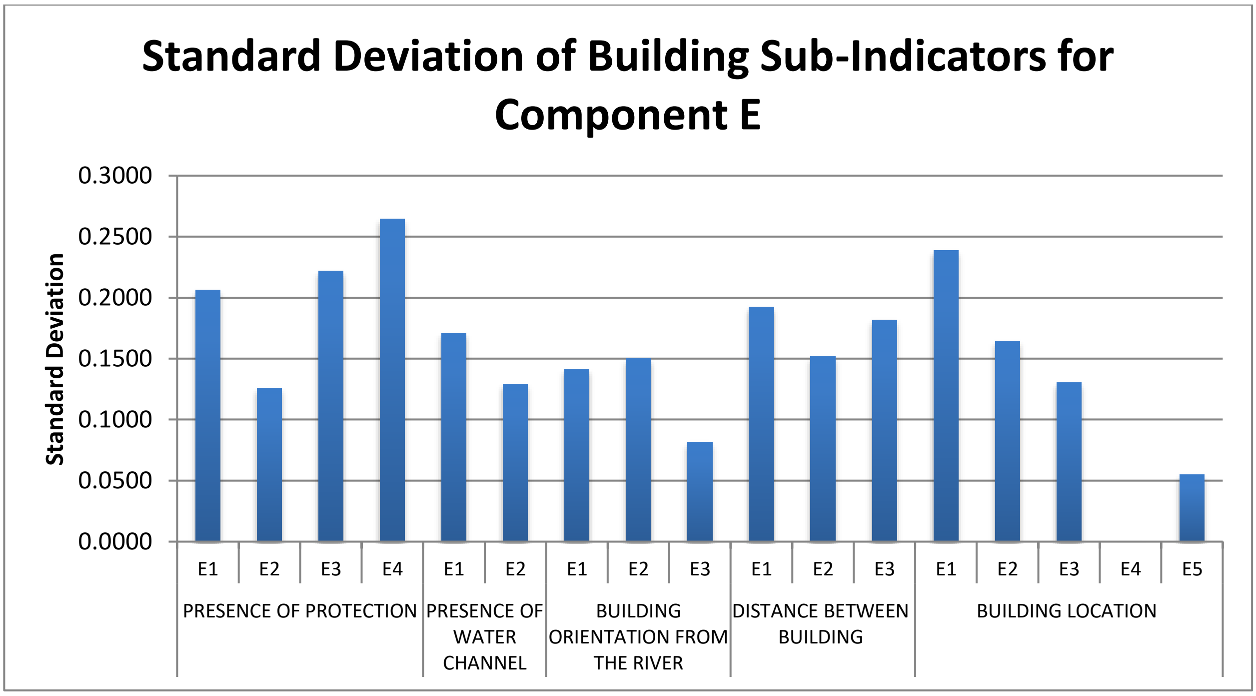


Figure 6.3: Standard deviation value of the weight assigned to the sub-indicators in component E (i.e. surrounding environment).

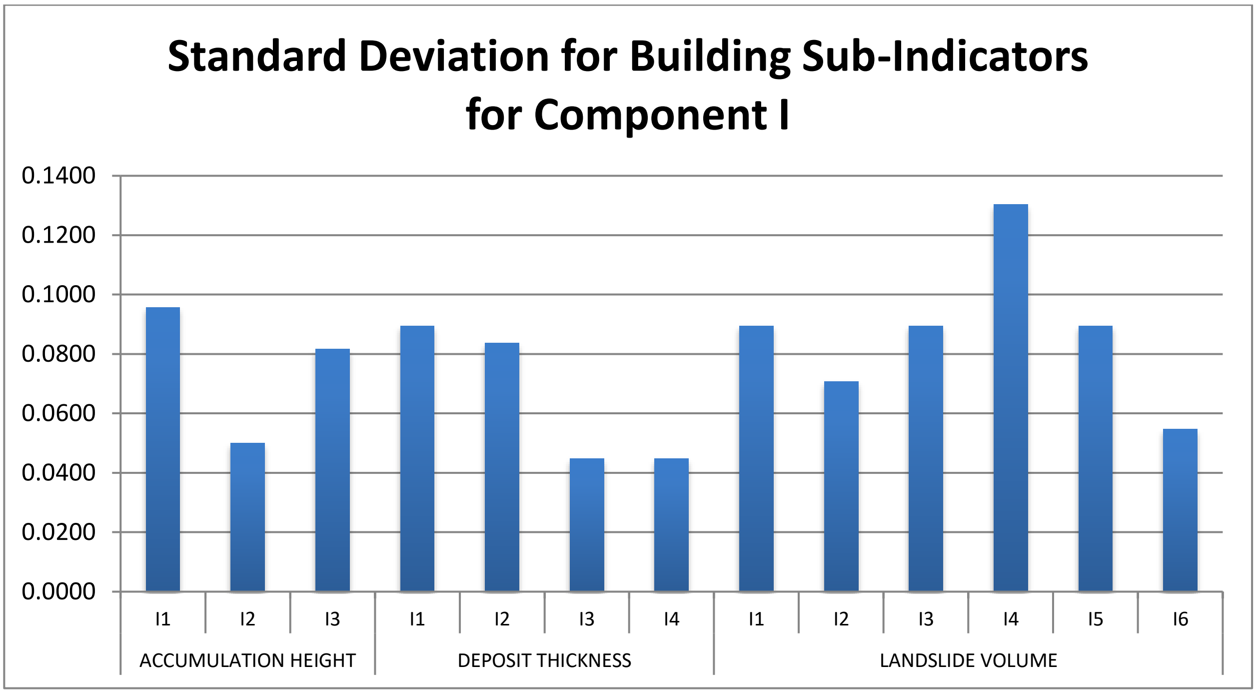


Figure 6.4: Standard deviation value of the weight assigned to the sub-indicators in component I (i.e. intensity of landslide).

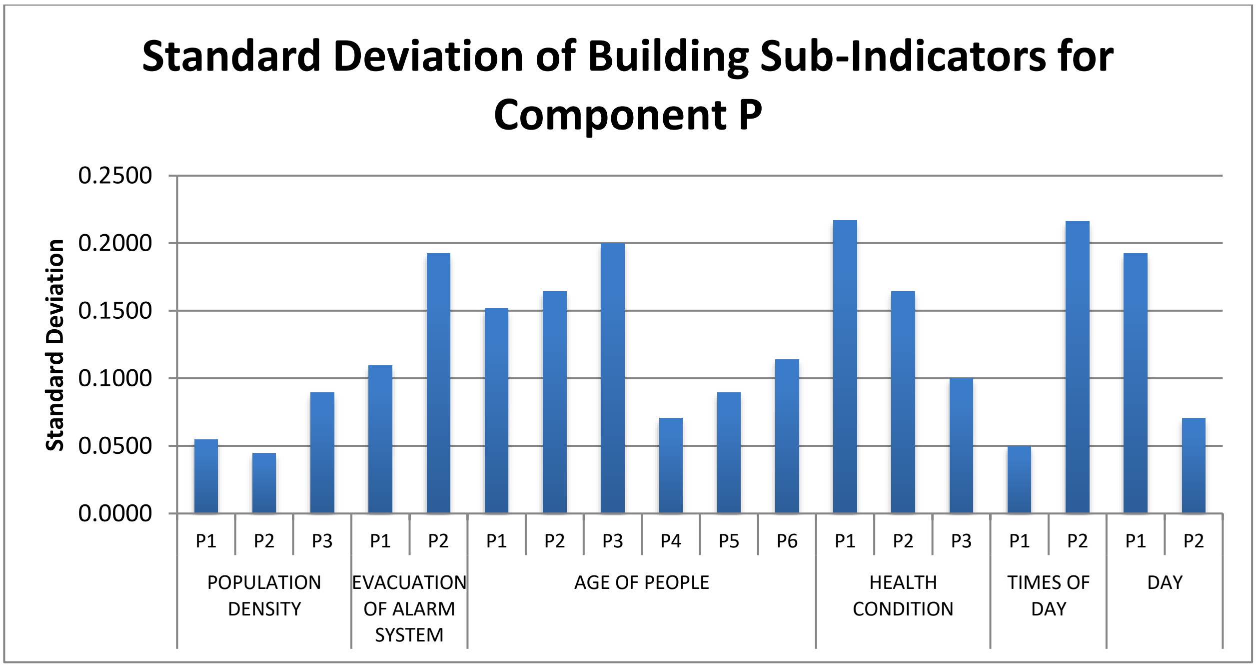


Figure 6.5: Standard deviation value of the weight assigned to the sub-indicators in component P (i.e. people inside the building).

Table 6.4: Percentage of standard deviation values exceeding 0.05 threshold for the sub-indicators (Building).

SUB-INDICATOR
Percentage of standard deviation (>0.05)
90.79 % (high variation)

The results show that the assigned weight values for indicators are consistent with the standard deviation less or equal to 0.05. However, large deviation (more than 90%) was observed for weight values assigned to the sub-indicators. The final weight values for the indicators can be calculated based on a simple average operation. However, the final weight value for the sub-indicators should be calculated based on the weighted average approach. Higher weight should be assigned to more reliable panels based on their working experience and knowledge on the vulnerability assessment. The calculation of the weight based on weighted average approach will be done later and in this report the final weight value for building and residential is calculated based on a simple averaging approach. **Appendix B** shows the final indicators, sub-indicators and their corresponding weights for building and residential.

6.2 Consistency Analysis of Landslide Vulnerability Indicators and Weight for Road

Table 6.5 shows the standard deviation value for weight value assigned to each indicator for road.

Table 6.5: Standard deviation value of the weight assigned to the indicators.

COMPONENT	INDICATOR	STANDARD DEVIATION
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	ROAD CATEGORY (JKR STANDARD DESIGN)	0.02
	LOCATION OF ROAD	0.02
	ROAD MATERIAL	0.01
	ROAD MAINTENANCE	0.03
SURROUNDING ENVIRONMENT [E]	PRESENCE OF PROTECTION	0.02
	PRESENCE OF WARNING SYSTEM	0.02
	ROAD DRAINAGE SYSTEM	0.04
LANDSLIDE INTENSITY [I]	ACCUMULATION HEIGHTS	0.04
	DEPOSIT THICKNESS	0.02
	LANDSLIDE VOLUME	0.02
PEOPLE INSIDE BUILDING [P]	TRAFFIC VOLUME	0.00

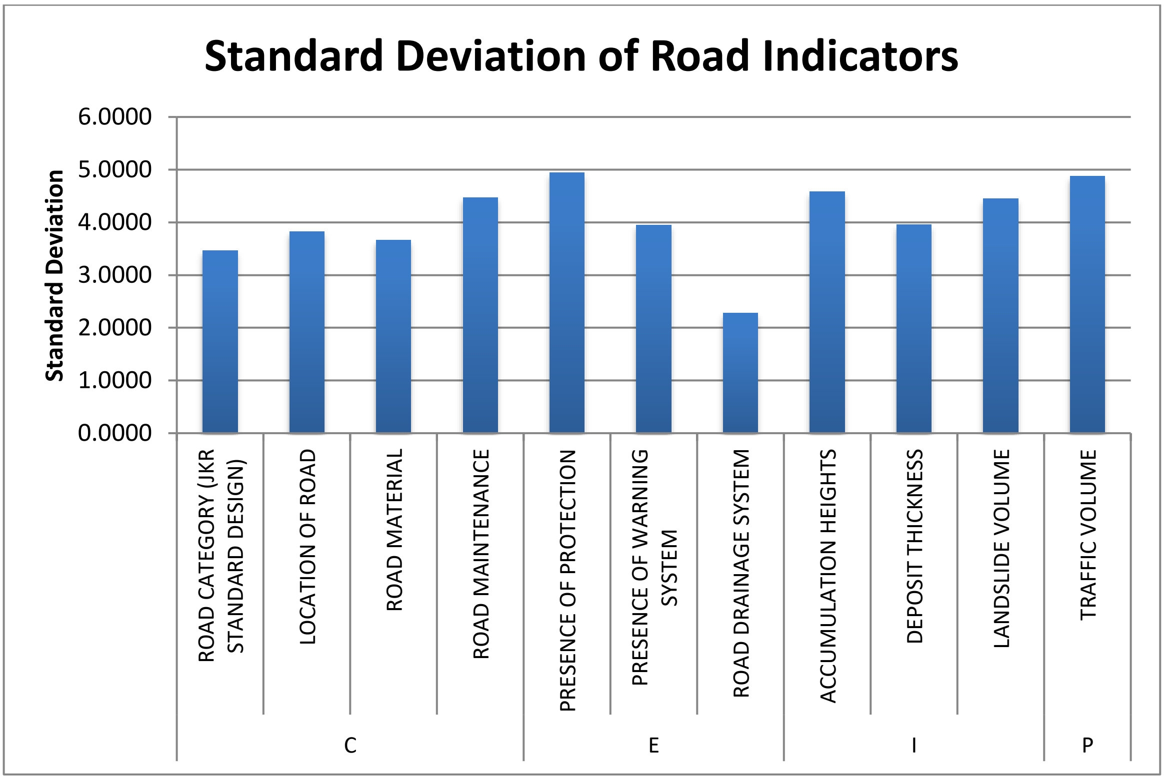


Figure 6.6: Standard deviation value of the weight assigned to the indicators.

Table 6.6: Percentage of standard deviation values exceeding 0.05 threshold for the indicators (Road).

INDICATOR
Percentage of standard deviation (>0.05 – low variation)
0.00 %

Table 6.7 shows the standard deviation value for weight value assigned to each sub-indicator for road.

Table 6.7: Standard deviation value of the weight assigned to the sub-indicators.

COMPONENT	INDICATOR	SUB-INDICATOR	STANDARD DEVIATION
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	ROAD CATEGORY (JKR STANDARD DESIGN)	R1 / R1a / R2 (minor rural road)	0.14
		R3 / R4 (secondary rural road)	0.15
		R4 / R5 (primary rural road)	0.08
		R5 (highway)	0.08
		R6 (Expressway)	0.11
		U1 / U1a / U2 / U3 (urban local street)	0.15
		U3 / U4 (urban collector road)	0.15
		U4 / U5 (urban arterial road)	0.12
		U6 (urban expressway)	0.11
	LOCATION OF ROAD	Road is located at a distance more than height of slope	0.28
		Road is located at a distance within height of slope	0.20
		Road is located at the toe of slope	0.15
		Road is located at the crest of slope	0.09
		Road is located at the mid-height of slope	0.09

	ROAD MATERIAL	Flexible Pavement / Bituminous Road	0.14
		Rigid Pavement / Concrete Road	0.16
		Unpaved Road	0.19
	ROAD MAINTENANCE	Yes	0.21
		No	0.24
SURROUNDING ENVIRONMENT [E]	PRESENCE OF PROTECTION	Engineered protection system	0.11
		Non- engineered protection system	0.11
		Natural / vegetation protection	0.15
		No protection	0.08
	PRESENCE OF WARNING SYSTEM	Yes	0.15
		No	0.10
	ROAD DRAINAGE SYSTEM	Yes	0.27
		No	0.29
LANDSLIDE INTENSITY [I]	ACCUMULATION HEIGHTS	Height <0.5 meter	0.10
		0.5 meter < height < 2 meter	0.05
		Height > 2 meter	0.08
	DEPOSIT THICKNESS	1.5 meter	0.10
		1.5 meter – 5 meter	0.09
		5 meter - 20 meter	0.05
		>20 meter	0.00
	LANDSLIDE VOLUME	Very Small, 0.001-0.5 meter3	0.15
		Very Small, <500 meter3	0.11

		Small, 500 - 10,000 meter3	0.11
		Medium, 10,000 - 50,000 meter3	0.071
		Large, >500,000 meter3	0.09
		Very Large, >>500,000 meter3	0.06
PEOPLE INSIDE BUILDING [P]	TRAFFIC VOLUME	(R2 / R1 / R1a / U2 / U1/ U1a (less than 1000 ADT))	0.11
		(R3 / U3 – 3000 to 1000 ADT)	0.11
		(R4 / U4 – 10,000 to 3000 ADT)	0.11
		(R5 / U5 – more than 10,000 ADT)	0.11
		(R6 / R5/ U6 – all traffic volume)	0.08

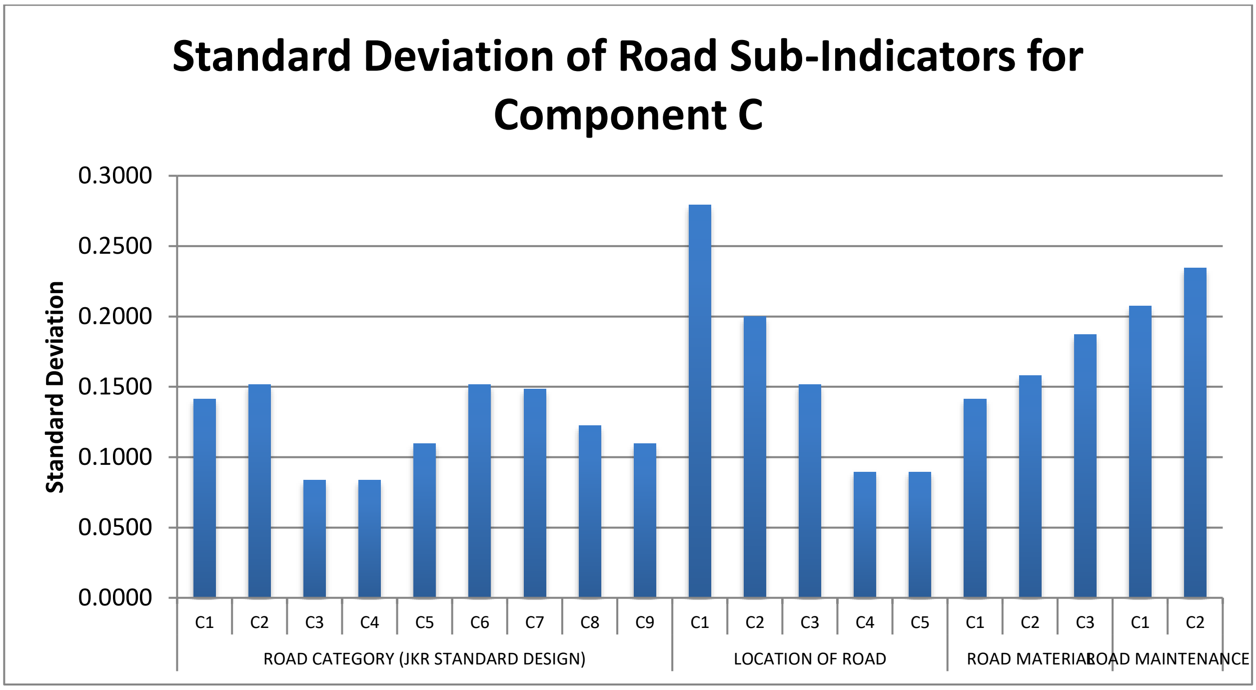


Figure 6.7: Standard deviation value of the weight assigned to the sub-indicators in component C (i.e. susceptibility of CI).

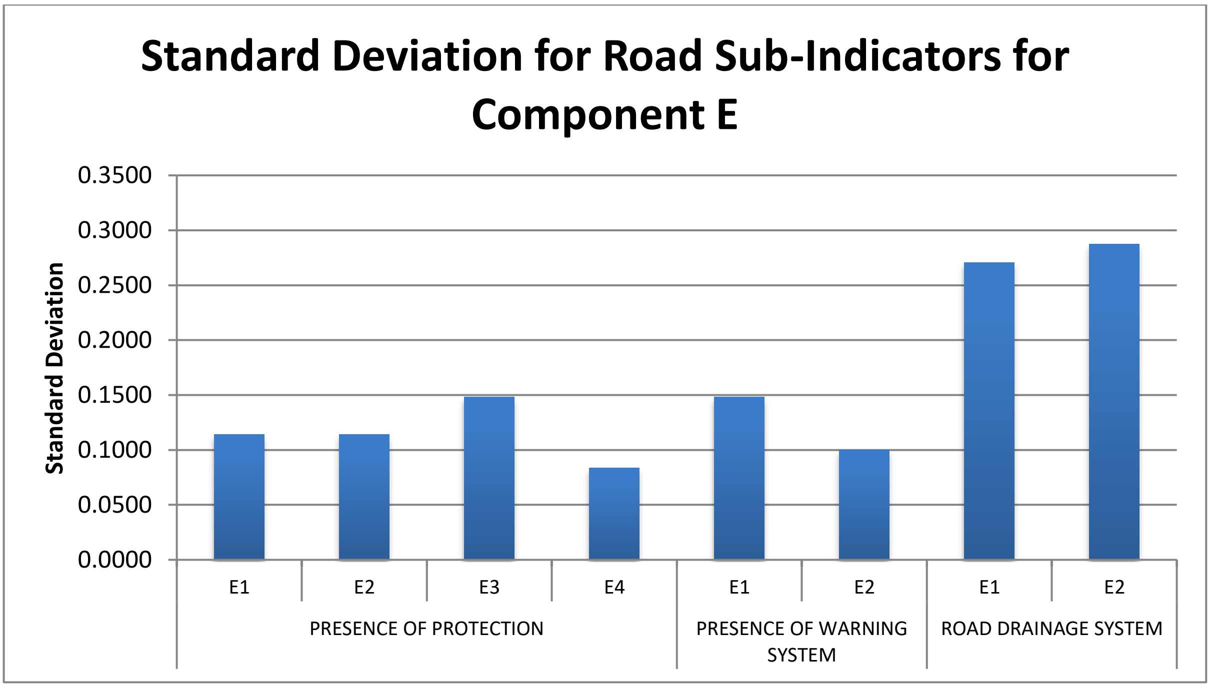


Figure 6.8: Standard deviation value of the weight assigned to the sub-indicators in component E (i.e. surrounding environment).

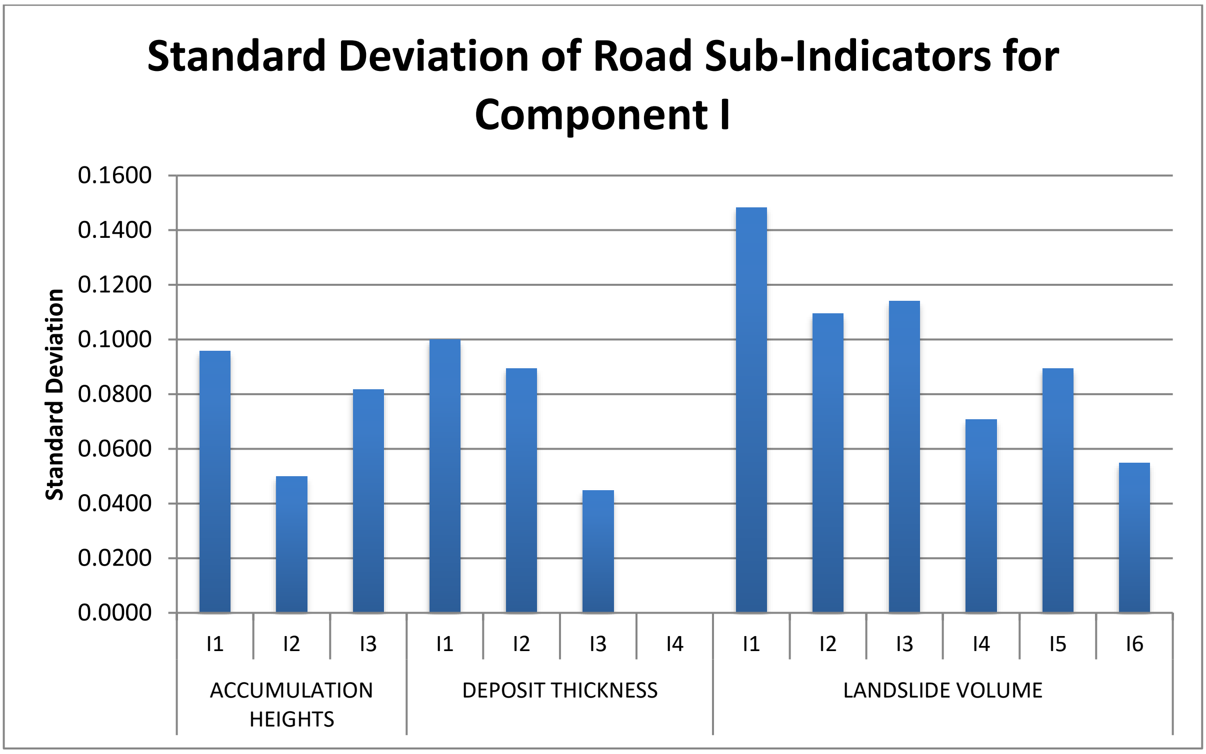


Figure 6.9: Standard deviation value of the weight assigned to the sub-indicators in component I (i.e. Landslide intensity).

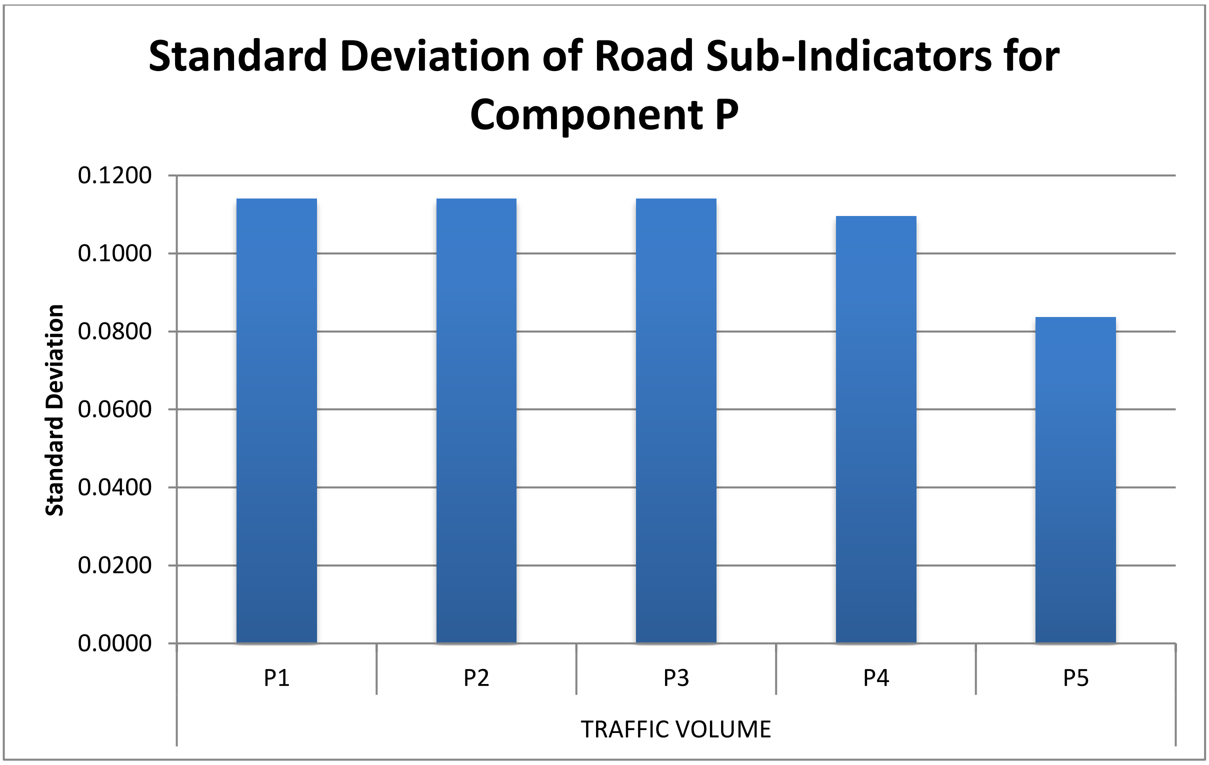


Figure 6.10: Standard deviation value of the weight assigned to the sub-indicators in component P (i.e. People use the road).

Table 6.8: Percentage of standard deviation values exceeding 0.05 threshold for the sub-indicators (Road).

SUB-INDICATOR
Percentage of standard deviation (>0.05 – high variation)
93.33 %

The results show that the assigned weight values for indicators are consistent with the standard deviation less or equal to 0.05. However, large deviation (more than 93%) was observed for weight values assigned to the sub-indicators. The final weight values for the indicators can be calculated based on a simple average operation. However, the final weight value for the sub-indicators should be calculated based on the weighted average approach. Higher weight should be assigned to more reliable panels based on their working experience and knowledge on the vulnerability assessment. However detailed information about the knowledge of the panels on vulnerability require further complicated analysis. Therefore, in this report the final weight value for building and residential is calculated based on a simple averaging approach. **Appendix C** shows the final indicators, sub-indicators and their corresponding weights for road.

6.3 Consistency Analysis of Landslide Vulnerability Indicators and Weight for Dam

Table 6.9 shows the standard deviation value for weight value assigned to each indicator for dam.

Table 6.9: Standard deviation value of the weight assigned to the indicators.

COMPONENT	INDICATOR	STANDARD DEVIATION
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	SIZE	0.00
	DAM TYPOLOGY/CATEGORIES	0.01
	DAM CONSTRUCTION MATERIALS	0.00
SURROUNDING ENVIRONMENT [E]	PRESENCE OF PROTECTION	0.00
	PRESENCE OF WARNING SYSTEM	0.00
LANDSLIDE INTENSITY [I]	ACCUMULATION HEIGHTS	0.02
	LANDSLIDE VOLUMELANDSLIDE THICKNESS / DEPTH (BODY OF LANDSLIDE)	0.01
	LANDSLIDE VOLUME	0.01
PEOPLE INSIDE BUILDING [P]	POPULATION DENSITY	0.00

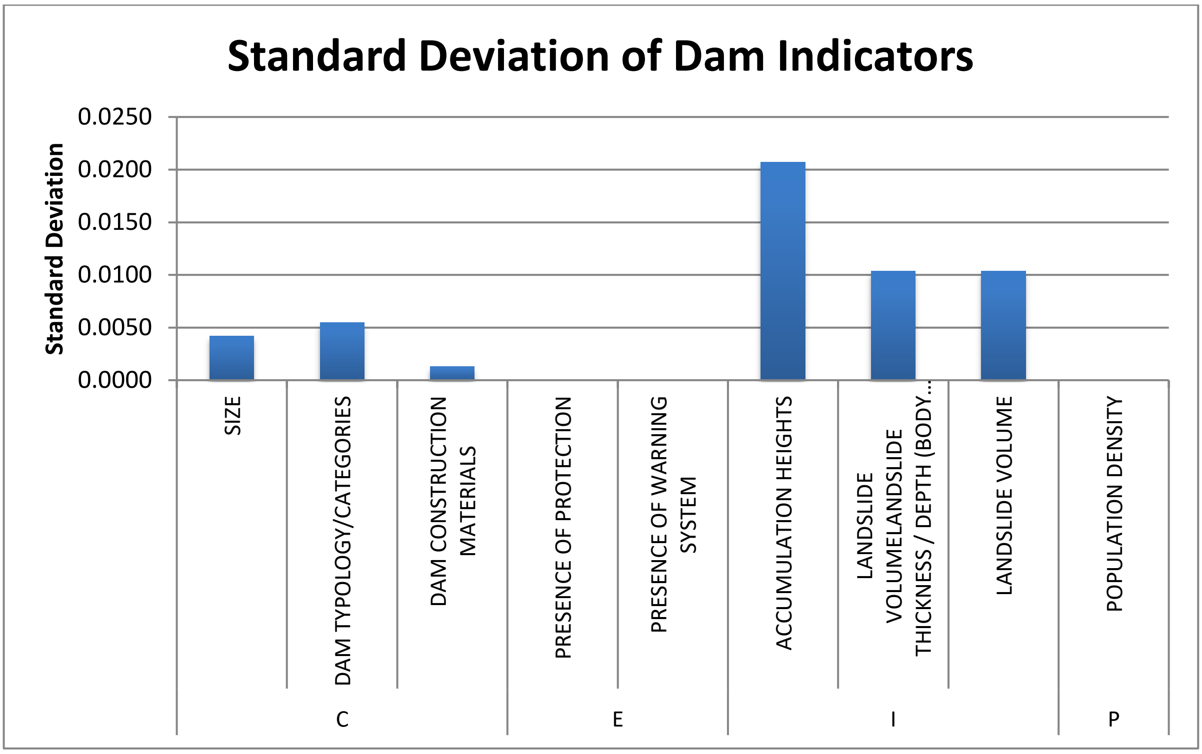


Figure 6.11: Standard deviation value of the weight assigned to the indicators.

Table 6.10: Percentage of standard deviation values exceeding 0.05 threshold for the indicators (Dam)

INDICATOR
Percentage of standard deviation (>0.05 – low variation)
0.00 %

Table 6.11 shows the standard deviation value for weight value assigned to each sub-indicator for dam.

Table 6.11: Standard deviation value of the weight assigned to the sub-indicators.

COMPONENT	INDICATOR	SUB-INDICATOR	STANDARD DEVIATION
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	SIZE	Basin / catchment (km2)	0.00
		Reservoir (m3)	0.00
		> 100 meter	0.04
		51 meter - 99 meter	0.04
		25 meter - 50 meter	0.04
		5 meter - 24 meter	0.04
		< 5 meter	0.00
	DAM TYPOLOGY/CATEGORIES	Water Supply	0.00
		Power Generation	0.12
		Irrigation	0.04
		Flood Mitigation	0.12
		Sedimentation / Recreational	0.04
	DAM CONSTRUCTION MATERIALS	Earthfill	0.08
		Rockfill	0.05
		Reinforced Concrete	0.01
		Composite	0.08
SURROUNDING ENVIRONMENT [E]	PRESENCE OF PROTECTION	No protection	0.08
		Natural protection (e.g vegetation)	0.04
		Partially man-made protection system	0.08
		Fully engineered protection system	0.08
	PRESENCE OF WARNING SYSTEM	Yes	0.18
		No	0.13
		Height ≤0.5 meter	0.08

LANDSLIDE INTENSITY [I]	ACCUMULATION HEIGHTS	0.5 meter < Height ≤ 2 meter	0.08
		2 meter < Height ≤ 3.5 meter	0.08
		>3.5 meter	0.08
	LANDSLIDE VOLUMELANDSLIDE THICKNESS / DEPTH (BODY OF LANDSLIDE)	Surficial landslide, 1.5 meter	0.08
		Shallow landslide, 1.5 meter – 5 meter	0.10
		Deep seated landslide, 5 meter - 20 meter	0.09
		Very deep seated landslide, >20 meter	0.00
	LANDSLIDE VOLUME	Very Small, <500 meter3	0.13
		Small, 500 - 10,000 meter3	0.16
		Medium, 10,000 - 50,000 meter3	0.12
		Large, 50,000 - 250,000 meter3	0.04
		Very Large, >250,000 meter3	0.04
PEOPLE INSIDE BUILDING [P]	POPULATION DENSITY	Low (0)	0.13
		Medium (1-10)	0.10
		High (11 - 100)	0.00
		Very High (> 100)	0.08

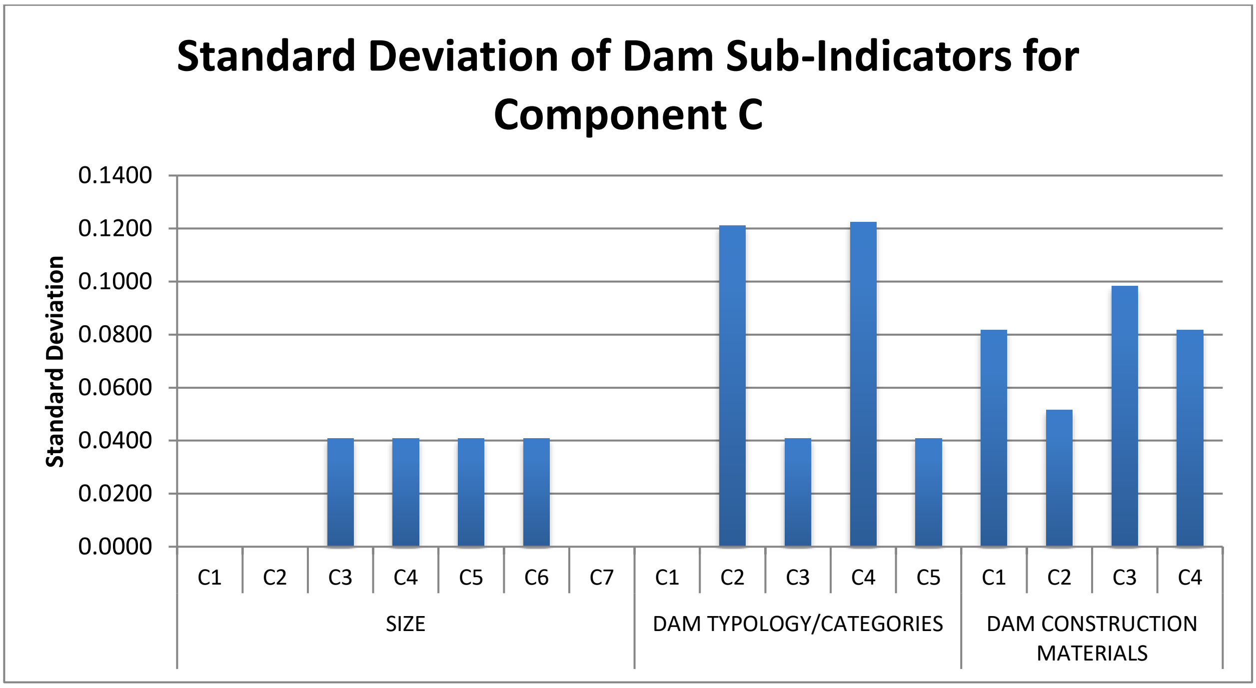


Figure 6.12: Standard deviation value of the weight assigned to the sub-indicators in component C (i.e. susceptibility of CI).

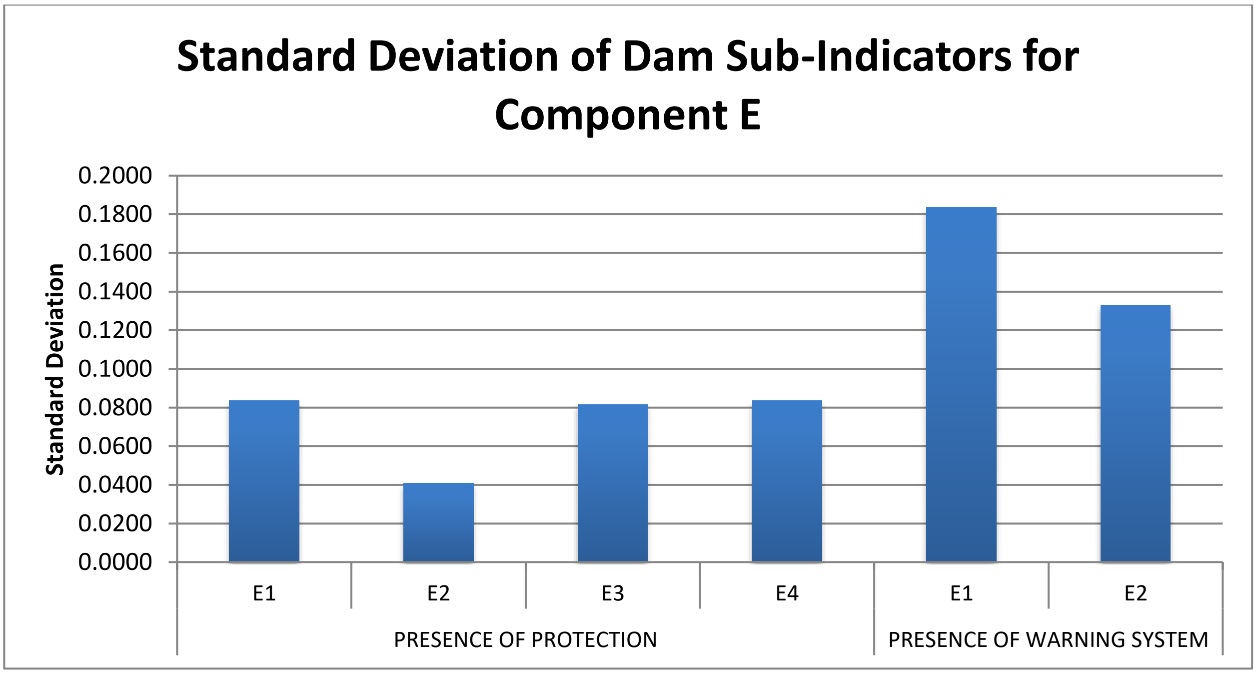


Figure 6.13: Standard deviation value of the weight assigned to the sub-indicators in component E (i.e. surrounding environment).

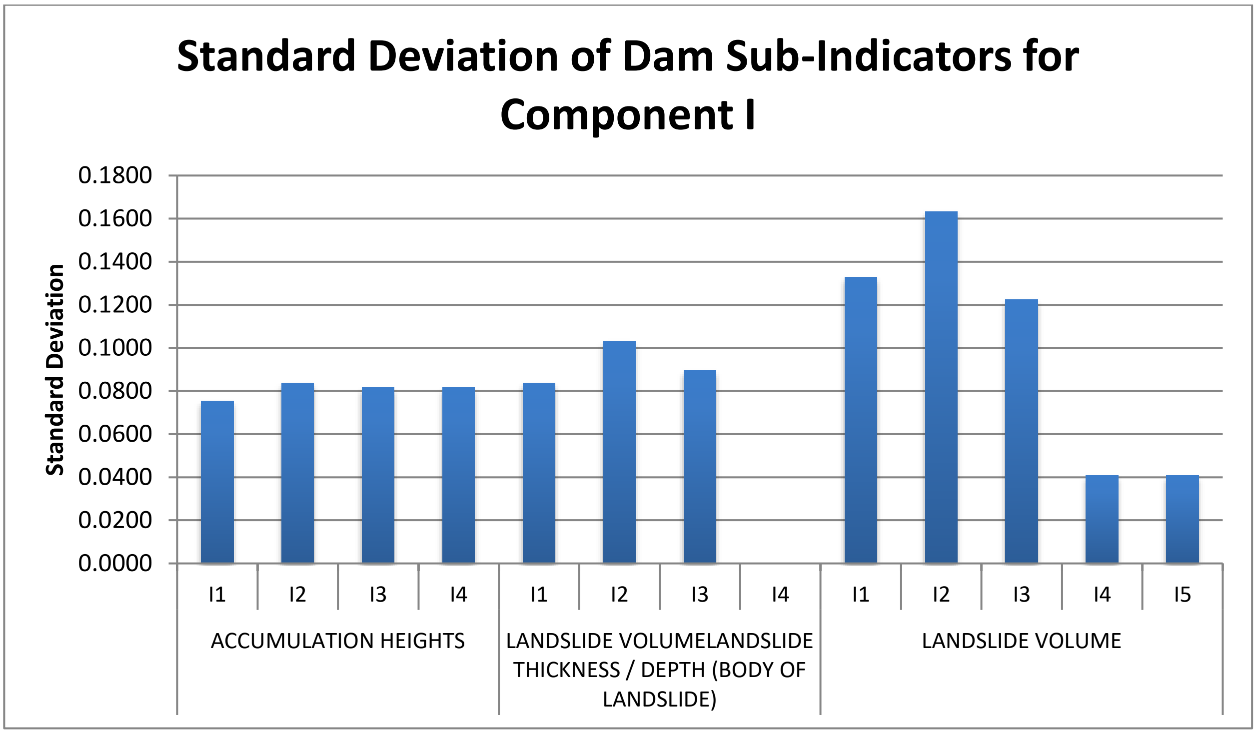


Figure 6.14: Standard deviation value of the weight assigned to the sub-indicators in component I (i.e. landslide intensity).

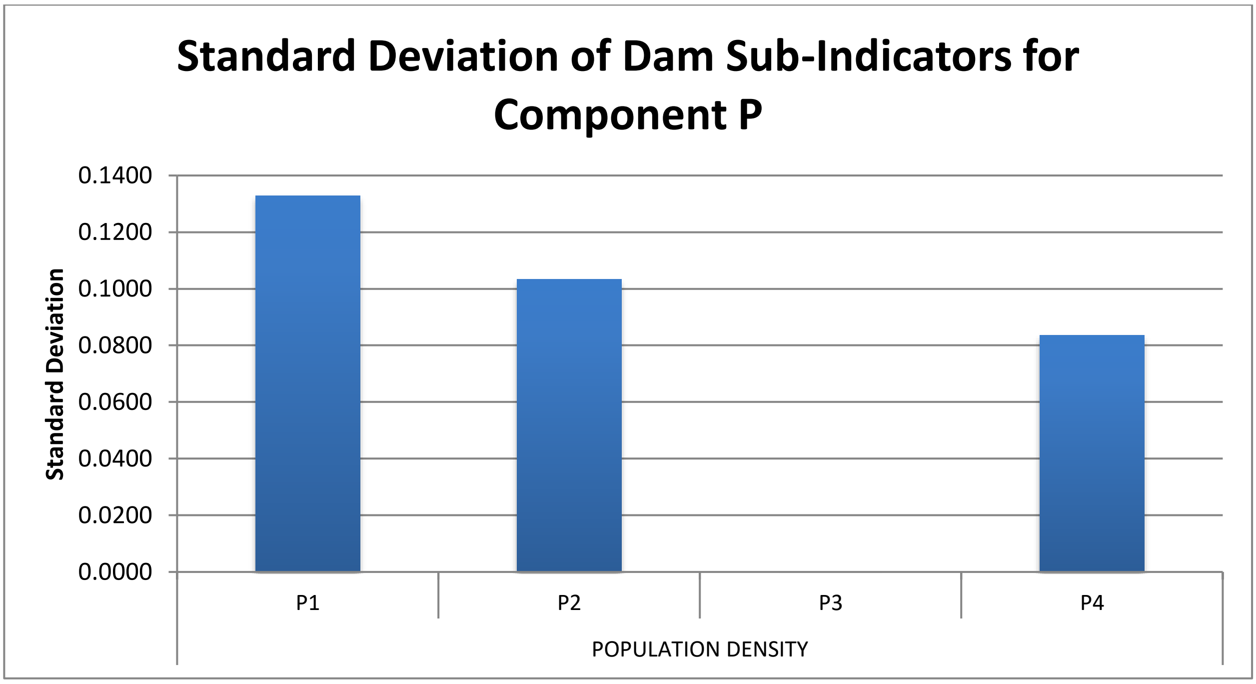


Figure 6.15: Standard deviation value of the weight assigned to the sub-indicators in component P (i.e. people affected by the operation of the dam).

Table 6.12: Percentage of standard deviation values exceeding 0.05 threshold for the sub-indicators (Dam).

SUB-INDICATOR
Percentage of standard deviation (>0.05 – mid variation)
38.46 %

The results show that the assigned weight values for indicators are consistent with the standard deviation less or equal to 0.05. However, low degree of deviation (more than 38%) was observed for weight values assigned to the sub-indicators. The final weight values for the indicators can be calculated based on a simple average operation. However, the final weight value for the sub-indicators should be calculated based on the weighted average approach. Higher weight should be assigned to more reliable panels based on their working experience and knowledge on the vulnerability assessment. The calculation of the weight based on weighted average approach will be done later on and in this report the final weight value for building and residential is calculated based on a simple averaging approach. **Appendix D** shows the final indicators, sub-indicators and their corresponding weights for dam.

6.4 Landslide Vulnerability Indicators and Weight for TNB powerline

During the first FGD session the discussion was only focussed on the TNB transmission tower and the results of the indicator and sub-indicator selections as well as the weight values were collected from a single input. **Appendix E** shows the final indicators, sub-indicators and their corresponding weights for TNB transmission tower.

6.5 Sensitivity Analysis of the FGD with stakeholders

Figure 6.16 shows the sensitivity analysis of the FGD with stakeholders for buildings and rotational/translational landslides. Presence of water channel, accumulation height, deposit thickness and landslide volume are the most sensitive indicators. On the other hand, the least sensitive indicators are function of building, distance between buildings and time of landslide occurrence (weekday or weekend). Overall the intensity (I) of landslide is the most sensitive cluster followed by surrounding environment (E). The least sensitive clusters are susceptibility of the CI (C) and impact on people inside the building (P) (Figure 6.17).

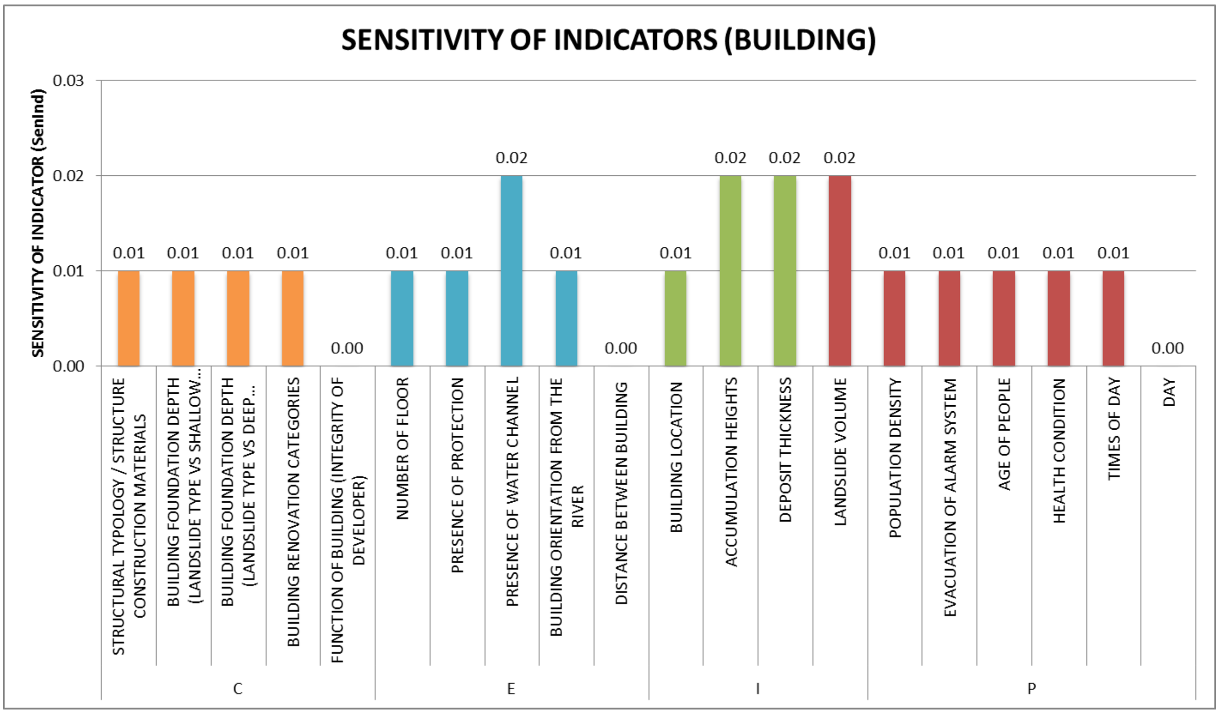


Figure 6.16: Sensitivity of indicator (*Sen$_{Ind}$*) calculated for each indicator for building and rotational/translational landslide.

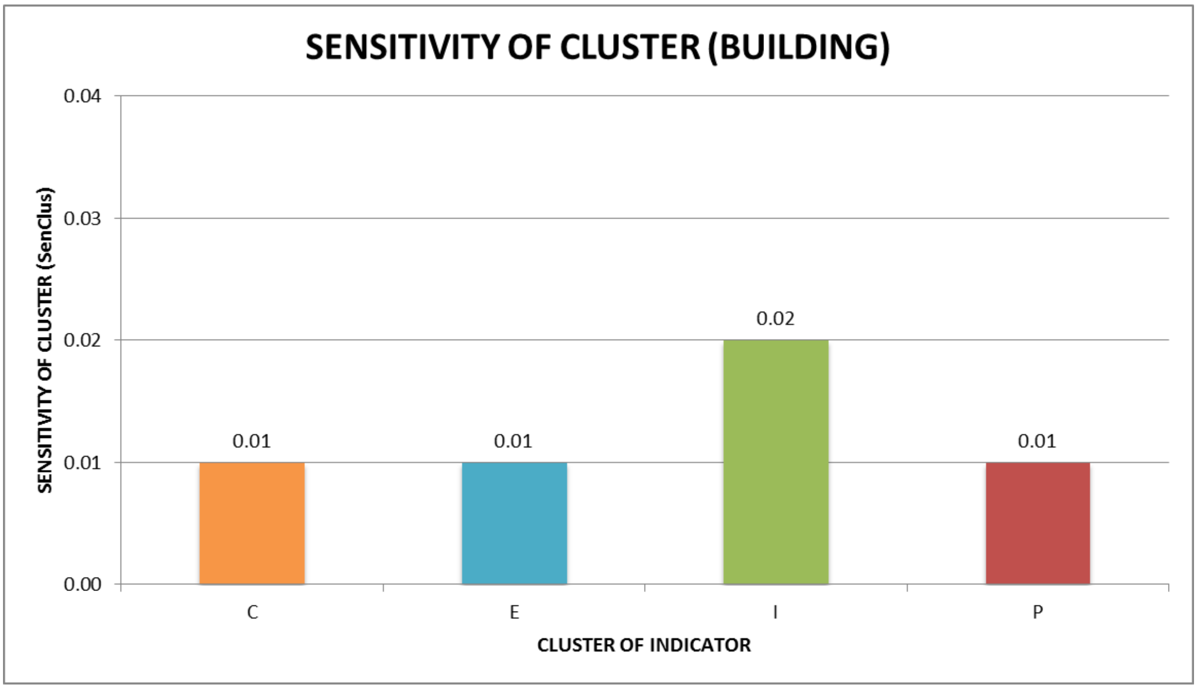


Figure 6.17: Sensitivity of cluster (*Sen_{Clus}*) calculated for each indicator for building and rotational/translational landslide.

Figure 6.18 shows the sensitivity of indicators for road. The impact on road user reflected by the traffic volume poses the most sensitive indicator. While road category and road materials are the least sensitive indicators. In general, the impact on road user (*P*) is the most sensitive cluster followed by intensity of landslide (*I*), surrounding environment (*E*) and susceptibility of the road towards landslide (*C*) (Figure 6.19).

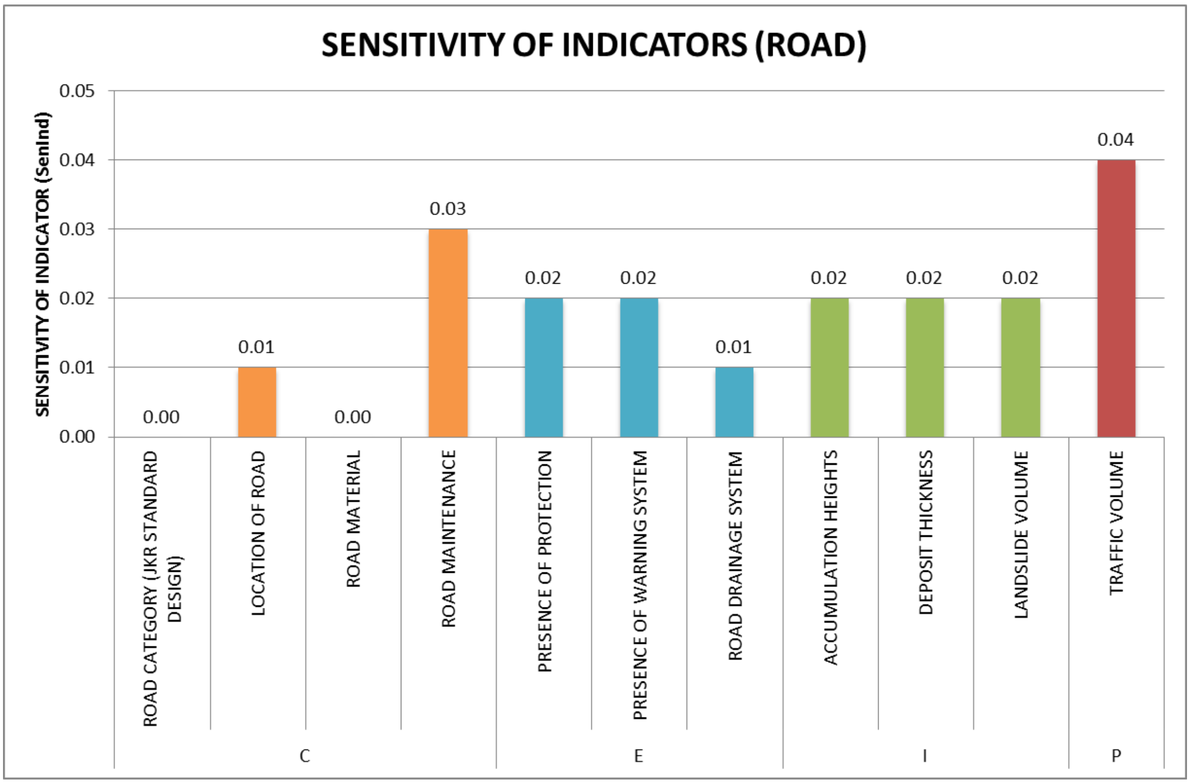


Figure 6.18: Sensitivity of indicator (Sen_{Ind}) calculated for each indicator for road and rotational/translational landslide.

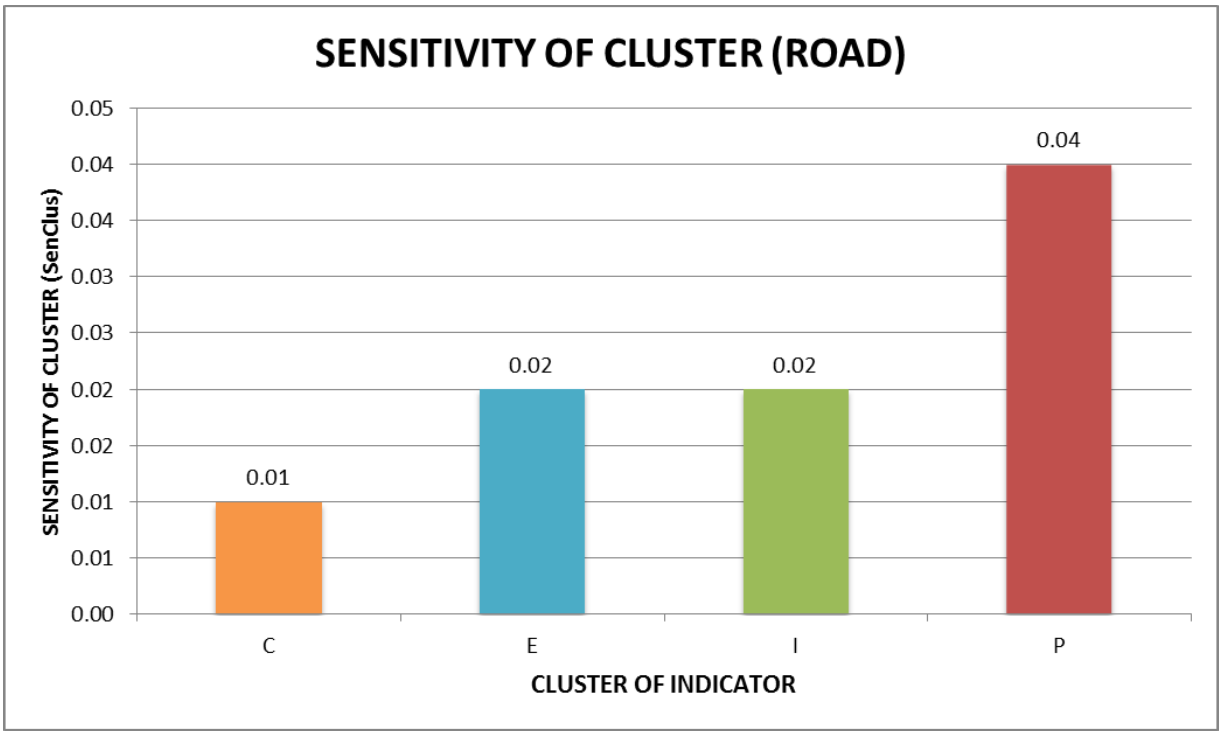


Figure 6.19: Sensitivity of cluster (Sen_{Clus}) calculated for each indicator for road and rotational/translational landslide.

Figure 6.20 shows the sensitivity of landslide vulnerability indicators for dam. The results show that presence of protection and landslide volume are the most sensitive indicators. Meanwhile basin and catchment size, reservoir size, main structure height, main structure length, presence of warning system and population density are the least sensitive indicators. Figure 6.21 shows that landslide intensity (*I*) is the most sensitive cluster of indicator followed by the surrounding environment (*E*). Furthermore, the susceptibility of the dam (*C*) and the impact of dam operation failed to the community (*P*) are the least sensitive indicator clusters.

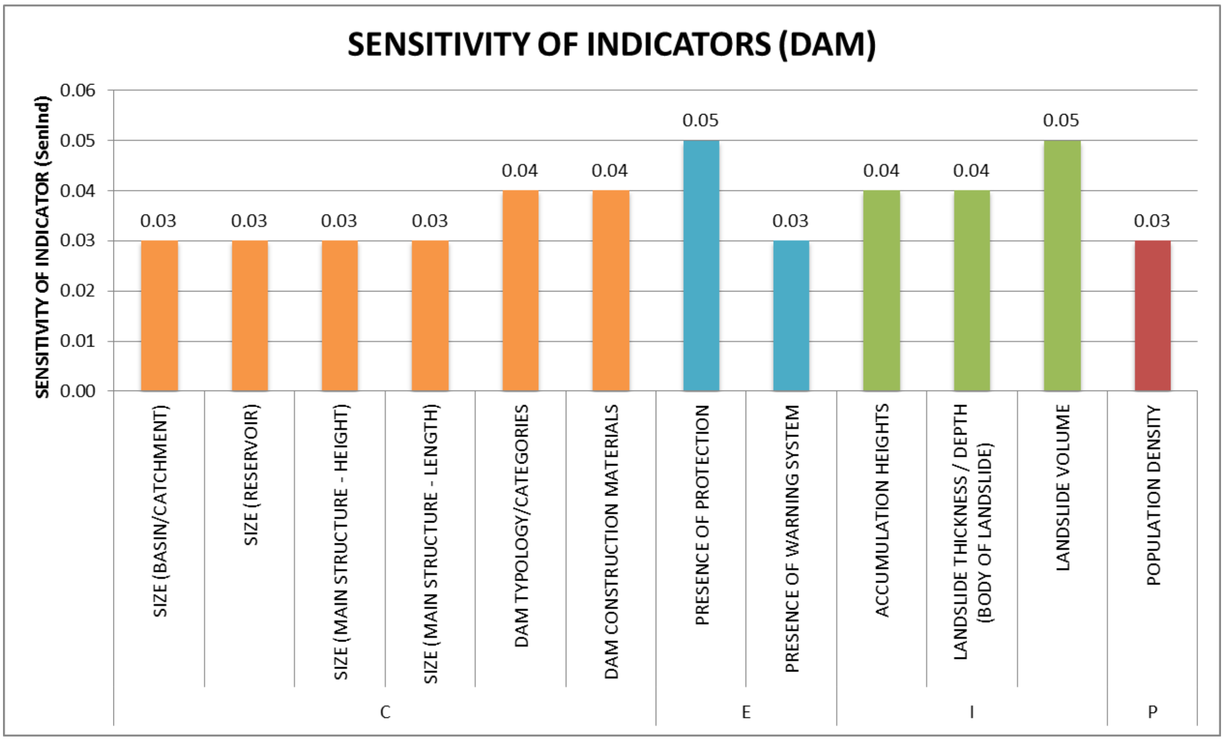


Figure 6.20: Sensitivity of indicator (Sen_{Ind}) calculated for each indicator for dam and rotational/translational landslide

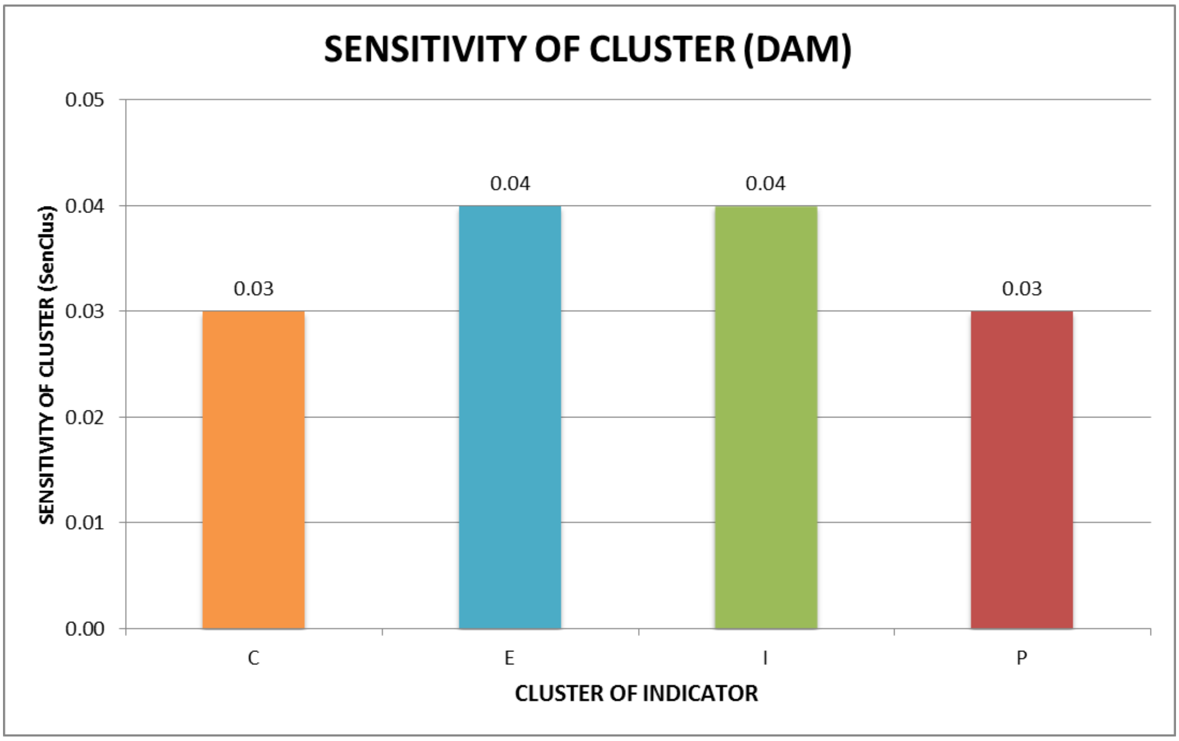


Figure 6.21: Sensitivity of cluster (Sen_{Clus}) calculated for each indicator for dam and rotational/translational landslide

Figure 6.22 shows the sensitivity of landslide vulnerability indicators for TNB powerline. The results show that landslide thickness / depth (body of landslide) (top, straight), population density and landslide thickness / depth (body of landslide) (top, concave) are the most sensitive indicators. Meanwhile, there are 14 indicators, which, 2 indicators came from the impact of TNB powerline to the user (*P*), 5 indicators came from surrounding environment (*E*), 7 indicators came from by the landslide intensity (*I*) clusters. In general, the impact of TNB powerline to the user (*P*) is the most sensitive cluster followed by the landslide intensity (*I*) and susceptibility of the powerline (*C*). Meanwhile surrounding environment (*E*) has the least sensitive indicators compared to other clusters (Figure 6.23).

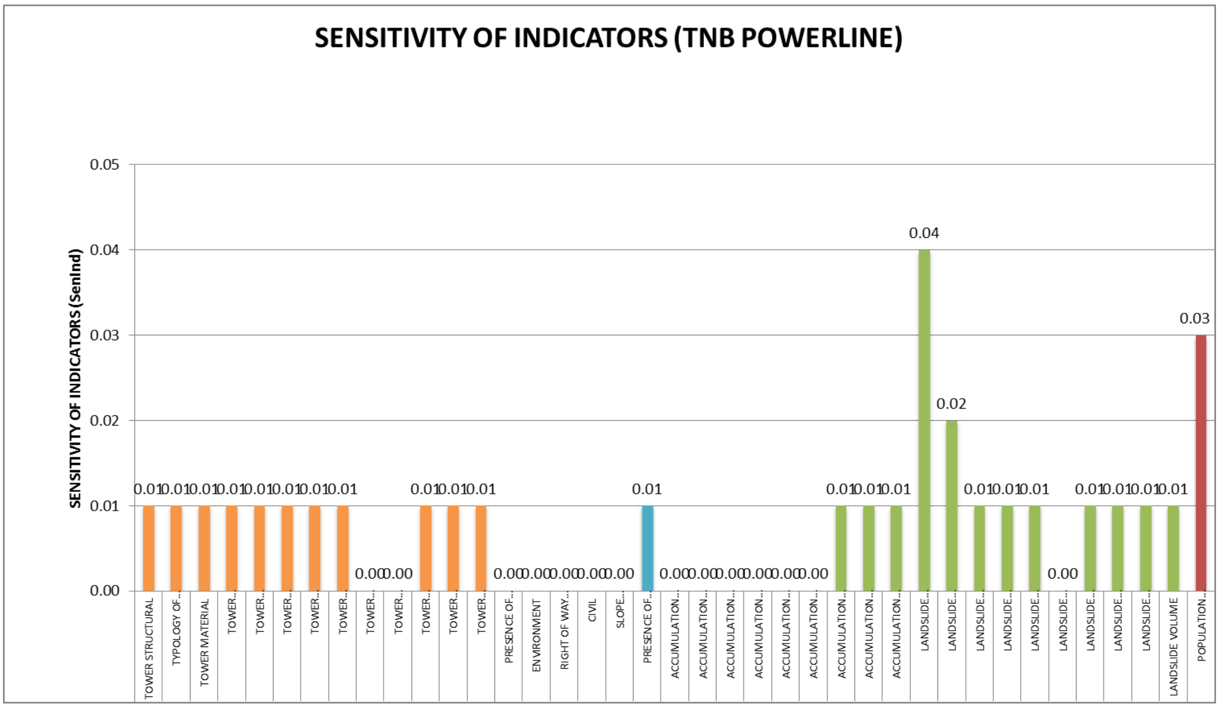


Figure 6.22: Sensitivity of indicator (Sen_{Ind}) calculated for each indicator for TNB powerline and rotational/translational landslide.

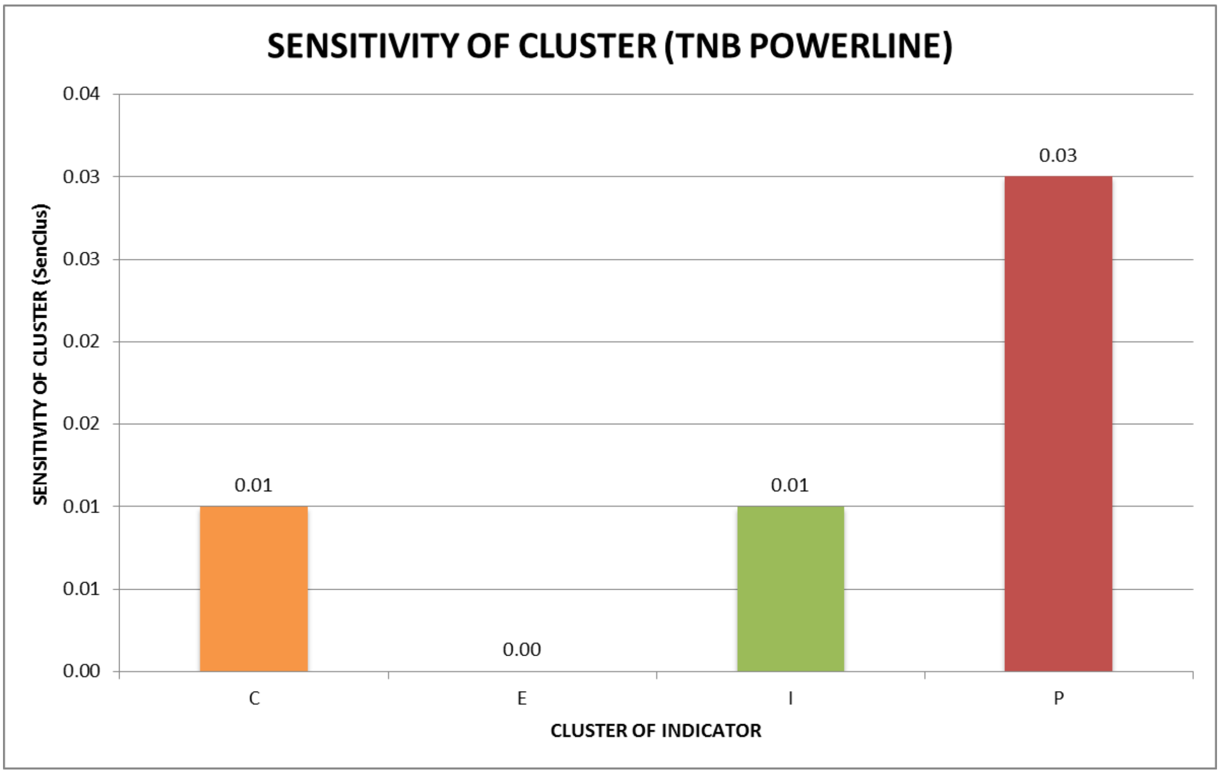


Figure 6.23: Sensitivity of cluster (Sen_{Clus}) calculated for each indicator for TNB powerline and rotational/translational landslide.

6.6 Sensitivity Analysis of the FGD with Internal Experts

Focus group discussion with the internal experts is the initiative to improve the indicators, sub-indicators and their corresponding weights as given by the FGD with the stakeholders and literature review. Based on the results of the previous FGD with the stakeholders, most of the time the clusters of indicators for susceptibility of CI (*C*) and landslide intensity (*I*) relatively less sensitive compared to other clusters. Furthermore, similar weight is given for all clusters. Since the aim of the guideline is to support sustainable development of CI towards landslide hazard, the internal experts tend to give more priority to cluster *C* and *I* followed by *E* and *P*. The following are the results of the sensitivity analysis on the indicators and cluster of landslide indicators based on the intensive discussion of the internal experts. Unlike the previous FGD with the stakeholders this FGD covers all landslide types i.e. rotational/translational, debris flow and rock fall. On the other hand, the assigned indicators have taken into account the factors concern on the area of the CI i.e. highland, tectonic region, rural and urban areas.

Rotational/Translational landslides

Figure 6.24 shows the sensitivity analysis of building towards the rotational and translational landslides. The results show that landslide volume is the most sensitive indicator and least sensitive indicators are population density, age of people and health condition of people inside the building. Overall, the landslide intensity cluster (*I*) is the most sensitive cluster followed by the susceptibility of CI (*C*) and surrounding environment (*E*). The impact of landslide on the people inside the building has the lowest sensitivity value.

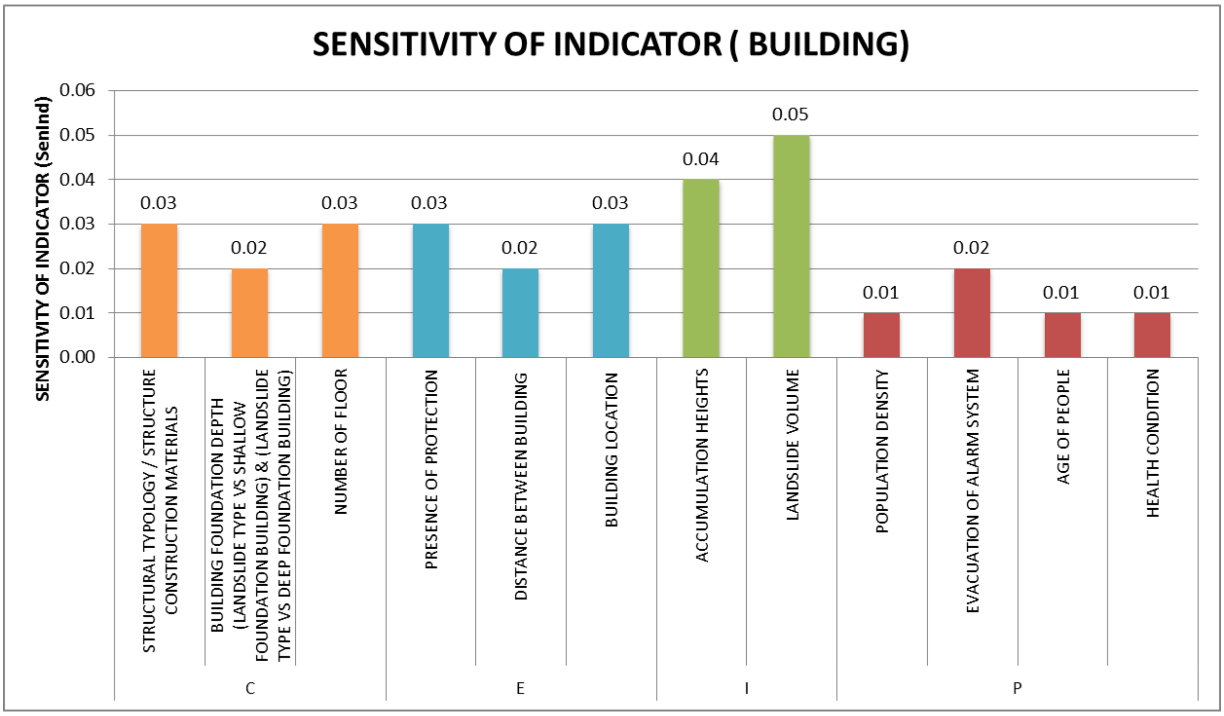


Figure 6.24: Sensitivity of indicator (Sen_{Ind}) calculated for each indicator for building and rotational/translational landslide.

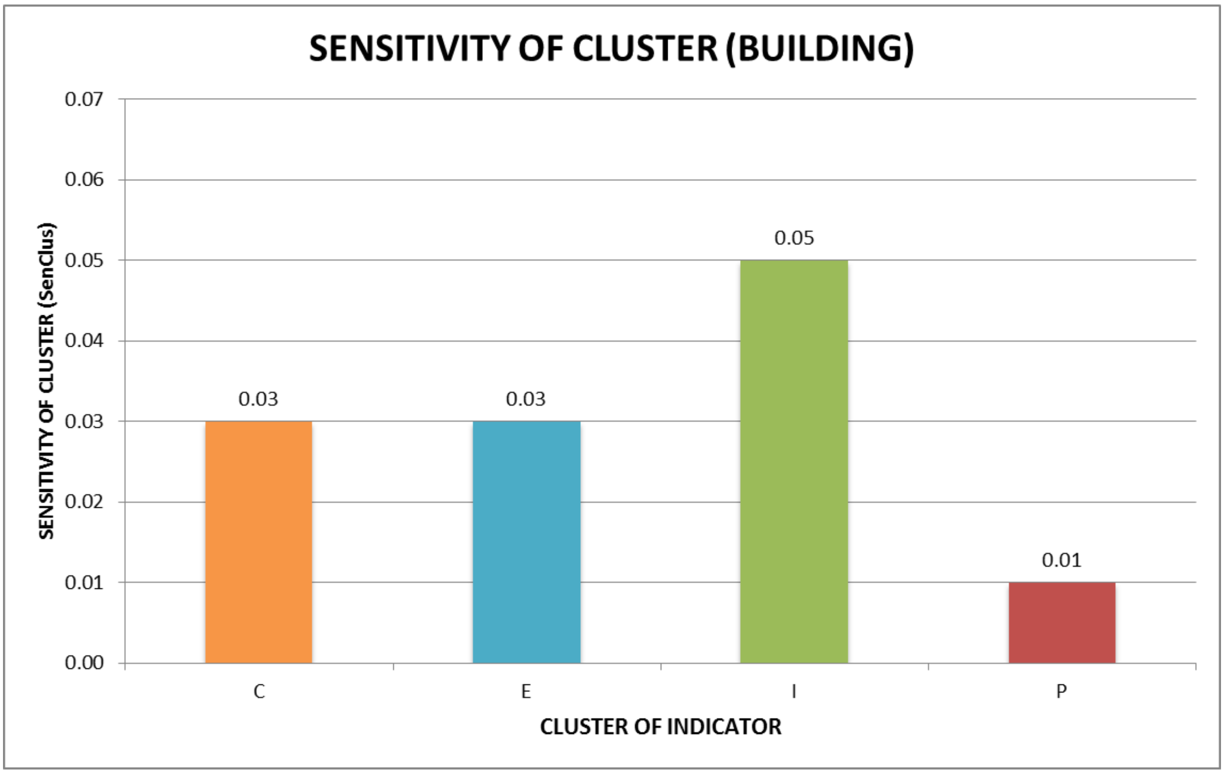


Figure 6.25: Sensitivity of cluster (Sen_{Clus}) calculated for each indicator for building and rotational/translational landslide

Figure 6.26 shows the sensitivity analysis of road. Presence of warning system and road maintenance appeared to be the most sensitive indicators. The least sensitive indicator is road category. Figure 6.27 shows that all cluster has similar sensitivity towards the estimation of landslide vulnerability.

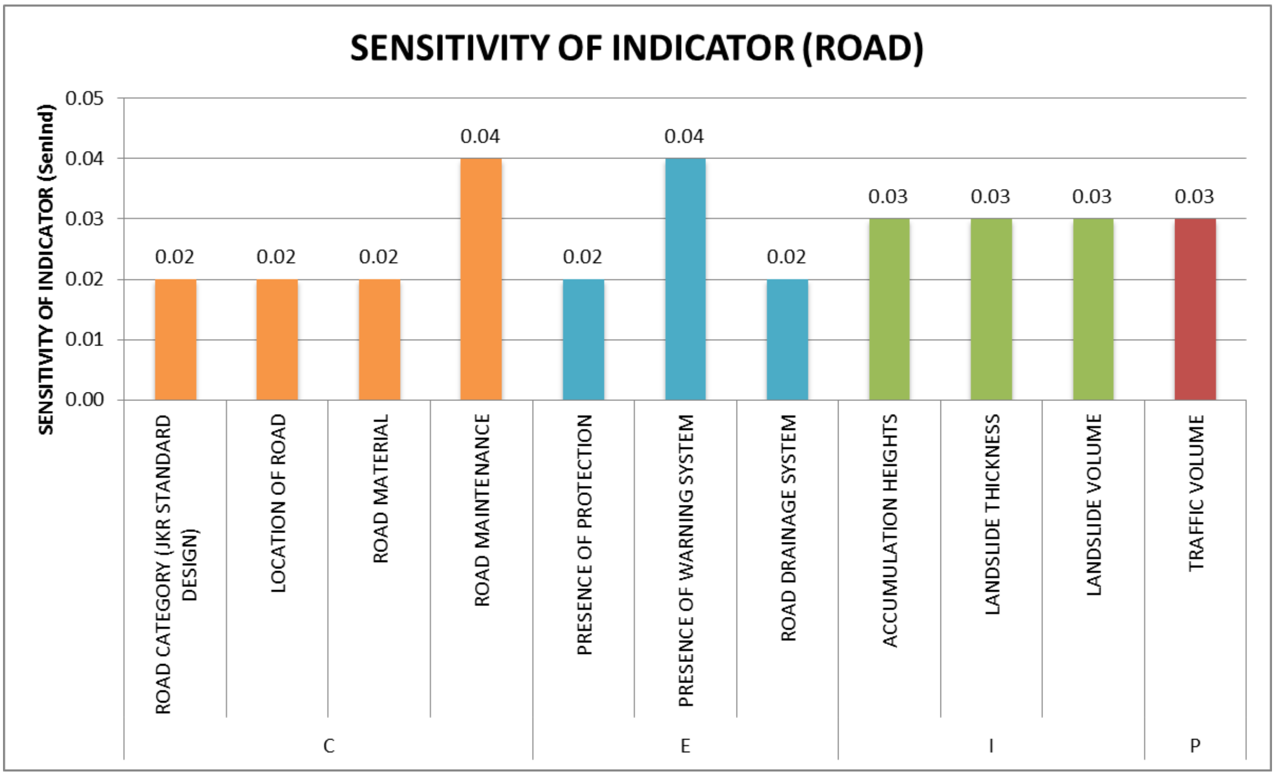


Figure 6.26: Sensitivity of indicator (Sen_{Ind}) calculated for each indicator for road and rotational/translational landslide

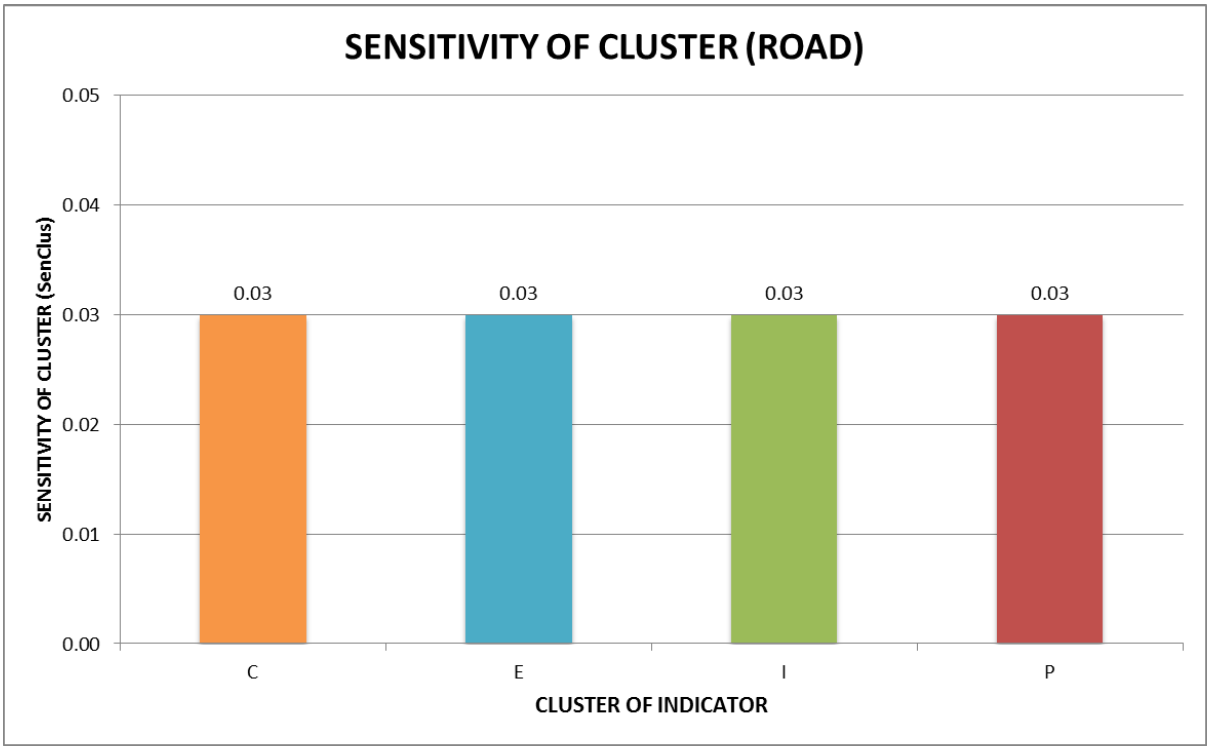


Figure 6.27: Sensitivity of cluster (Sen_{Clus}) calculated for each indicator for road and rotational/translational landslide

Figure 6.28 shows the sensitivity analysis of dam. Landslide volume appeared to be the most sensitive vulnerability indicators. Meanwhile the least sensitive indicators are dam dimension (main structure - height), dam dimension (main structure - length), dam typology/category and dam construction materials. Figure 6.29 shows that the impact of the dam operation on the user (*P*) and surrounding environment (*E*) are the most sensitive cluster followed by landslide intensity (*I*) and susceptibility of the CI (*C*).

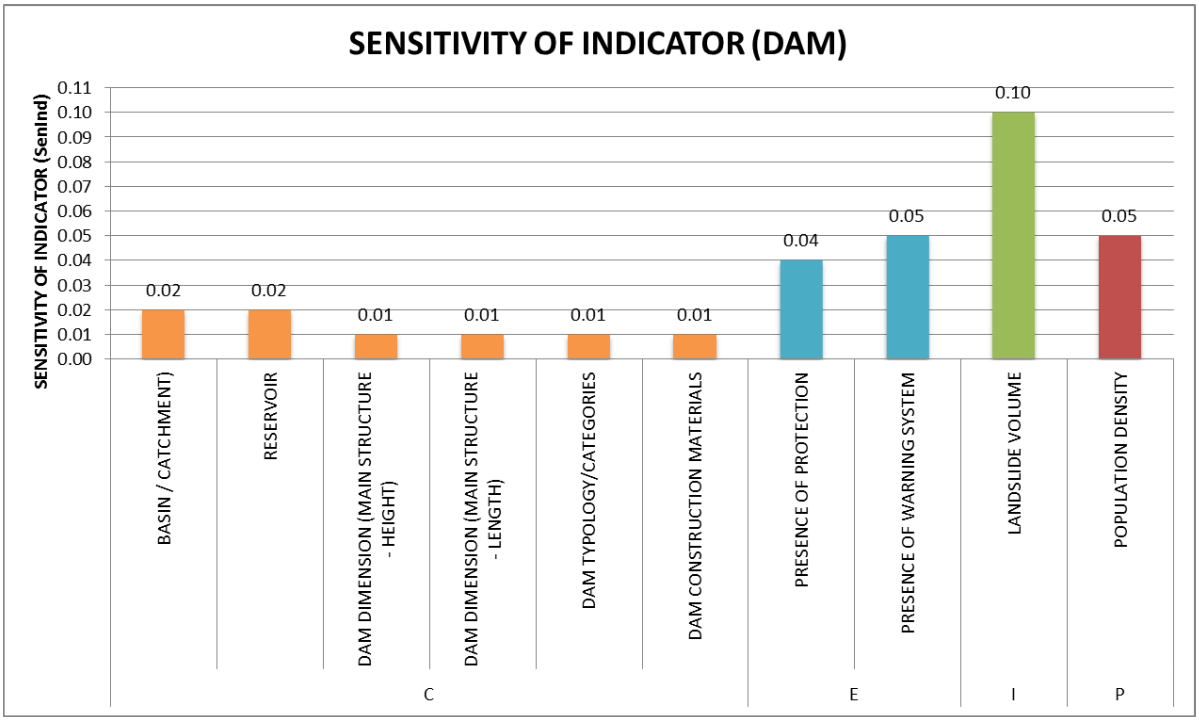


Figure 6.28: Sensitivity of indicator (*Sen_{Ind}*) calculated for each indicator for dam and rotational/translational landslide.

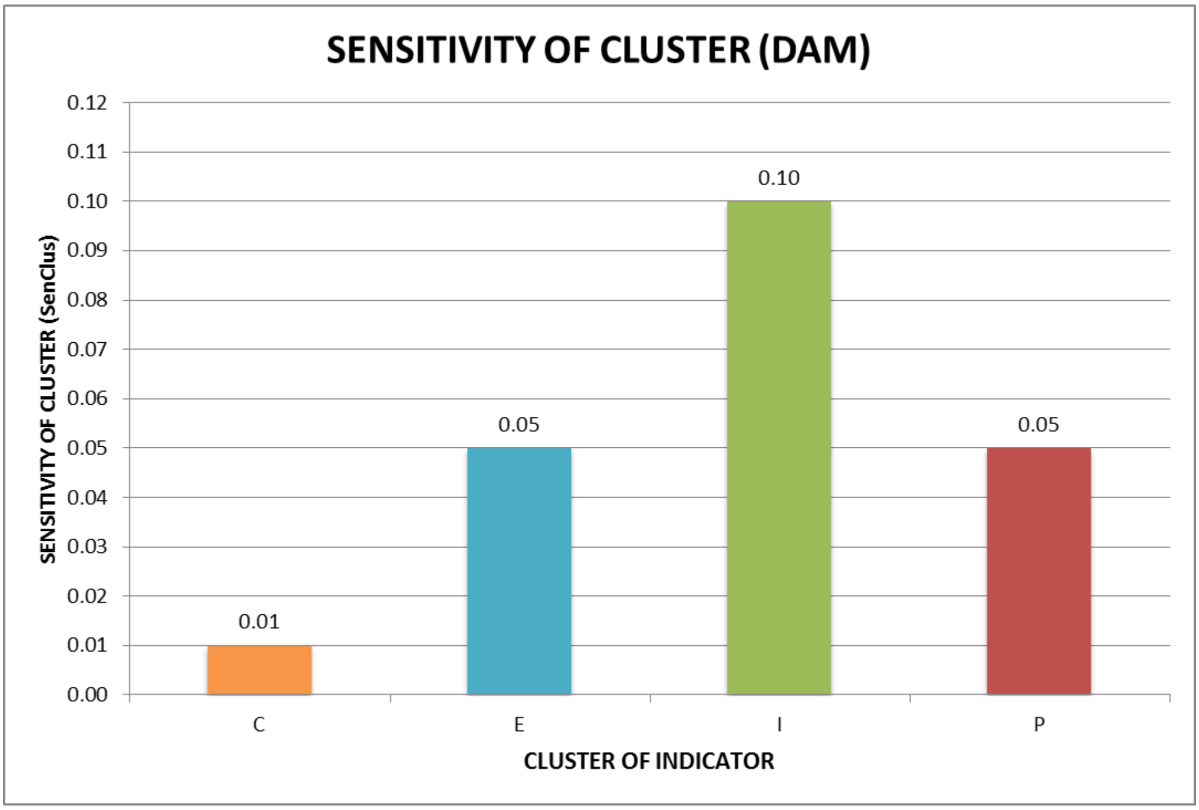


Figure 6.29: Sensitivity of cluster (Sen_{Clus}) calculated for each indicator for dam and rotational/translational landslide.

Figure 6.30 shows the sensitivity analysis of TNB powerline. Presence of warning system and population density affected by the operation appeared to be the most sensitive vulnerability indicators. Meanwhile the least sensitive indicators are right of way (ROW) and slope morphology. Figure 6.31 shows that the impact of the powerline operation on the user (*P*) is the most sensitive cluster followed by landslide intensity (*I*) and susceptibility of the CI (*C*). Surrounding environment is the least sensitive cluster of indicators.

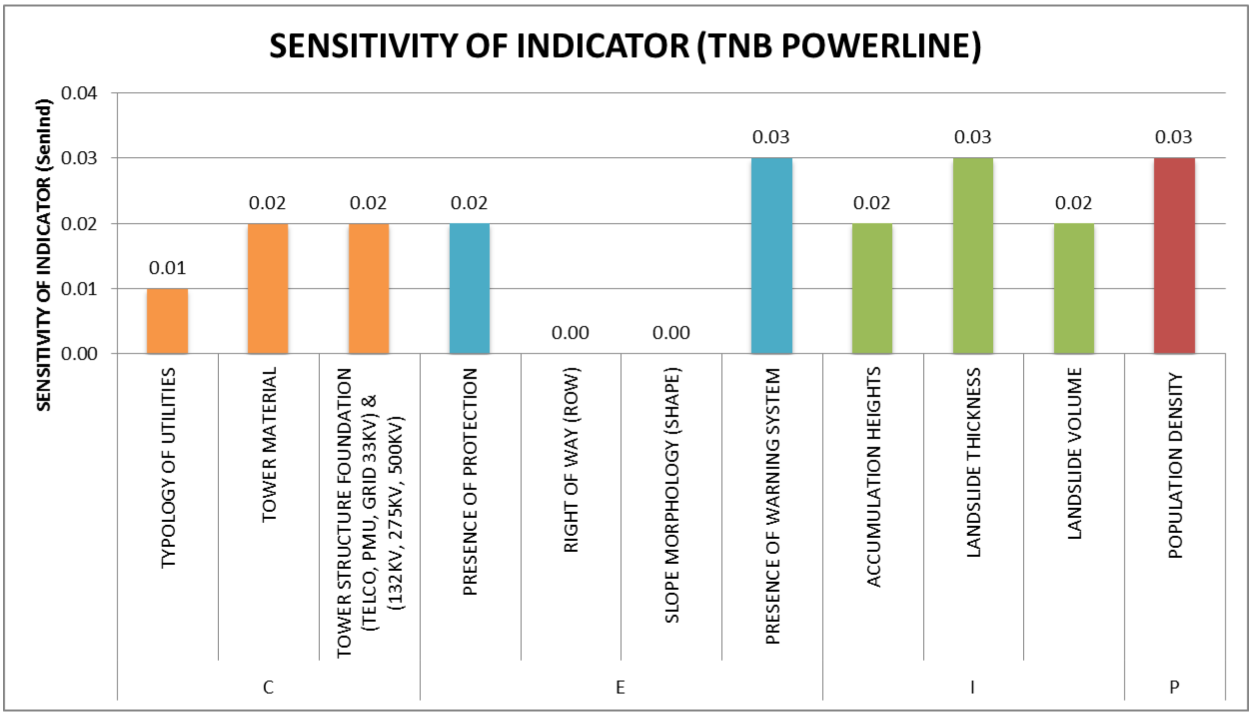


Figure 6.30: Sensitivity of indicator (*Sen*$_{Ind}$) calculated for each indicator for TNB powerline and rotational/translational landslide.

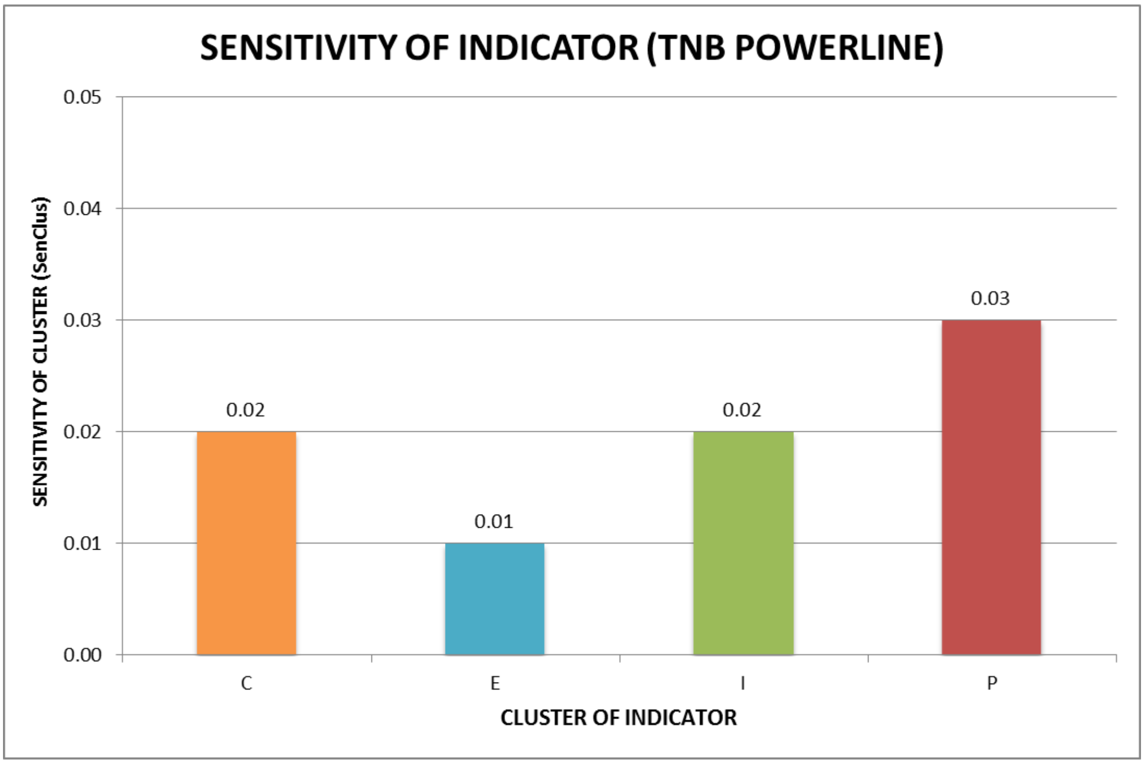


Figure 6.31: Sensitivity of cluster (Sen_{Clus}) calculated for each indicator for TNB powerline and rotational/translational landslide.

Debris flow

Figure 6.32 shows the sensitivity analysis of building for debris flow. Building foundation depth appeared to be the most sensitive vulnerability indicators. Meanwhile the least sensitive indicators landside thickness, population density, age of people and health of people. Figure 6.33 shows that the susceptibility of the CI (*C*) is the most sensitive cluster followed by surrounding environment (*E*), landslide intensity (*I*) and impact of the building on people (*P*).

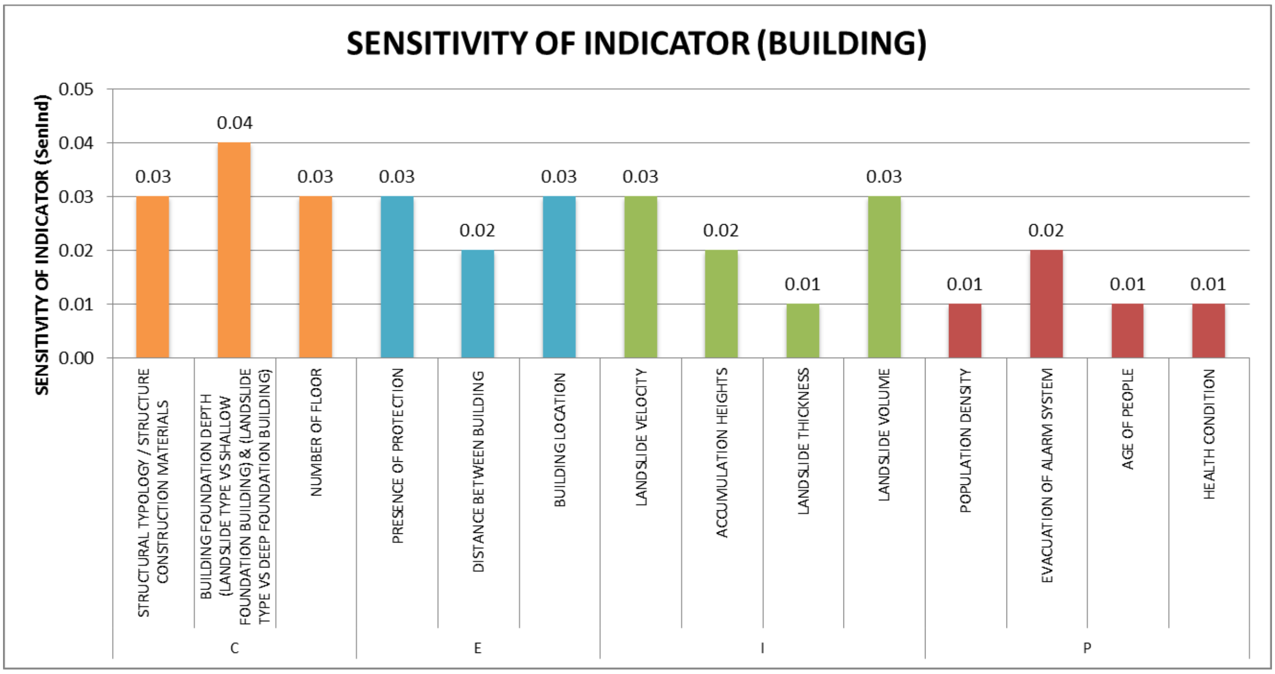


Figure 6.32: Sensitivity of indicator (Sen_{Ind}) calculated for each indicator for building and debris flow landslide.

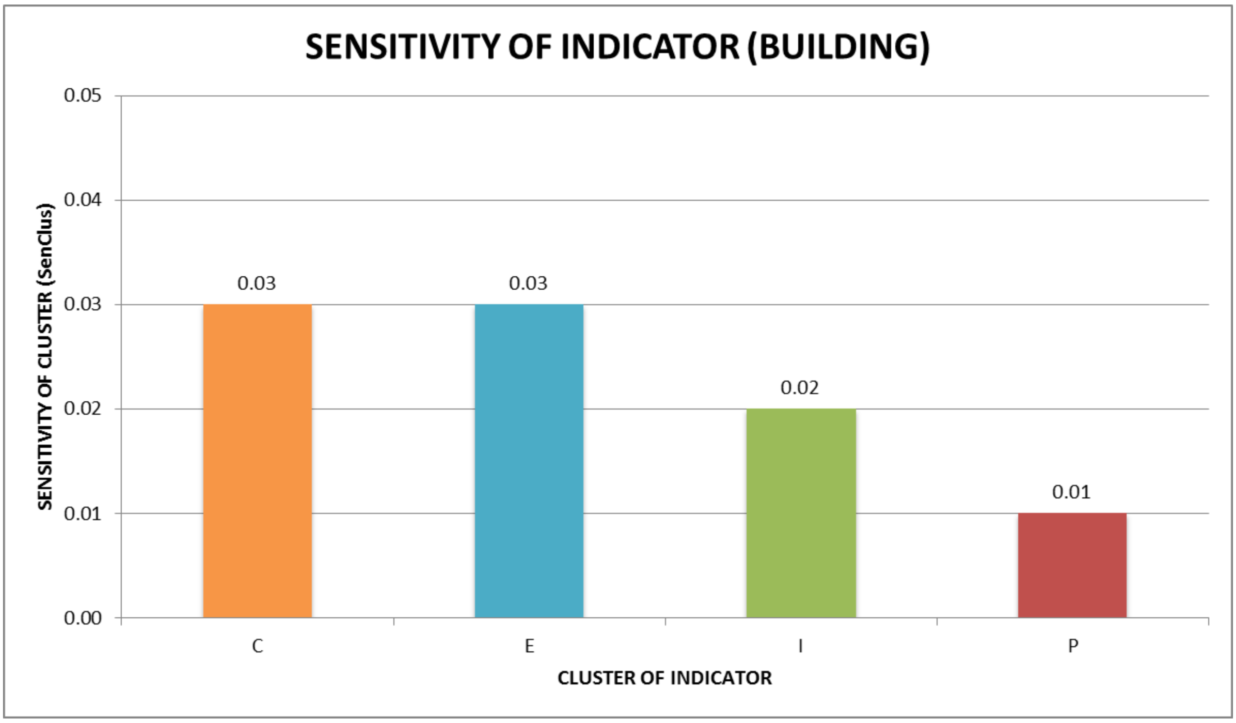


Figure 6.33: Sensitivity of cluster (Sen_{Clus}) calculated for each indicator for building and debris flow landslide.

Figure 6.34 shows the sensitivity analysis of road. Road maintenance and presence of warning system appeared to be the most sensitive vulnerability indicators. Meanwhile the least sensitive indicators are road category, road materials, presence of protection, road drainage system, accumulation height, landslide thickness and landslide volume. Figure 6.35 shows that the impact of the road operation on the user (*P*) is the most sensitive cluster and followed by susceptibility of the CI (*C*) and surrounding environment (*E*). Landslide intensity (*I*) is the least sensitive cluster.

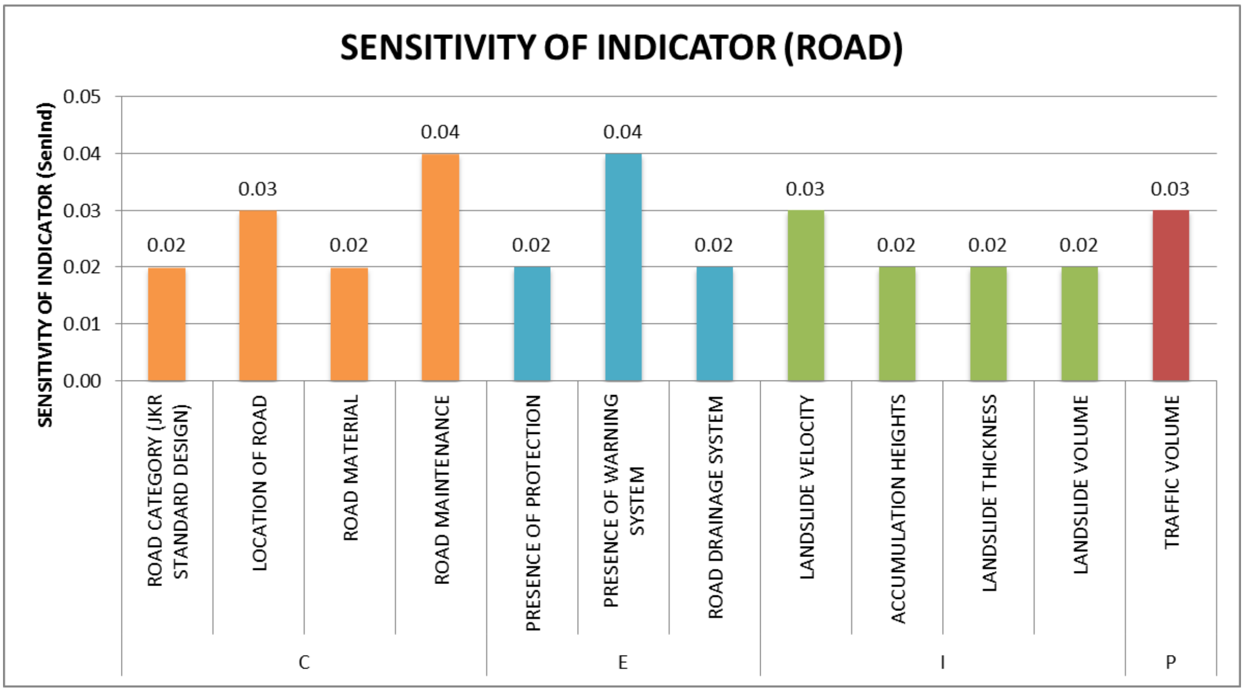


Figure 6.34: Sensitivity of indicator (Sen_{Ind}) calculated for each indicator for road and debris flow landslide.

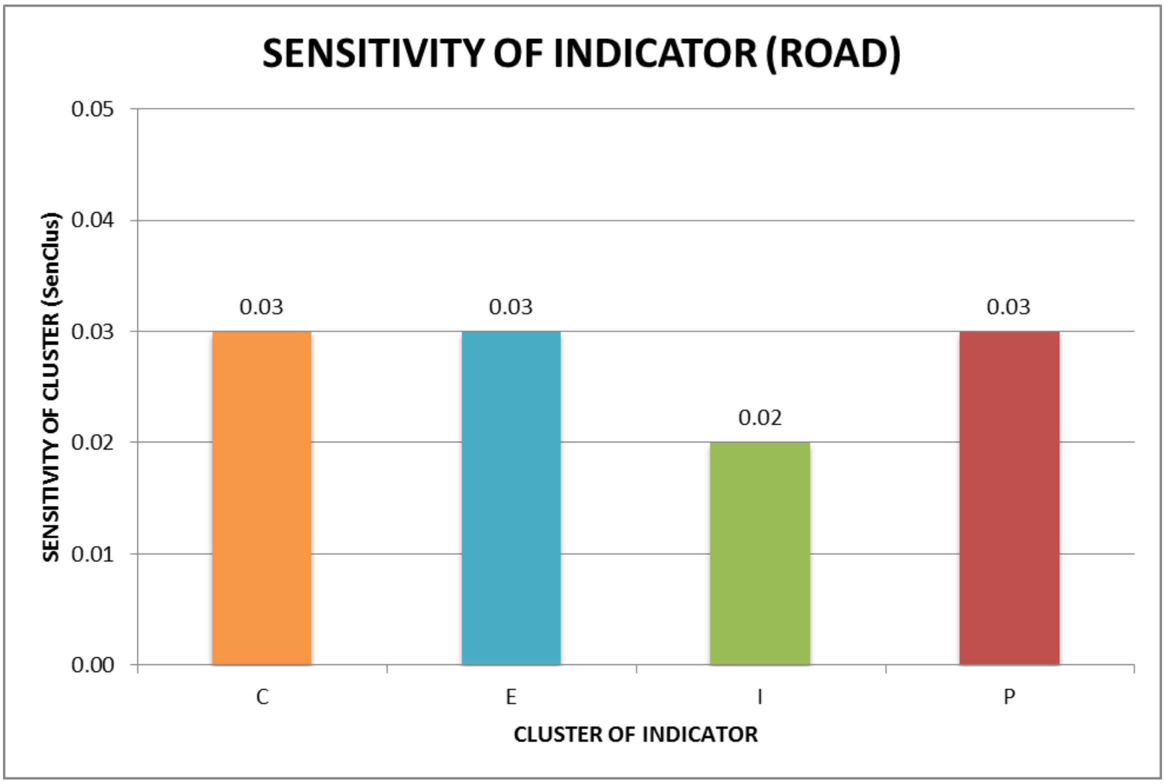


Figure 6.35: Sensitivity of cluster (*Sen_{Clus}*) calculated for each indicator for road and debris flow landslide.

Figure 6.36 shows the sensitivity analysis of dam. Landslide velocity appeared to be the most sensitive vulnerability indicators. Meanwhile the least sensitive indicators are dam dimension (main structure - height), dam dimension (main structure - length), dam typology/category and dam construction materials. Figure 6.37 shows that the landslide intensity (*I*) is the most sensitive cluster followed by the impact of the dam operation on the user (*P*) and surrounding environment (*E*). Susceptibility of the CI (*C*) is the least sensitive cluster of indicators.

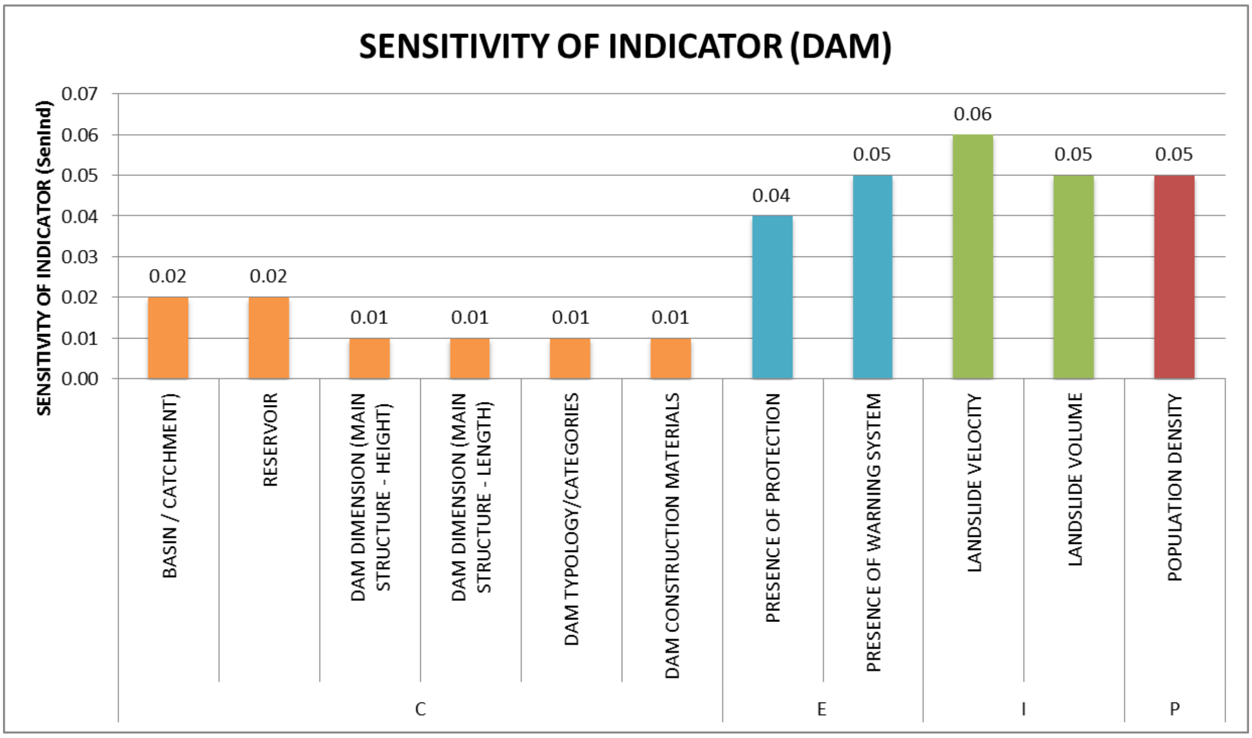


Figure 6.36: Sensitivity of indicator (*Sen*$_{Ind}$) calculated for each indicator for dam and debris flow landslide.

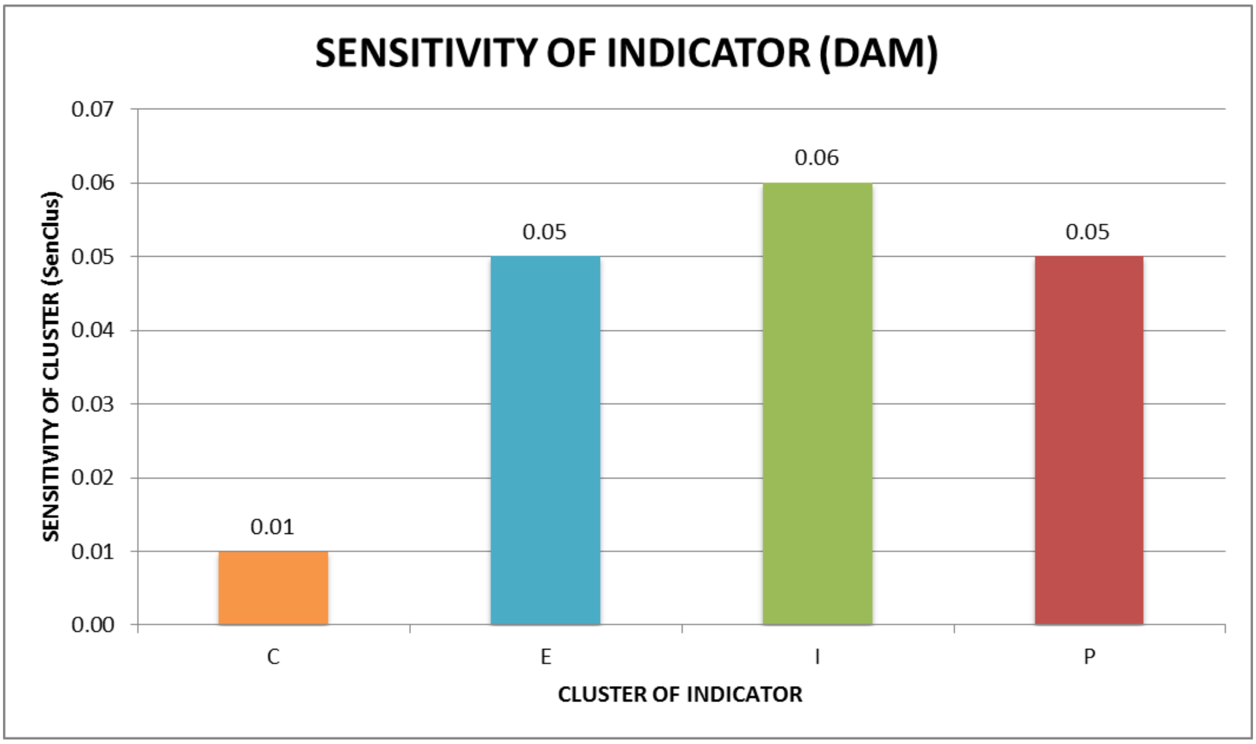


Figure 6.37: Sensitivity of cluster (*Sen*$_{Clus}$) calculated for each indicator for dam and debris flow landslide.

Figure 6.38 shows the sensitivity analysis of TNB powerline. Presence of warning system, landslide velocity and population density appeared to be the most sensitive vulnerability indicators. Meanwhile the least sensitive indicators are right of way (ROW) and slope morphology. Figure 5.39 shows that the impact of the powerline operation on the user (*P*) is the most sensitive cluster followed by landslide intensity (*I*) susceptibility of the CI and surrounding environment (*E*).

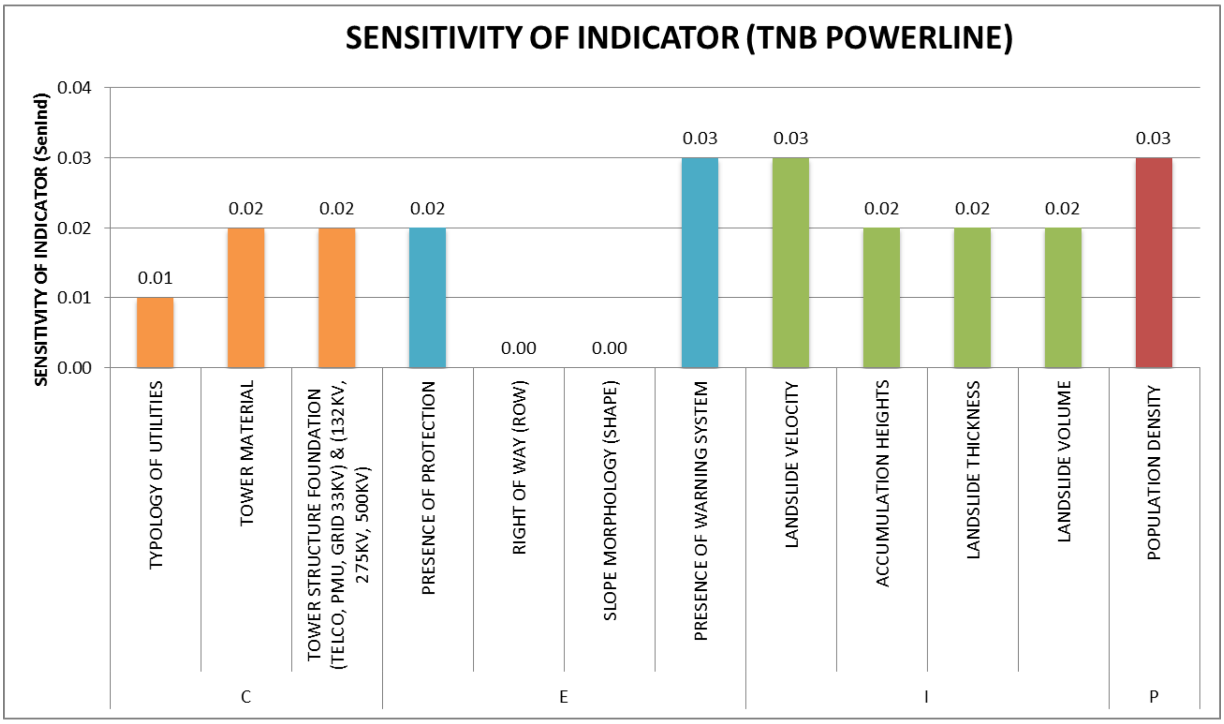


Figure 6.38: Sensitivity of indicator (Sen_{Ind}) calculated for each indicator for TNB powerline and debris flow landslide.

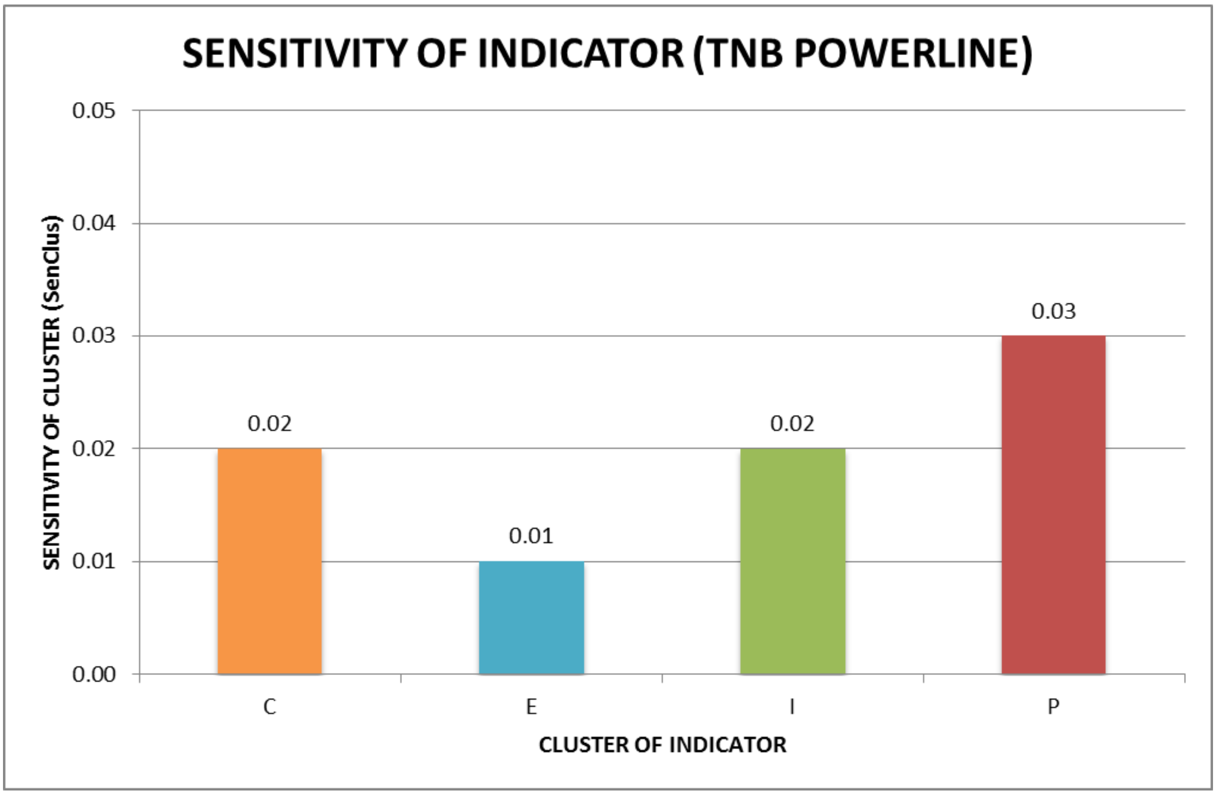


Figure 6.39: Sensitivity of cluster (*Sen_{Clus}*) calculated for each indicator for TNB powerline and debris flow landslide.

Rockfall

Figure 6.40 shows the sensitivity analysis of building for rock fall. Building foundation depth appeared to be the most sensitive vulnerability indicators. Meanwhile the least sensitive indicators, population density, age of people and health of people. Figure 6.41 shows that the susceptibility of the CI (*C*) and landslide intensity (*I*) are the most sensitive clusters followed by surrounding environment (*E*), and impact of the building on people (*P*).

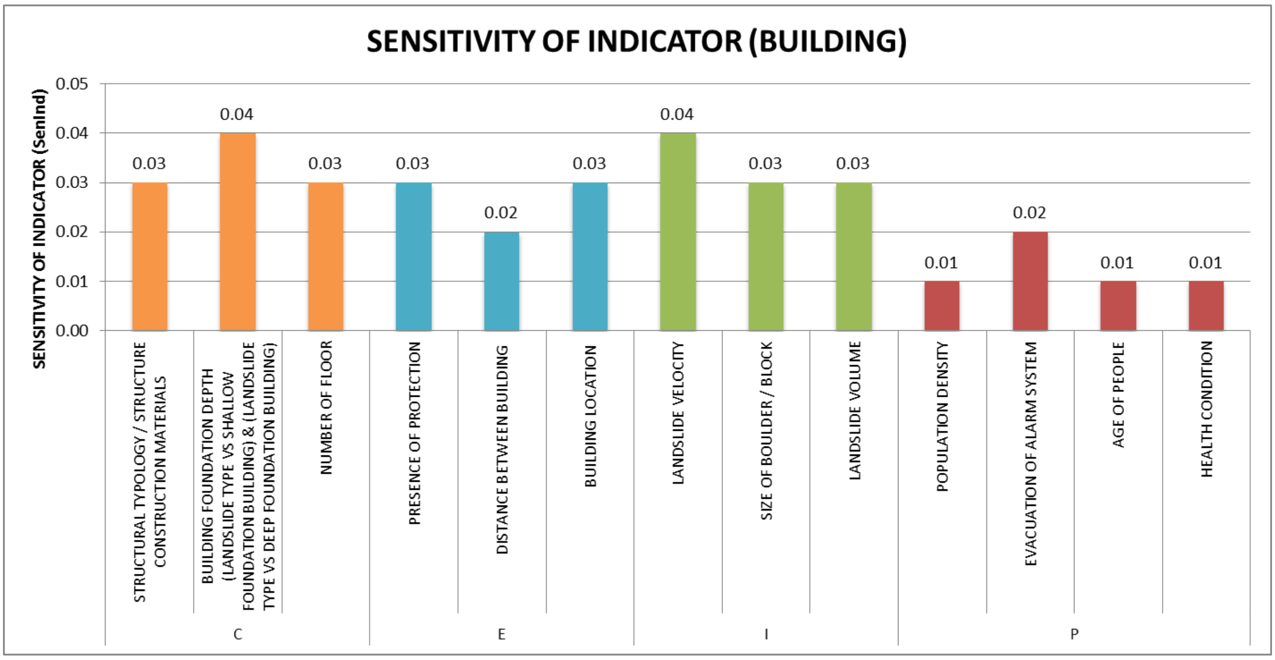


Figure 6.40: Sensitivity of indicator (*Sen$_{Ind}$*) calculated for each indicator for building and rock fall landslide.

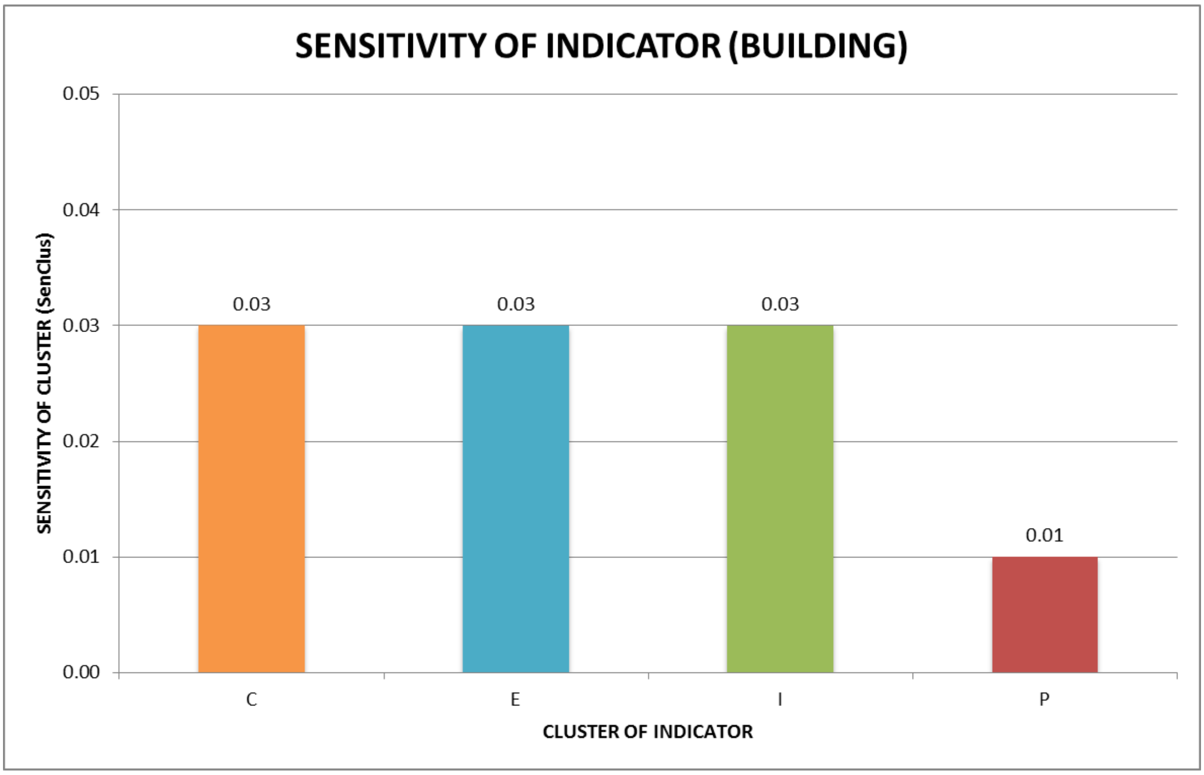


Figure 6.41: Sensitivity of cluster (*Sen$_{Clus}$*) calculated for each indicator for building and rock fall landslide.

Figure 6.42 shows the sensitivity analysis of road. Road maintenance, presence of warning system and landslide velocity appeared to be the most sensitive vulnerability indicators. Meanwhile the least sensitive indicators are road category, road materials, presence of protection, road drainage system, and size of boulder/block. Figure 6.43 shows that all of the clusters; impact of the road operation on the user (*P*), susceptibility of the CI (*C*), surrounding environment (*E*), landslide intensity (*I*) have the same sensitivity.

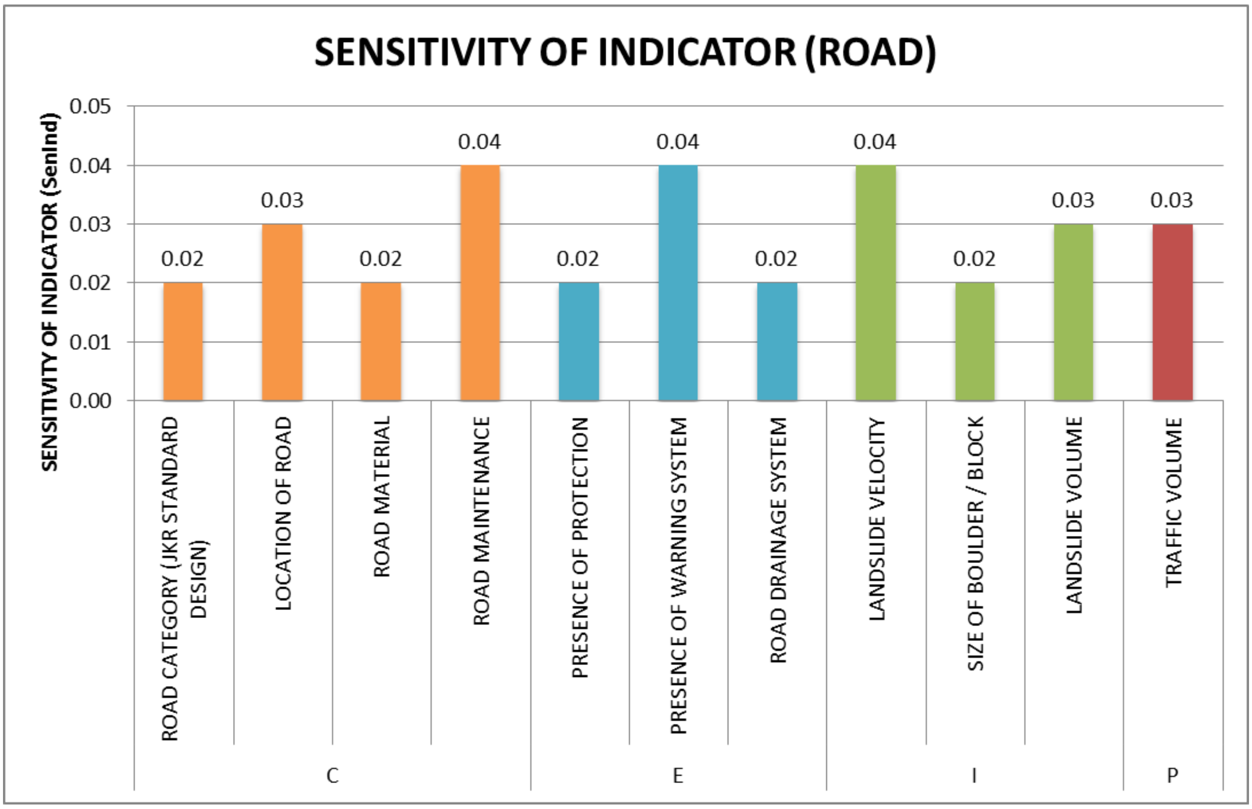


Figure 6.42: Sensitivity of indicator (Sen_{Ind}) calculated for each indicator for road and rock fall landslide.

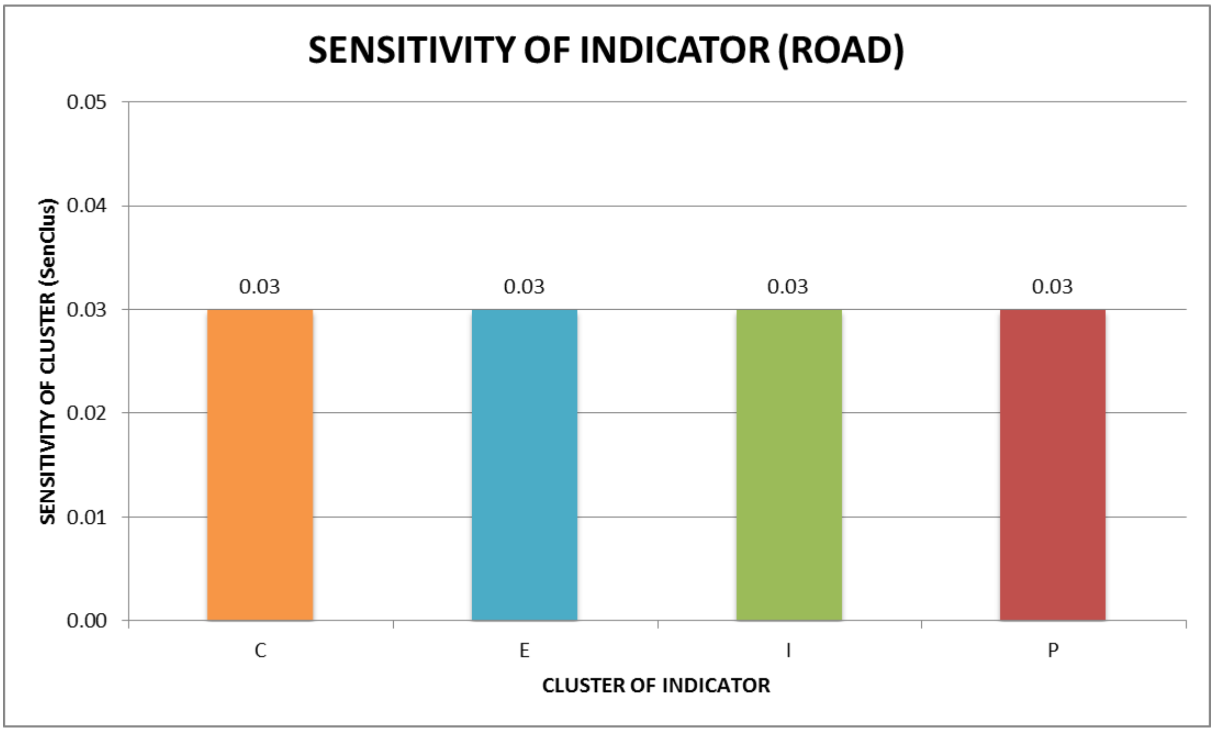


Figure 6.43: Sensitivity of cluster (Sen_{Clus}) calculated for each indicator for road and rock fall landslide.

Figure 6.44 shows the sensitivity analysis of dam. Presence of warning system and population density appeared to be the most sensitive vulnerability indicators. Meanwhile the least sensitive indicators are dam dimension (main structure - height), dam dimension (main structure - length), dam typology/category and dam construction materials. Figure 6.45 shows that the impact of the dam operation on the user (*P*) is the most sensitive cluster followed by the surrounding environment (E) and the landslide intensity (*I*). Susceptibility of the CI (*C*) is the least sensitive cluster of indicators.

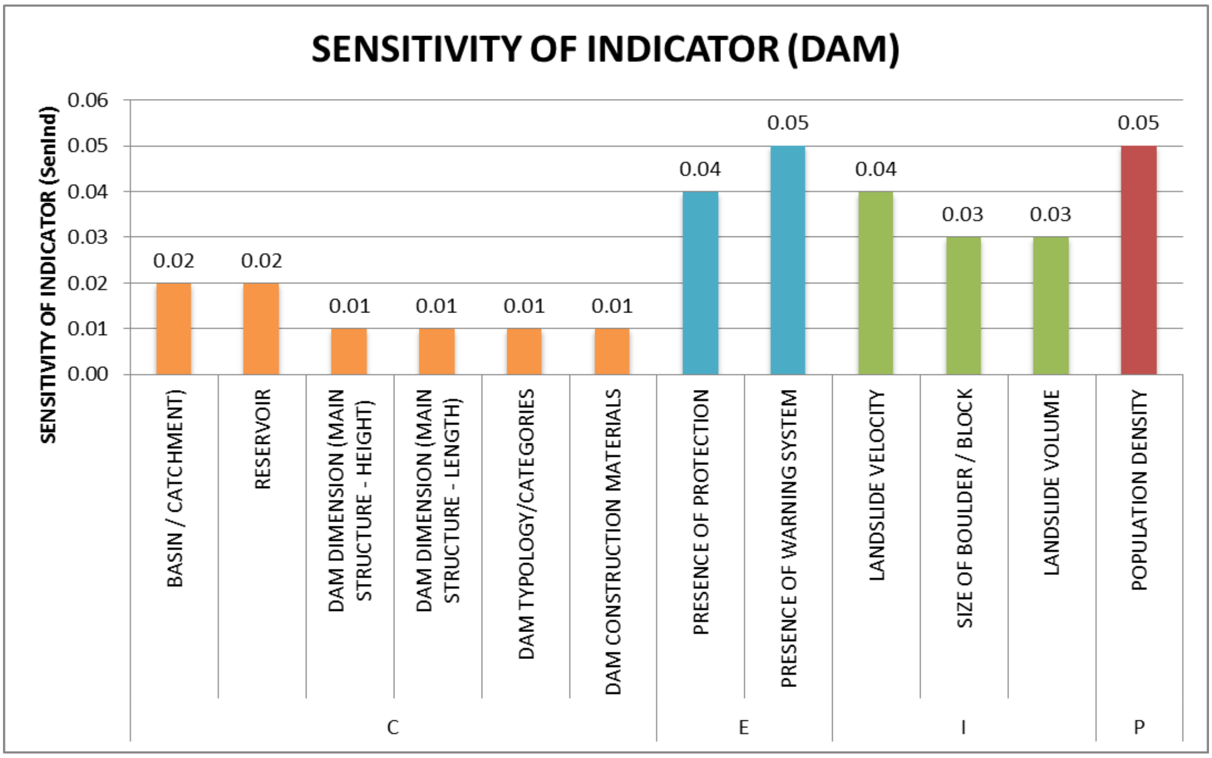


Figure 6.44: Sensitivity of indicator (*Sen*$_{Ind}$) calculated for each indicator for dam and rock fall landslide.

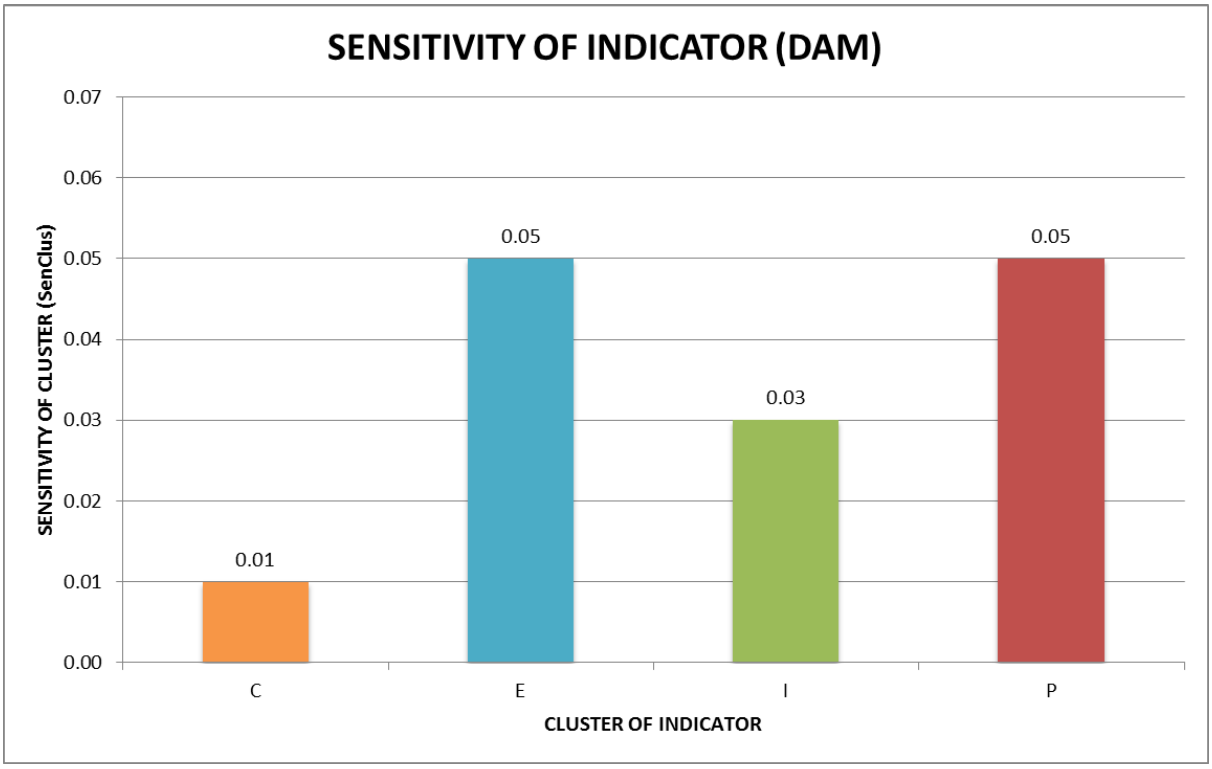


Figure 6.45: Sensitivity of cluster (*Sen*$_{Clus}$) calculated for each indicator for dam and rock fall landslide.

Figure 6.46 shows the sensitivity analysis of TNB powerline. Presence of warning system, landslide velocity and population density appeared to be the most sensitive vulnerability indicators. Meanwhile the least sensitive indicators are right of way (ROW) and slope morphology. Figure 6.47 shows that the landslide intensity (*I*) and the impact of the powerline operation on the user (*P*) are the most sensitive cluster followed by susceptibility of the CI and surrounding environment (*E*).

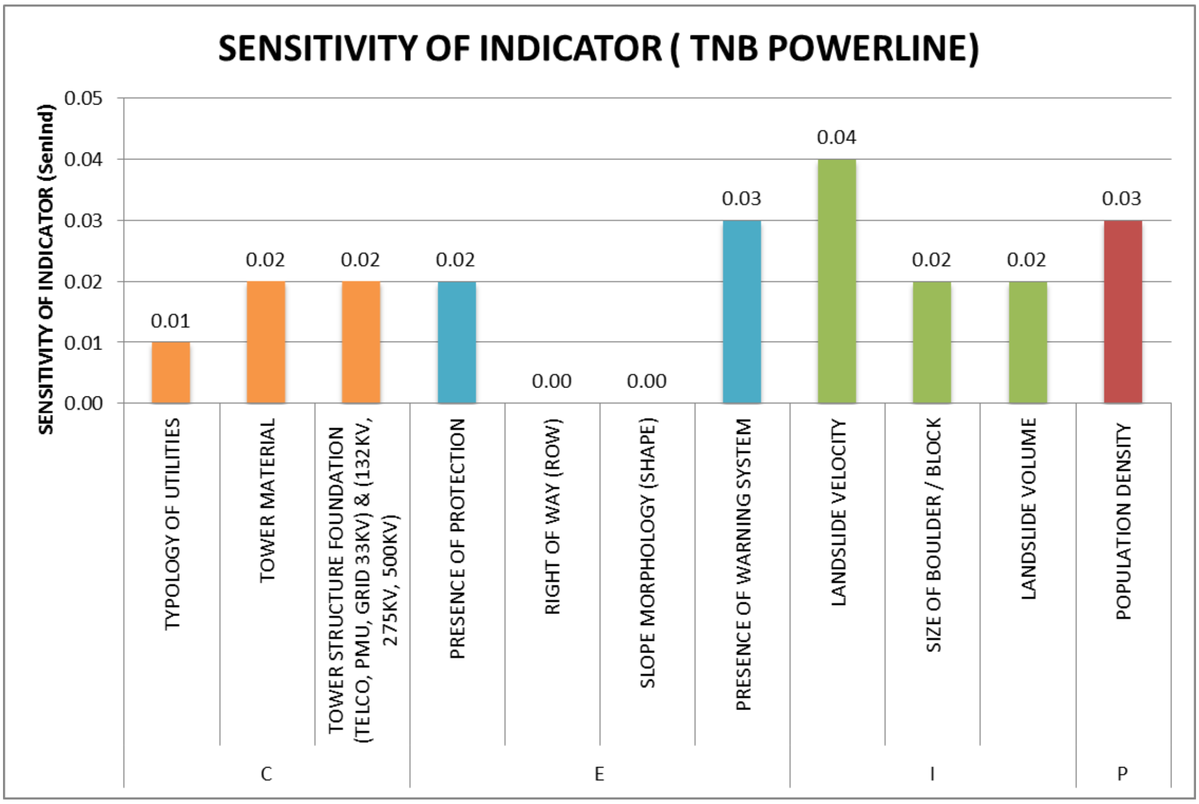


Figure 6.46: Sensitivity of indicator (Sen_{Ind}) calculated for each indicator for TNB powerline and rock fall landslide.

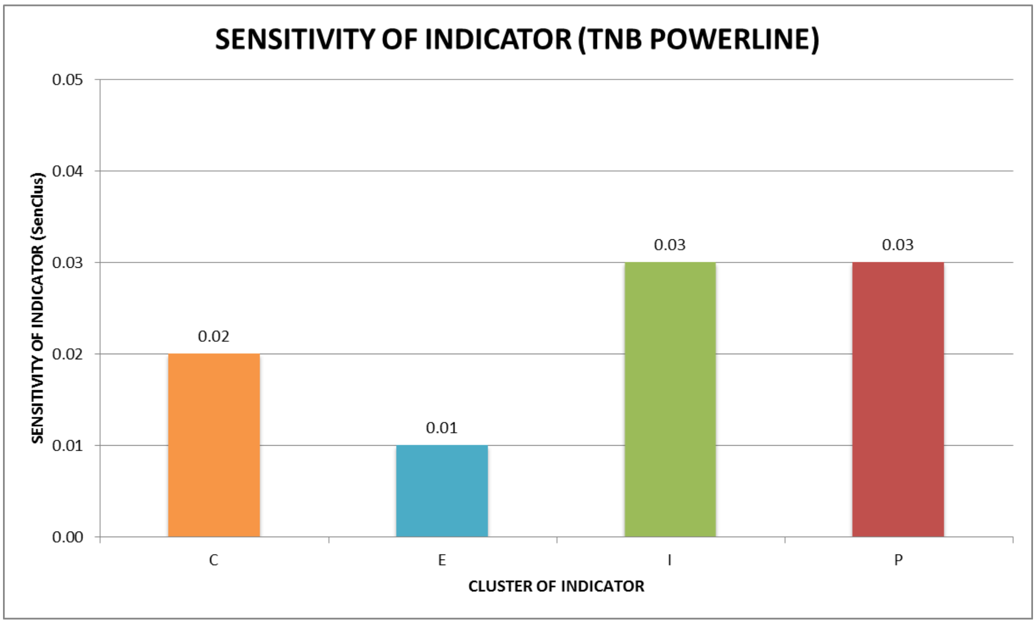


Figure 6.47: Sensitivity of cluster (Sen_{CLus}) calculated for each indicator for TNB powerline and rock fall landslide.

6.7 Landslide Vulnerability Assessment Based on Different Scenarios

6.7.1 FGD with stakeholders

In this experiment, the best case scenarios is expected to produce the lowest vulnerability value and classified as “very low vulnerability” class. On the other hand, the medium case scenario expects the estimated vulnerability value will be classified as “medium vulnerability” class. Finally, the worst case scenario is expected to produce the highest vulnerability value that can be classified as “very high vulnerability” class. Table 6.13 shows the results of the simulated building’s and residential’s landslide vulnerability for best, medium and worst-case scenarios. The best case scenario only produces vulnerability value of 0.42 that can only be classified as “medium vulnerability” class. Furthermore, the medium case scenario has successfully produced vulnerability value that has been classified as “medium vulnerability” class. However, the worst case scenario has only produced 0.8 value which only can be as “very high vulnerability class”. Based on the results we can conclude that further improvement should be made on the indicators, sub-indicators and more importantly on the weight values. The weight values assigned for each sub-indicator and indicator should have good distribution between 0.1 and 1.0. However, the results of the FGD shows that panels tend to give similar score to all indicator and sub-indicators.

Building/Residential:

Table 6.13: Results of the simulated building's and residential's landslide vulnerability for best, medium and worst-case scenarios

Scenario: Best case scenario
Landslide type: Translational/Rotational

Susceptibility of CI (C):
- *Building typology*: Steel structure (T1)
- *Foundation depth*: (For landslide depth <1.5 meter, depth of building foundation >3 meter)
- *Building categories*: Original building
- *Function of building*: Commercial building (office)
- *Number of floor*: Low rise (<3 storey)

Surrounding Environment (E):
- *Presence of protection*: Natural /vegetation protection
- *Presence of water channel*: Non-exist
- *Building orientation from the river*: Third row and above from the river
- *Distance between building*: 3- 5 meter
- *Building location*: Building is located at a distance more than height of slope

Landslide intensity (I):
- *Deposit thickness*: < 1.5 meter
- *Accumulation height*: Height <0.5 meter
- *Landslide volume*: Very Small, <0.001 - 0.5 meter^3

People inside the building (P):
- *Population density*: Low
- *Evacuation of alarm system*: Yes
- *Age of people*: Adults
- *Health condition*: Health (Good)
- *Times of day*: Non- peak hour
- *Day*: Weekdays

Estimated vulnerability value: 0.42
Class of vulnerability: Medium

Scenario: Medium case scenario
Landslide type: Translational/Rotational

Susceptibility of CI (C):
- *Building typology*: Timber Structure
- *Foundation depth*: (For landslide depth 5 - 10 meter, depth of building foundation >3 meter)
- *Building categories*: Original building with certified extension
- *Function of building*: Hospitals
- *Number of floor*: Medium rise (4 to 5 storey)

Surrounding Environment (E):
- *Presence of protection*: Non- engineered protection system
- *Presence of water channel*: Exist
- *Building orientation from the river*: Second row from the river
- *Distance between building*: 3-5 meter
- *Building location*: Building is located at the toe of slope

Landslide intensity (I):
- *Deposit thickness*: 5 meter - 20 meter
- *Accumulation height*: 0.5 meter < height < 2 meter
- *Landslide volume*: Medium, 10,000 - 50,000 meter^3

People inside the building (P):
- *Population density*: Medium
- *Evacuation of alarm system*: Yes
- *Age of people*: Children
- *Health condition*: Health (Poor)
- *Times of day*: Non- peak hour
- *Day*: Weekdays

Estimated vulnerability value: 0.76
Class of vulnerability: Medium

Scenario: Worst case scenario
Landslide type: Translational/Rotational

Susceptibility of CI (C):
- *Building typology*: Light weight
- *Foundation depth*: (For landslide depth >20 meter, depth of building foundation >3 meter)
- *Building categories*: Original building with non-certified extension
- *Function of building*: Residential
- *Number of floor*: High rise (>6 storey)

Surrounding Environment (E):
- *Presence of protection*: No protection
- *Presence of water channel*: Exist
- *Building orientation from the river*: First row from the river
- *Distance between building*: <3 meter
- *Building location*: Building is located at the mid-height of slope

Landslide intensity (I):
- *Deposit thickness*: >20 meter
- *Accumulation height*: Height > 2 meter
- *Landslide volume*: Very Large, >>500,000 meter^3

People inside the building (P):
- *Population density*: High
- *Evacuation of alarm system*: No
- *Age of people*: Senior Citizen (>85 years old)
- *Health condition*: Disabled person
- *Times of day*: Peak hour
- *Day*: Weekend/ Public holiday

Estimated vulnerability value: 0.80
Class of vulnerability: High

6.7.2 FGD with internal experts

In this experiment, the best-case scenarios is expected to produce the lowest vulnerability value and classified as “very low vulnerability” class. On the other hand, the medium case scenario expects the estimated vulnerability value will be classified as “medium vulnerability” class. Finally, the worst case scenario is expected to produce the highest vulnerability value that can be classified as “very high vulnerability” class. Table 6.14 describes the results of the simulated building’s and residential’s landslide vulnerability for best, medium and worst-case scenarios.

The best-case scenario produced vulnerability value of 0.21 that only achieved the class of “low vulnerability”. Furthermore, the medium case scenario has successfully produced vulnerability value that fall into “medium vulnerability” class with the value of 0.50. The worst-case scenario successfully achieved “very high vulnerability” class with the value of 0.93. Based on the results, we can conclude that the indicators, sub-indicators have been improvised better and the weight values have good distribution which shown from the vulnerability value. For clarification, Figure 6.48 which highlighted the arrangement of indicators and sub-indicators for building and residential vulnerability of the best-case scenario is presented. On top of that, Figure 6.49 which shows the corresponding calculation for building and residential vulnerability of the best-case scenario is also put forward.

Table 6.14: Results of the simulated building's and residential's landslide vulnerability for best, medium and worst-case scenarios.

Scenario: Best case scenario
Landslide type: Translational/Rotational

Susceptibility of CI (C):
- *Structural Typology (0.14): Steel structure (0.04)*
- *Foundation Depth (0.12): Landslide Type Vs Deep Foundation Building : Accumulation height/landslide depth <1.5 meter, deep foundation (pile) (0.01)*
- *Number of floor (0.10): High rise (> 5 storey) (0.02)*

Surrounding Environment (E):
- *Presence of protection (0.07): Engineered protection system (0.01)*
- *Distance between building (0.04): < 3 meter (0.04)*
- *Building location (0.07): Building is located at a distance more than height of slope (0.01)*

Landslide intensity (I):
- *Accumulation height (0.15): Height < 0.2 meter (0.02)*
- *Landslide volume (0.18): Very Small, < 0.001 – 0.5 meter3 (0.05)*

People inside the building (P):
- *Population density (0.04): Low (0.01)*
- *Evacuation of alarm system (0.03): Yes (0.01)*
- *Age of people (0.03): Adults (0.01)*
- *Health condition (0.03): Health (Good) (0.01)*

Estimated vulnerability value: 0.21
Class of vulnerability: Low

Scenario: Medium case scenario
Landslide type: Translational/Rotational

Susceptibility of CI (C):
- *Building typology: Masonry structure*
- *Building Foundation Depth (Landslide Type Vs Deep Foundation Building: Accumulation height/landslide depth > 5 meter, deep foundation (pile)*
- *Number of floor: Medium rise (2 - 5 storey)*

Surrounding Environment (E):
- *Presence of protection: Non- engineered protection system*
- *Distance between building: 3-5 meter*
- *Building location: Building is located at the toe of slope*

Landslide intensity (I):
- *Accumulation height: 0.5 meter < Height < 2 meter*
- *Landslide volume: Medium, 10,000 - 50,000 meter^3*

People inside the building (P):
- *Population density: Medium*
- *Evacuation of alarm system: Yes*
- *Age of people: Children*
- *Health condition: Health (Poor)*

Estimated vulnerability value: 0.50
Class of vulnerability: Medium

Scenario: Worst case scenario
Landslide type: Translational/Rotational

Susceptibility of CI (C):
- *Building typology: Light weight*
- *Building Foundation Depth (Landslide Type Vs Shallow Foundation Building): Accumulation height/landslide depth > 5 meter, shallow foundation (pad footing)*
- *Number of floor: Low rise (Single storey)*

Surrounding Environment (E):
- *Presence of protection: No protection*
- *Distance between building: <3 meter*
- *Building location: Building is located at the mid-height of slope*

Landslide intensity (I):
- *Accumulation height: > 2 meter*
- *Landslide volume: Very Large, > 250,000 meter^3*

People inside the building (P):
- *Population density: High*
- *Evacuation of alarm system: No*
- *Age of people: Senior Citizen (> 85 years old)*
- *Health condition: Disabled person*

Estimated vulnerability value: 0.93
Class of vulnerability: High

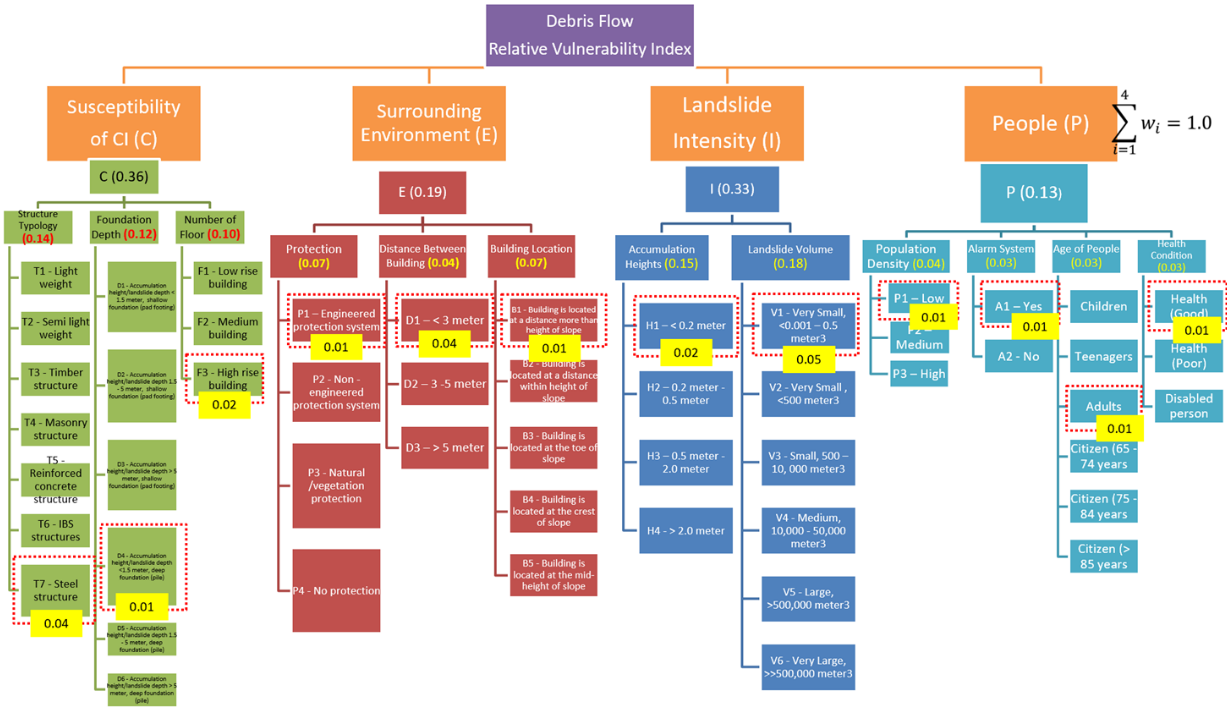


Figure 6.48: The arrangement of indicators and sub-indicators for building and residential vulnerability of the best-case scenario

Landslide Vulnerability Assessment (Scenario 1)

Landslide Type: Translational/ Rotational
CI Type: Building/Residential
Susceptibility of CI (C):

VULNERABILITY INDEX

((0.056) + (0.0012) + (0.002)) + ((0.0007) + (0.0016) + (0.0007)) + ((0.003) + (0.009)) + ((0.0004) + (0.0003) + (0.0003) + (0.0003))

VI = 0.0755 (Very Low Vulnerability)

Slight non-structural damage, stability not affected, furnishing or fitting damaged and no human casualty expected.

Figure 6.49: The corresponding calculation for building and residential vulnerability of the best-case scenario.

Table 6.15: Different weight of clusters (scenario 1).

COMPONENT	WEIGHTAGE (BUILDING, ROAD & TNB POWERLINE)	WEIGHTAGE (DAM)
CRITICAL INFRASTUCTURE [C]	0.30	0.30
SURROUNDING ENVIRONMENT [E]	0.30	0.10
LANDSLIDE INTENSITY [I]	0.30	0.50
PEOPLE DENSITY [P]	0.10	0.10

LANDSLIDE TYPE	ROTATIONAL / TRANSLATIONAL		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.20	0.52	0.94
ROAD	0.30	0.49	0.86
DAM	0.18	0.53	0.95
TNB POWERLINE	0.45	0.60	0.92

LANDSLIDE TYPE	DEBRIS FLOW		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.18	0.49	0.95
ROAD	0.22	0.43	0.86
DAM	0.11	0.35	0.95
TNB POWERLINE	0.43	0.59	0.93

LANDSLIDE TYPE	ROCK FALL		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.19	0.49	0.97
ROAD	0.30	0.45	0.88
DAM	0.17	0.46	0.91
TNB POWERLINE	0.45	0.62	0.95

Table 6.16: Different weight of clusters (scenario 2).

COMPONENT	WEIGHTAGE
CRITICAL INFRASTUCTURE [C]	0.90
SURROUNDING ENVIRONMENT [E]	0.03
LANDSLIDE INTENSITY [I]	0.04
PEOPLE DENSITY [P]	0.03

LANDSLIDE TYPE	ROTATIONAL / TRANSLATIONAL		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.20	0.53	0.94
ROAD	0.29	0.48	0.86
DAM	0.20	0.51	0.84
TNB POWERLINE	0.55	0.71	0.93

LANDSLIDE TYPE	DEBRIS FLOW		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.20	0.47	0.94
ROAD	0.27	0.48	0.86
DAM	0.20	0.45	0.84
TNB POWERLINE	0.54	0.71	0.93

LANDSLIDE TYPE	ROCK FALL		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.20	0.47	0.95
ROAD	0.29	0.48	0.87
DAM	0.20	0.48	0.84
TNB POWERLINE	0.55	0.71	0.94

Table 6.17: Different weight of clusters (scenario 3).

COMPONENT	WEIGHTAGE
CRITICAL INFRASTUCTURE [C]	0.70
SURROUNDING ENVIRONMENT [E]	0.20
LANDSLIDE INTENSITY [I]	0.05
PEOPLE DENSITY [P]	0.05

LANDSLIDE TYPE	ROTATIONAL / TRANSLATIONAL		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.22	0.53	0.94
ROAD	0.30	0.50	0.86
DAM	0.20	0.52	0.88
TNB POWERLINE	0.50	0.67	0.92

LANDSLIDE TYPE	DEBRIS FLOW		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.20	0.47	0.94
ROAD	0.26	0.48	0.86
DAM	0.17	0.42	0.88
TNB POWERLINE	0.49	0.67	0.93

LANDSLIDE TYPE	ROCK FALL		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.21	0.48	0.96
ROAD	0.30	0.49	0.88
DAM	0.19	0.47	0.87
TNB POWERLINE	0.51	0.68	0.95

Table 6.18: Different weight of clusters (scenario 4).

COMPONENT	WEIGHTAGE
CRITICAL INFRASTUCTURE [C]	0.50
SURROUNDING ENVIRONMENT [E]	0.10
LANDSLIDE INTENSITY [I]	0.30
PEOPLE DENSITY [P]	0.10

LANDSLIDE TYPE	ROTATIONAL / TRANSLATIONAL		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.22	0.52	0.94
ROAD	0.33	0.51	0.84
DAM	0.19	0.52	0.91
TNB POWERLINE	0.46	0.63	0.91

LANDSLIDE TYPE	DEBRIS FLOW		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.20	0.48	0.94
ROAD	0.25	0.48	0.84
DAM	0.14	0.39	0.91
TNB POWERLINE	0.44	0.63	0.92

LANDSLIDE TYPE	ROCK FALL		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.21	0.49	0.97
ROAD	0.33	0.49	0.87
DAM	0.18	0.48	0.84
TNB POWERLINE	0.47	0.65	0.95

Table 6.19: Different weight of clusters (scenario 5).

COMPONENT	WEIGHTAGE
CRITICAL INFRASTUCTURE [C]	0.30
SURROUNDING ENVIRONMENT [E]	0.10
LANDSLIDE INTENSITY [I]	0.50
PEOPLE DENSITY [P]	0.10

LANDSLIDE TYPE	ROTATIONAL / TRANSLATIONAL		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.24	0.53	0.93
ROAD	0.33	0.52	0.84
DAM	0.18	0.53	0.95
TNB POWERLINE	0.42	0.58	0.90

LANDSLIDE TYPE	DEBRIS FLOW		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.20	0.49	0.94
ROAD	0.25	0.49	0.85
DAM	0.11	0.35	0.95
TNB POWERLINE	0.38	0.58	0.92

LANDSLIDE TYPE	ROCK FALL		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.22	0.50	0.98
ROAD	0.33	0.51	0.89
DAM	0.17	0.46	0.91
TNB POWERLINE	0.43	0.61	0.97

Table 6.20: Different weight of clusters (scenario 6).

COMPONENT	WEIGHTAGE
CRITICAL INFRASTUCTURE [C]	0.10
SURROUNDING ENVIRONMENT [E]	0.05
LANDSLIDE INTENSITY [I]	0.80
PEOPLE DENSITY [P]	0.05

LANDSLIDE TYPE	ROTATIONAL / TRANSLATIONAL		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.27	0.54	0.92
ROAD	0.32	0.53	0.87
DAM	0.19	0.57	0.98
TNB POWERLINE	0.37	0.53	0.88

LANDSLIDE TYPE	DEBRIS FLOW		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.21	0.50	0.93
ROAD	0.25	0.51	0.89
DAM	0.07	0.31	0.98
TNB POWERLINE	0.31	0.53	0.91

LANDSLIDE TYPE	ROCK FALL		
CRITICAL INFRASTRUCTURE	BEST SCENARIO (VI)	MEDIUM SCENARIO (VI)	WORST SCENARIO (VI)
BUILDING	0.25	0.52	0.99
ROAD	0.32	0.54	0.95
DAM	0.16	0.48	0.93
TNB POWERLINE	0.38	0.58	0.99

7.0 LANDSLIDE VULNERABILITY AND RISK ASSESSMENTS AT HABU, CAMERON HIGHLANDS

7.1 Description of Study Area

The proposed landslide vulnerability and risk evaluation and mapping discussed in the previous section will be tested at Ringlet and Lembah Bertam, Cameron Highland, Pahang (Figure 7.1 and Figure 7.2). The study site at Ringlet and Lembah Bertam cover about 3.66 km^2 and 5.00 km^2 respectively.

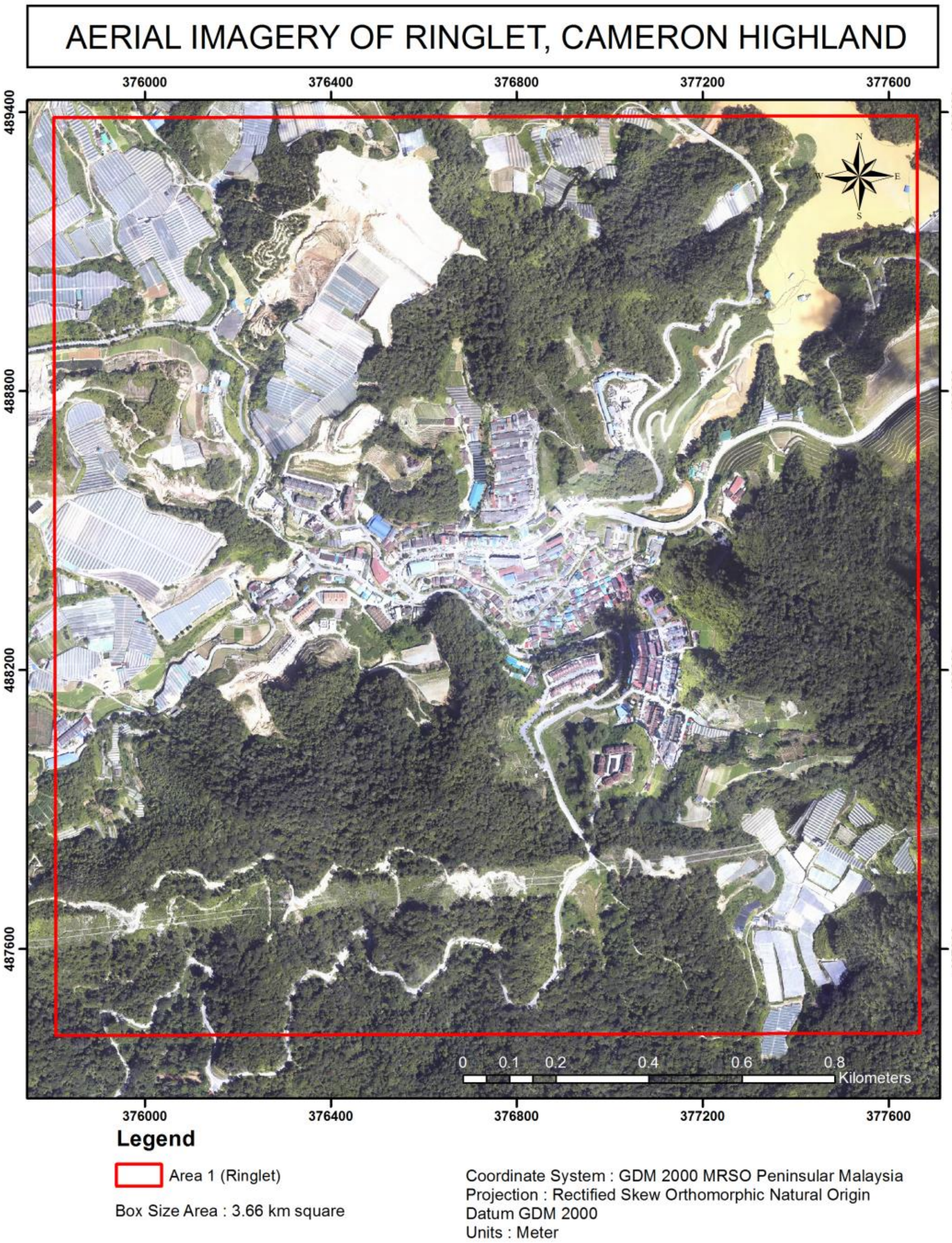


Figure 7.1: Location of study area at Ringlet, Cameron Highlands.

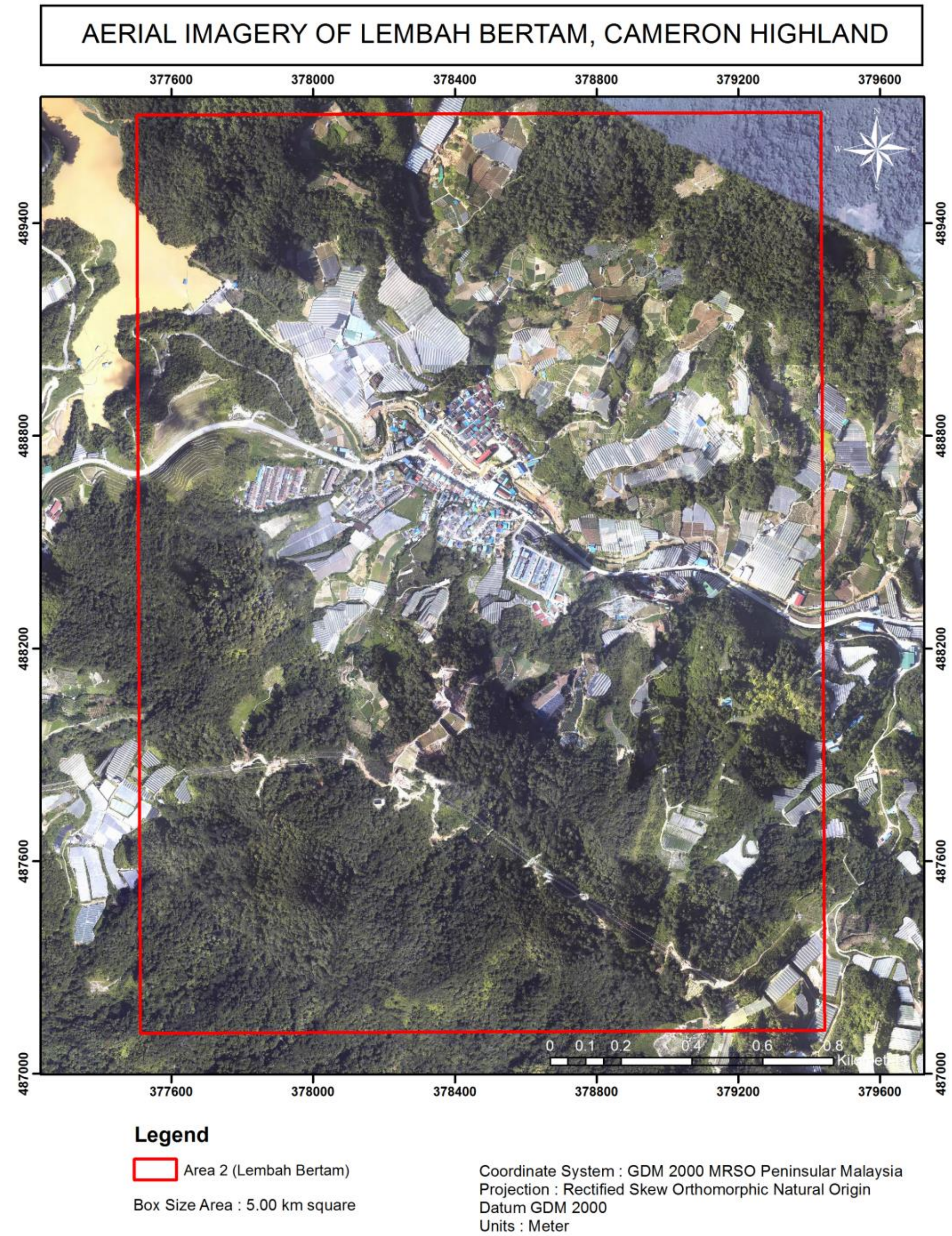


Figure 7.2: Location of study area at Lembah Bertam, Cameron Highlands.

7.1.1 Geology of Study Area

Lithology

Generally, geology of Cameron Highlands divided into two main lithologies, namely granite and schist. Granite made up most of the Cameron Highland (84.65% area) meanwhile shicst are found on west of Cameron Highlands as roof pendant (15.35% area).

Granite

Granite of Cameron Highland is part of Main Range Granite dated Triassic Age around 207-230 million years ago (Bignell & Snelling, 1997). Main Range Granite formed Titiwangsa Range, where Cameron Highland is located.

Generally, Main Range Granite are described as medium to coarse grained biotite granite with feldspar megacryst (Krahenbuhl, 1991) which can be found in the study area Figure 7.3. However, variation of granite can also be found in the study area as fine to medium grained granite.

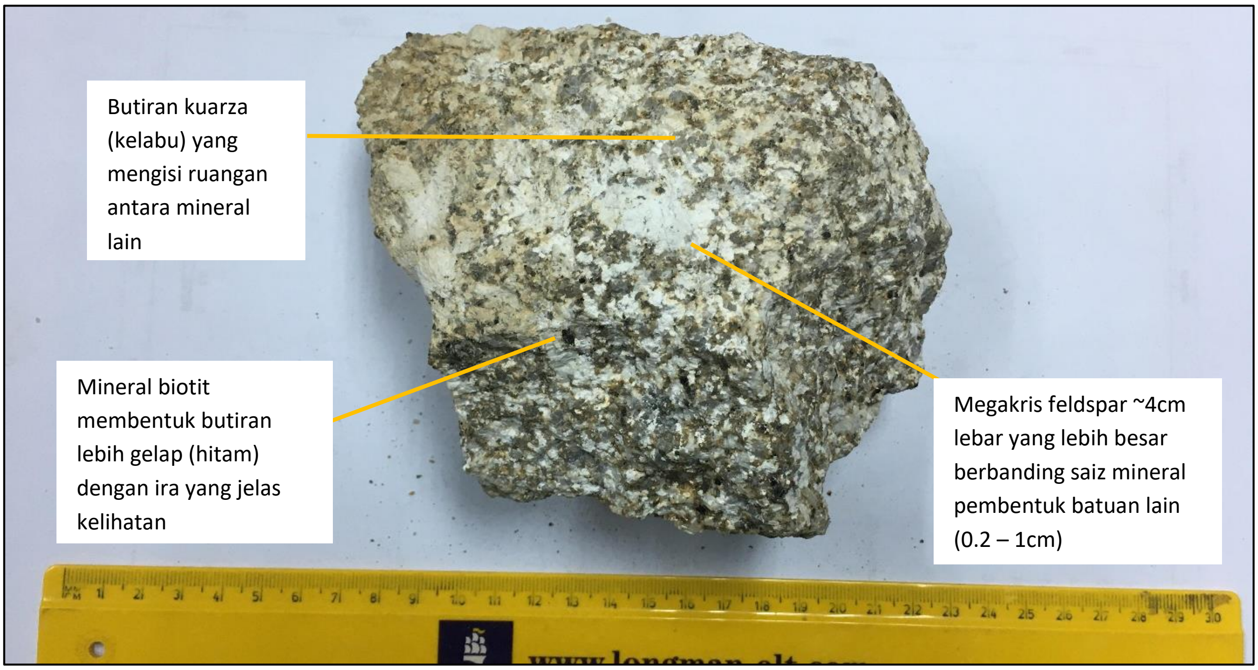


Figure 7.3: Granite sample shows medium to coarse grained with feldspar megacryst.

Granite in Cameron Highlands had been jointed and faulted due to tectonic stress. Weathering profile of the granite is described as Grade I that is light grey, and Grade II with slightly brown. Grade IV-VI granite formed the residual soil has reddish brown in colour due to existence of iron element from biotite that has been weathered. However, the weathering of the granite is not continuous from the surface downward, in fact, it is controlled by geological structure such as faults and joints that allow the existence of fresh rock boulders inside the weathered granite. Figure 7.4 shows the weathered profile of granite body that can be observed on site.

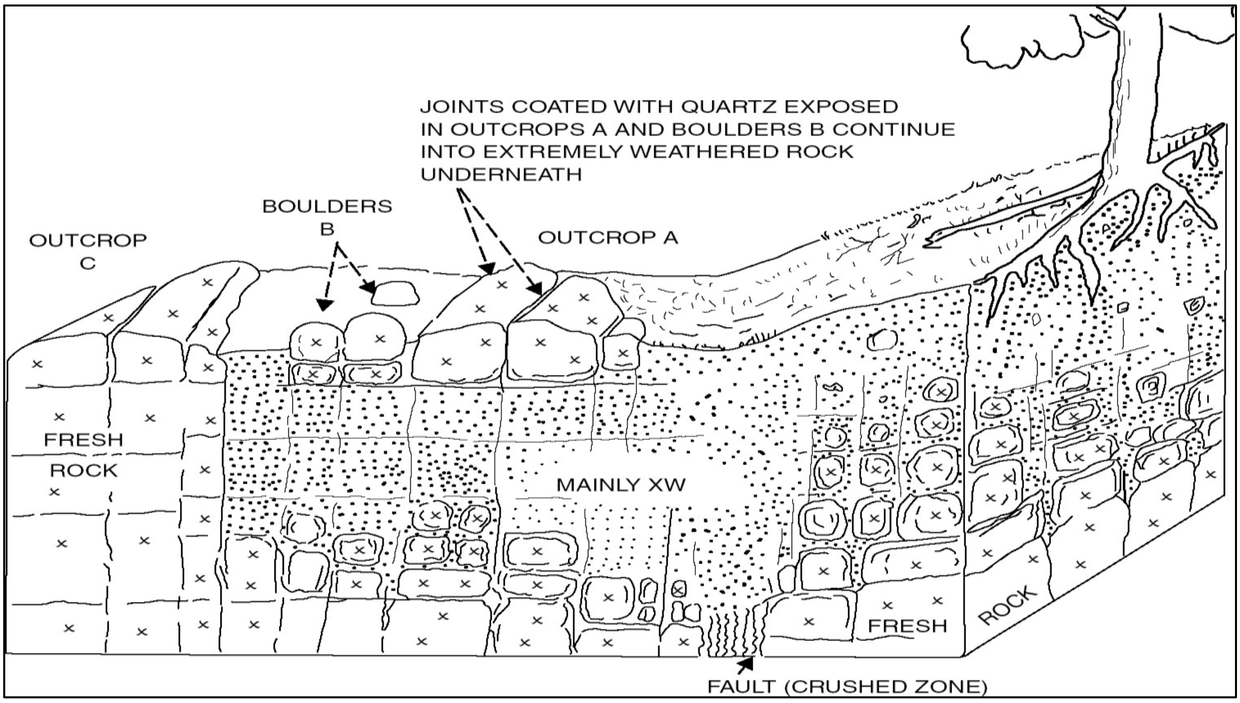


Figure 7.4: Weathering profile of granitic body that describe the existance of fresh rock boulders in the residual soil of highly weathered granite.

Schist

Schist in Cameron Highlands formed as roof pendant, which is a body of schist left islanated on the intrusive granite body. Schist that found in the study area is quartz mica schist. the age of the schist is interpreted around Palaeozoic due to younger intrusive granite is defined as Triassic.

Figure 7.5: Schist that can be found in the Cameron Higlands. The left sample shows weathering Grade II while the right shows weathering Grade III of schist**.**

Distribution of schist is limited to west part of Cameron Highlands. However, outcrops can be found in Ringlet area (Figure 7.6) and Habu (Figure 7.7). The difference of lithology between granite and schist can be identified by the different soil properties. Weathered schist did not form rounded rock boulders like granite, but the the boulders are in tabular shape with darker reddish soil colour. Schist residual soil colours are the oxidation product of iron element in biotite.

Figure 7.6: Schist outcrop in Ringlet shows distinct foliation planes towards west with reddish in colour due to weathering. White banding parallel to foliation are quartz veins filling the foliation planes.

Figure 7.7: Schist outcrop in Habu exposed due to cutslope. The schist is identified as Grade III-IV with foliation dipping towards west.

7.2 Landslide Vulnerability and Risk Assessments Framework

The landslide vulnerability and risk assessment involve different phases of data processing and modelling:

1. Geospatial data processing and analysis
2. Development of landslide inventory
3. Acquisition of landslide hazard map
4. Mapping and characterization of CI
5. Field survey
6. Estimation of vulnerability and risk for CI
7. Evaluation of the estimated vulnerability and risk based on expert judgment

The first phase involves detailed processing of multi-resolution remote sensing data and other supporting data to develop landslide inventory map and CI map. The acquisition of hazard map also takes this into consideration. Landslide inventory map is required to support detailed characterization of landslide type and intensity as required by the vulnerability assessment method. The landslide hazard map will be combined with the vulnerability map for landslide risk assessment. For this, the hazard map is expected to be detail for proper integration with landslide vulnerability map. The hazard map should be developed based on detailed requirement by the vulnerability assessment approach. Characterization of CI in the study area is done based on the indicators (C, E, and P) of the landslide vulnerability assessment approach. This process should be supported by detailed field survey and the final CI map is developed based on satellite image and aerial photos interpretation, and data collected during field survey. The landslide risk index for each CI is estimated by combining vulnerability index and hazard index assigned for each polygon of CI. Finally, the estimated vulnerability and risk indexes are evaluated by the experts.

7.2.1 Geospatial Data Processing and Analysis

In this project acquisition of remotely sensed data includes topographic laser scanning or also known as light detection and ranging (LiDAR), high and medium resolution satellite imagery. This data is required to extract important information on the critical element-at-risk of the study area. Each element-at-risk will be identified and its important and relevant characteristics i.e. types, materials, dimensions and locations will be extracted from the LiDAR and satellite imagery. The pre-processing of high-resolution satellite imagery involves the following task:

1. Geometric correction
2. Radiometric correction
3. Feature extraction prior to classification
4. Quality Assurance (QA) and Quality Control (QC)

In addition, the interpretation of CI characteristics is supported by high spatial resolution aerial photos obtained in the study area. The aerial photos have been oriented (relative and absolute orientations) based on control points obtained by on-board GPS attached on the Unmanned Aerial Vehicle (UAV). The photogrammetric processing approach on the aerial photos produces digital terrain model (DTM), digital surface model (DSM) and orthophoto of the study area. Landslide inventory in the study area is developed using LiDAR data.

7.2.2 Development of landslide inventory

The landslide inventory map is produced based on the manual interpretation of LiDAR data acquired by JMG in 2015. The DTM from LiDAR has been used to delineate the area of landslide, possible area of landslide runout and detailed characteristics of each landslide as required by the landslide intensity (*I*) indicator of the landslide vulnerability assessment i.e. landslide volume, landslide velocity and accumulation height. There are in total about 56 and 54 landslides identified at Ringlet and Lembah Bertam respectively. Basic principles and methods of landslides identification and detection are detailed out in the followings sub-sections. In order to identify the location of CI affected by the landslide area, the expert based landslide runout area was developed based on the geomorphologic and topographic features of the suspected area.

a) <u>Landslides identification</u>

Understanding some basic geologic and geomorphologic features associated with a landslide is the key to reliable landslide detections, either in the field or from remotely sensed images. Figure 7.8 illustrates the common geomorphic features that are associated in a landslide.

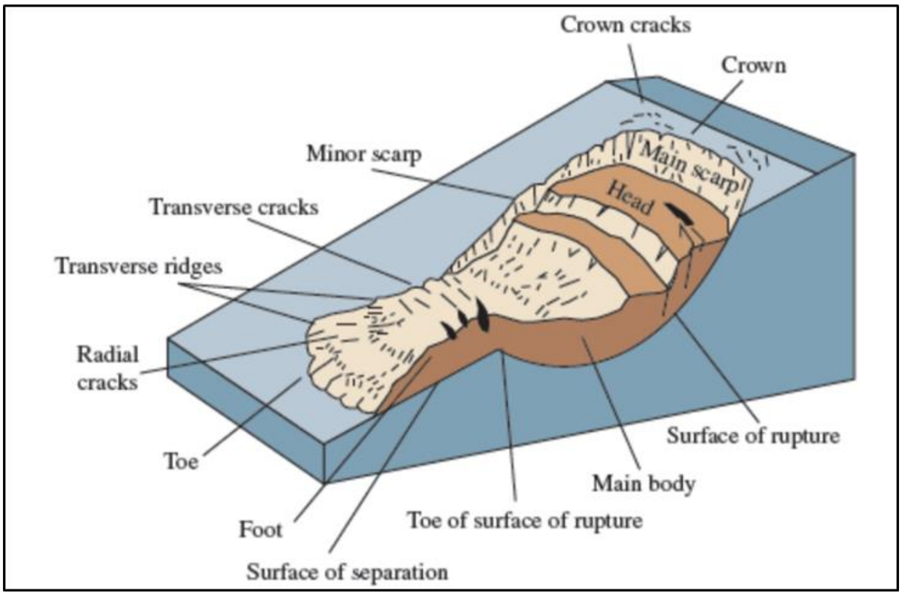


Figure 7.8: An idealised sketch of a landslide (rotational slides or slump) and the associated geomorphological features. (Varnes, 1978).

Some basic examples of landslide detection based on pattern of contour lines are shown in Figure 7.9. In this exercise, drainage and topographic keys, such as divergent contours, opposing contours, crenulated contours, arcuate headscarp evacuation areas, and isolated topographic benches, are used to recognise anomalous site characteristics typical of landslides.

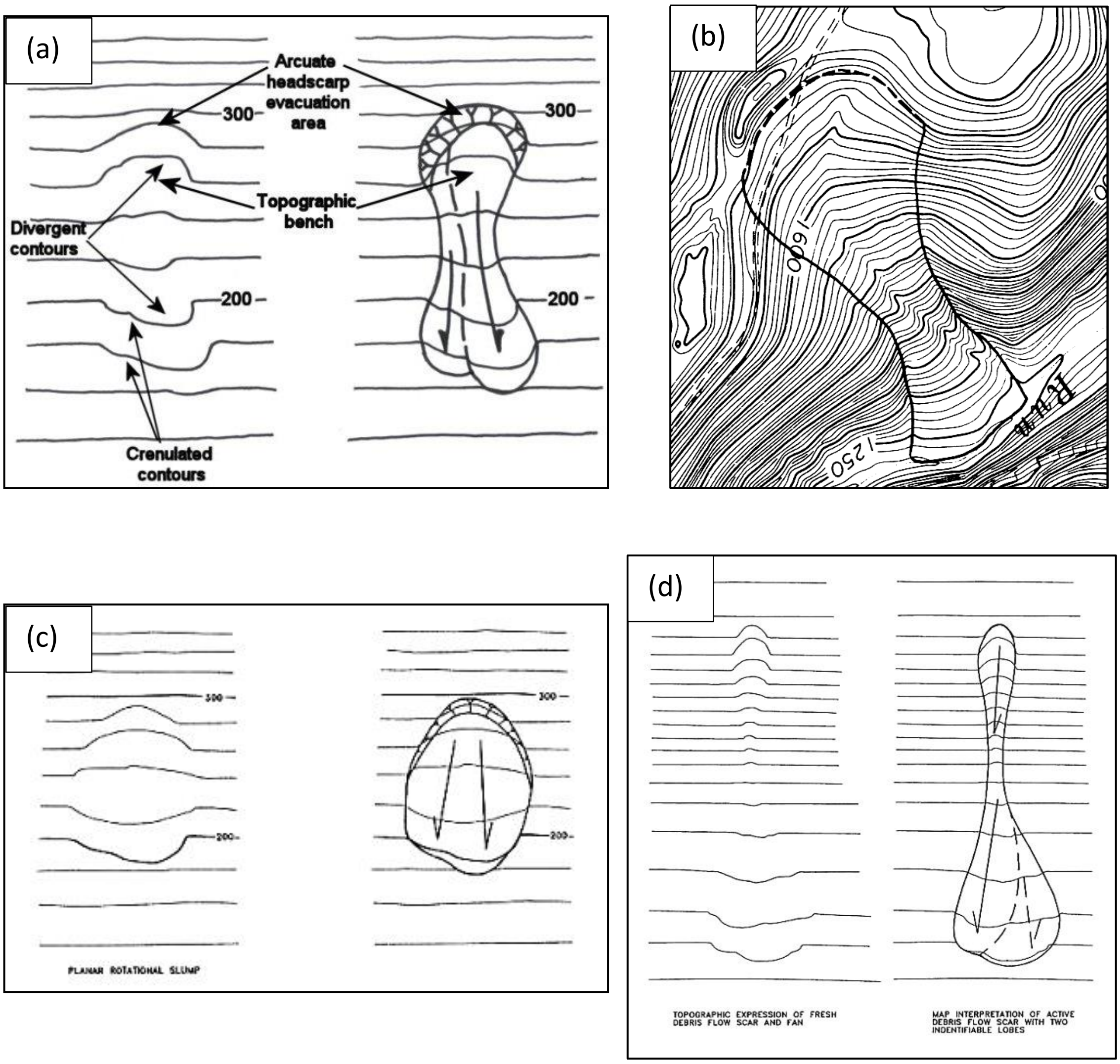


Figure 7.9: Landslide detection based on topographic expressions and pattern of contour lines (a) Earthflows, (b) Actual example of earthflow in the Appalachian highlands mapped by USGS, (c) Topographic expression of a rotational slump, such as commonly occur in the soil regolith overlying resistant bedrock, (d) Topographic expression of debris flow scar and fan. (Rogers, 1995).

Features on the ground surface provide the key to understanding the details of landslide types, processes and causes. Landslide deposits can be classified by age and type of movement according to the features observed on the ground surface. Therefore, particular attention must be paid to these features in landslide detection and mapping from the remotely sensed images and/or topographic map. The boundaries of landslide deposits may appear gradational, but a boundary may actually be a zone of suhparallel cracks and bulges that mark a shear zone.

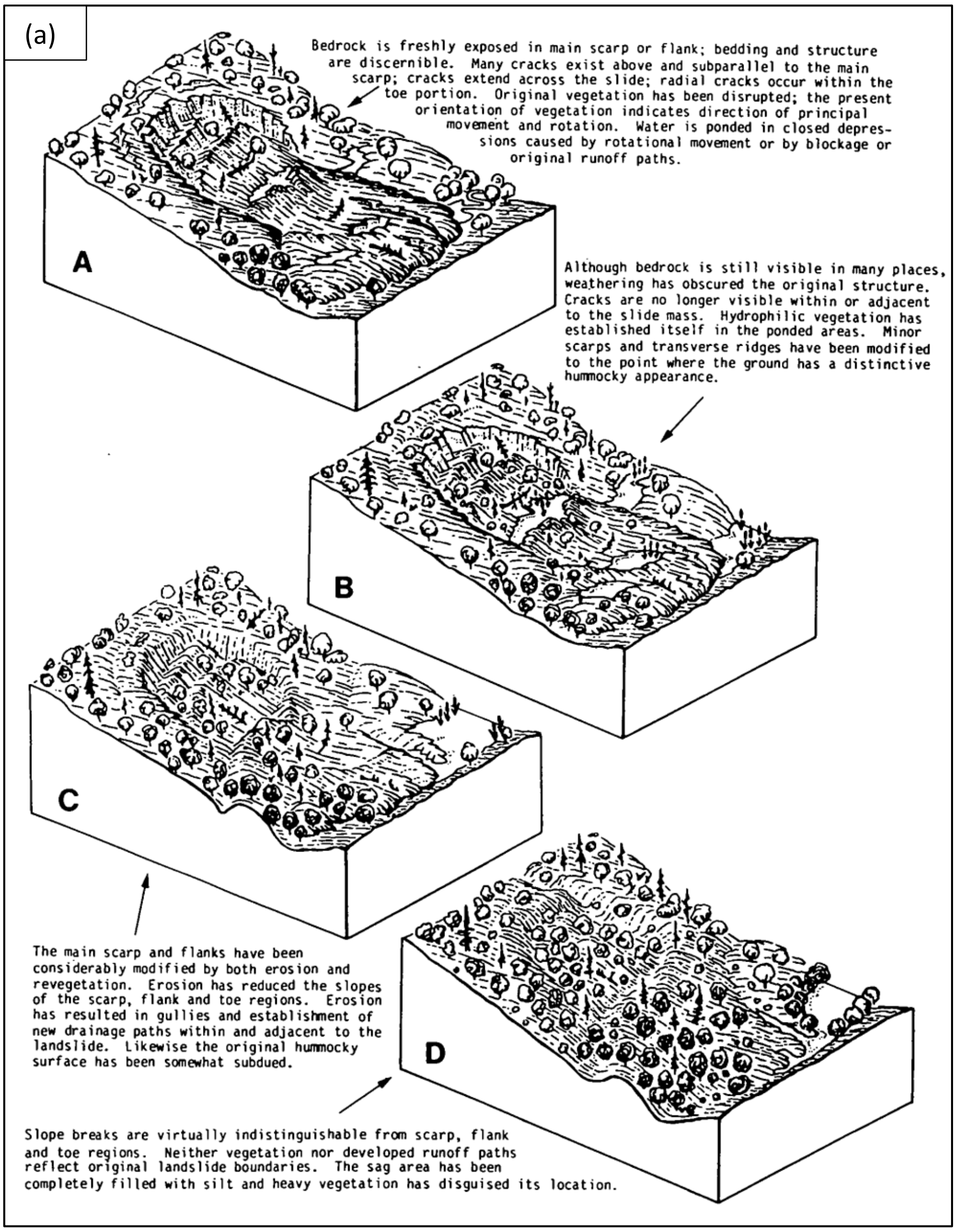
An active landslide may affect existing structures, utilities, and other man-made features in ways that provide insight into the processes and cause of the feature. Cracks in pavement, buildings, and other brittle materials can support inferences about the stress produced by movement of the landslide. The timing of breakage of water lines, electrical cables, and similar utilities can suggest the sequence of deformation before field observations or supplement observations of continuing movement. Measuring the tilt of structures assumed to be vertical or horizontal before movement can give an idea of the amount of displacement on certain parts of the landslide.

The geometry and nature of the sliding surface are among the most important of the subsurface conditions in landslide evaluations. Surface measurements can be employed to estimate the shape of the slip surface. A series of lines is projected through stations used to construct a topographic cross section from the main scarp to the toe of the landslide. By graphical representation, the lines define the probable slip surface can thus be projected to estimate landslide's thickness and volume. Hutchinson (1983) noted several other techniques using surface observations to infer the slip surface and related subsurface movement. Seismic-refraction and electrical-resistivity techniques (Carroll et al. 1968; Miller et al. 1980; Cummings and Clark 1988; Palmer and Weisgarber 1988) and electromagnetic methods (McCann and Forster 1990) can also be used in landslide investigations. It probably will be necessary to interpret the results obtained along a number of geophysical lines and to incorporate surface observations of ground cracks- and bedrock exposures.

For an old and dormant landslide, their existence can be detected through careful observation and by understanding the geological processes involved in modifying and altering the original slope morphology. Landslide features become modified with age and mollified by geological processes acting on slopes (e.g. weathering, erosions, deposition of sediments and washed down materials). Active landslides have sharp, well-defined surface features, whereas landslides that have been stable for hundreds or thousands of years have features that are subdued and poorly defined. The changes of landslide features from sharp and well-defined to subdued and poorly defined were incorporated into an age classification by McCalpiñ (1984), as shown in Table 6.1, for the Rocky Mountains of western North America. In wet tropical country such as Malaysia, the challenges in landslide detection is even greater by rapid growth and dense vegetation covers, intense weathering and erosions due to prolonged and heavy rainfalls. Mollification of landslide features and bodies are often relatively faster. The key features are the main scarp, lateral flanks, internal morphology, contrast in vegetation cover and density, and toe relationships. In the hilly terrain such as Cameron Highlands, hanging valley morphology or isolated sub-catchment areas are favourable sites for landslides to occur naturally. In this exercise, systematic panning of the LiDAR derived DEM/hillshaded topographic map were done manually looking for key features like: a) Hummocky surface, b) Steep and arcuate scarps and flanks, c) Thick and bulging toe and d) Concavity of valley walls or hanging valley morphology.

The rate of change of landslide features summarised in Table 7.1 (McCalpin, 1984) might be useful as a guide to guestimate the relative age of landslides activity. By intuition, the general sequence of changes must occur in all climates and terrains.

Figure 7.10 can serve as a useful guide in the identification, detection and mapping of landslide geohazards in the study area. Figure 7.10 A - shows an example of a new and active landslide that is still clear, sharp and well-defined geomorphic features. An inactive and relatively yound-dormant landslide is shown in Figure 7.10 B, where the bedrock might still be visible in places, but weathering has obscured the original structure. Cracks may no longer visible within or adjacent to the slide mass. Minor scarps and transverse ridges have been modified to the point where the ground has a distinctive hummocky appearance. For a dormant-mature landslide (Figure 7.10 C) The main scarp and flanks have been considerably modified by both erosion and revegetation. Erosion has reduced the slopes of the scarp, flank and toe regions. Erosion has resulted in gullies and establishment of new drainage paths within and adjacent to the landslide. Likewise, the original hummocky surface has been somewhat subdued. For an old-dormant landslide (Figure 7.10 D), slope breaks are virtually indistinguishable from scarp, flank and toe regions. Neither vegetation nor developed runoff paths reflect original landslide boundaries. The sag area almost completely filled up with sediments and heavy vegetation might obscured its location. Each of these landslides catageries can be classified as landslide geohazards. Malaysia's experiences (e.g. Tajul Anuar Jamaluddin, 2006, 2011, 2015) indicate that old landslides bodies and scars are areas prone to landslide recurrence and reactivation, notably under extreme climatic conditions and disturbance by human activities.



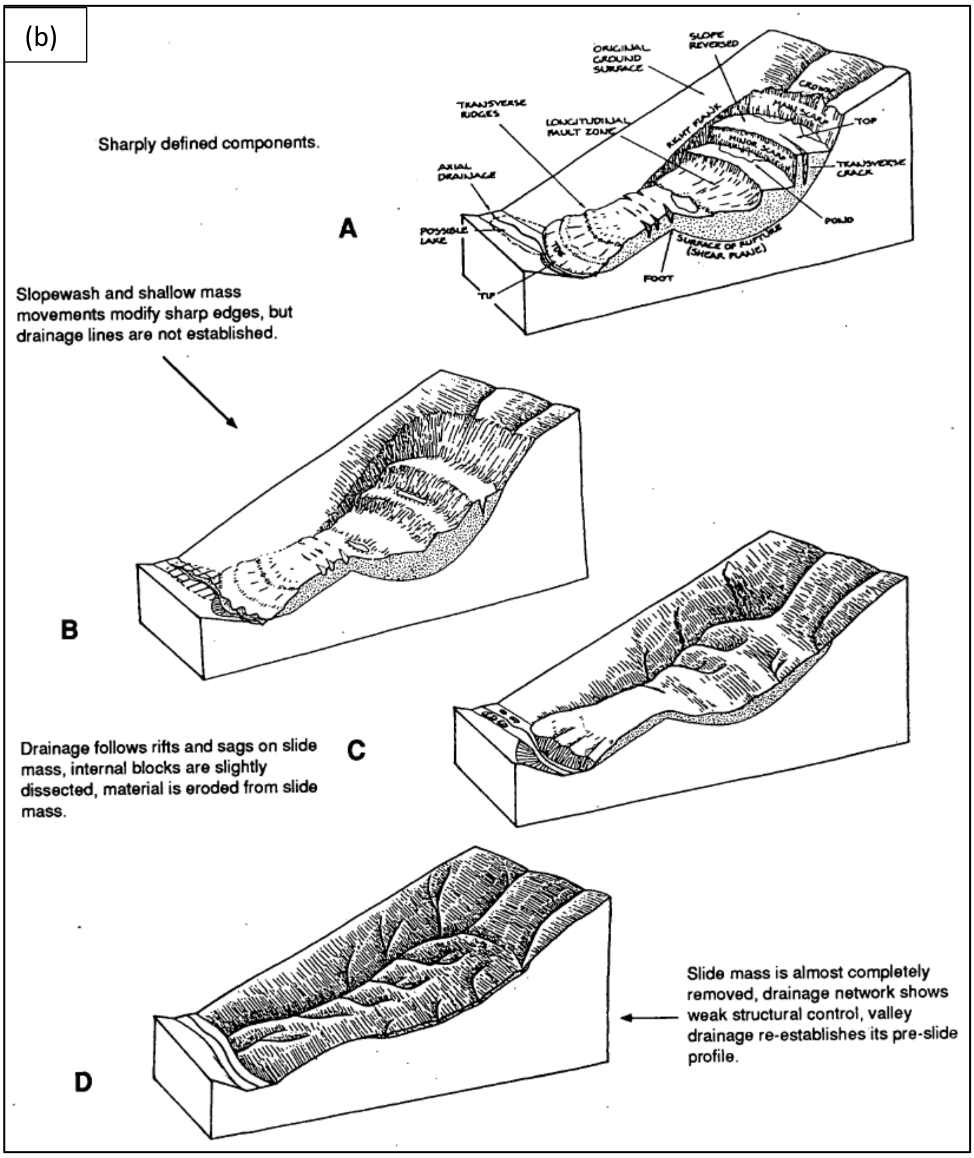


Figure 7.10: Block diagrams of morphologic changes with time of idealized landslide (a) in humid climate (Wieczorek 1984) and (b) in and or semiarid climate (modified from McCalpin 1984).

Note:

A. active or recently active (dormant-historic) landslide features are sharply defined and distinct;
B. dormant-young landslide features remain clear but are not sharply defined owing to slope wash and shallow mass movements on steep scarps;
C. dormant-mature landslide features are modified by surface drainage, internal erosion and deposition, and vegetation;
D. dormant-old landslide features are weak and often subtle.

Table 7.1: Age classification of most recent activity for landslides in Rocky Mountain-Type climate (after McCalpin, 1984).

Activity State	Main Scarp	Lateral Flanks	Internal Morphology	Vegetation	Toe Relationships	Estimated Age (years)
Active, reactivated, or suspended; dormant-historic	Sharp; unvegetated	Sharp; unvegetated; streams at edge	Undrained depressions; hummocky topography; angular blocks separated by scarps	Absent or sparse on lateral and internal scarps; trees tilted and/or bent	Main valley stream pushed by landslide; floodplain covered by debris; lake may be present	< 100 (historic)
Dormant-young	Sharp; partly vegetated	Sharp; partly vegetated; small tributaries to lateral streams	Undrained and drained depressions; hummocky topography; internal cracks vegetated	Younger or different type or density than adjacent terrain; older tree trunks may be bent	Same as for active class but toe may be modified by modern stream	100 to 5,000 (Late Holocene)
Dormant-mature	Smooth; vegetated	Smooth; vegetated; tributaries extend onto body of slide	Smooth, rolling topography; disturbed internal drainage network	Different type or density than adjacent terrain but same age	Terraces covered by slide debris; modern stream not constricted but wider upstream floodplain	5,000 to 10,000 (Early Holocene)
Dormant-old or relict	Dissected; vegetated	Vague lateral margins; no lateral drainage	Smooth, undulating topography; normal stream pattern	Same age, type, and density as adjacent terrain	Terraces cut into slide debris; uniform modern floodplain	> 10,000 (Late Pleistocene)

Note: See Chapter 3 for definitions of terms. Activity states dormant-stabilized and dormant-abandoned may have features of any age classification; the stabilized and abandoned states must be interpreted from other conditions.

b) Results – Landslide Inventory map

Based on the basic principles and methods of landslide identification and detection described above, the resulted landslide inventory map for Ringlet and Habu areas are given in Figure 7.11 and Figure 7.12, respectively. In this map, the identified landslides are delineated by red polygons. It is important to note that in this study, although field verifications were not conducted, the landslide inventory map has been produced by an expert with many years of experience in landslide identification and interpretation.

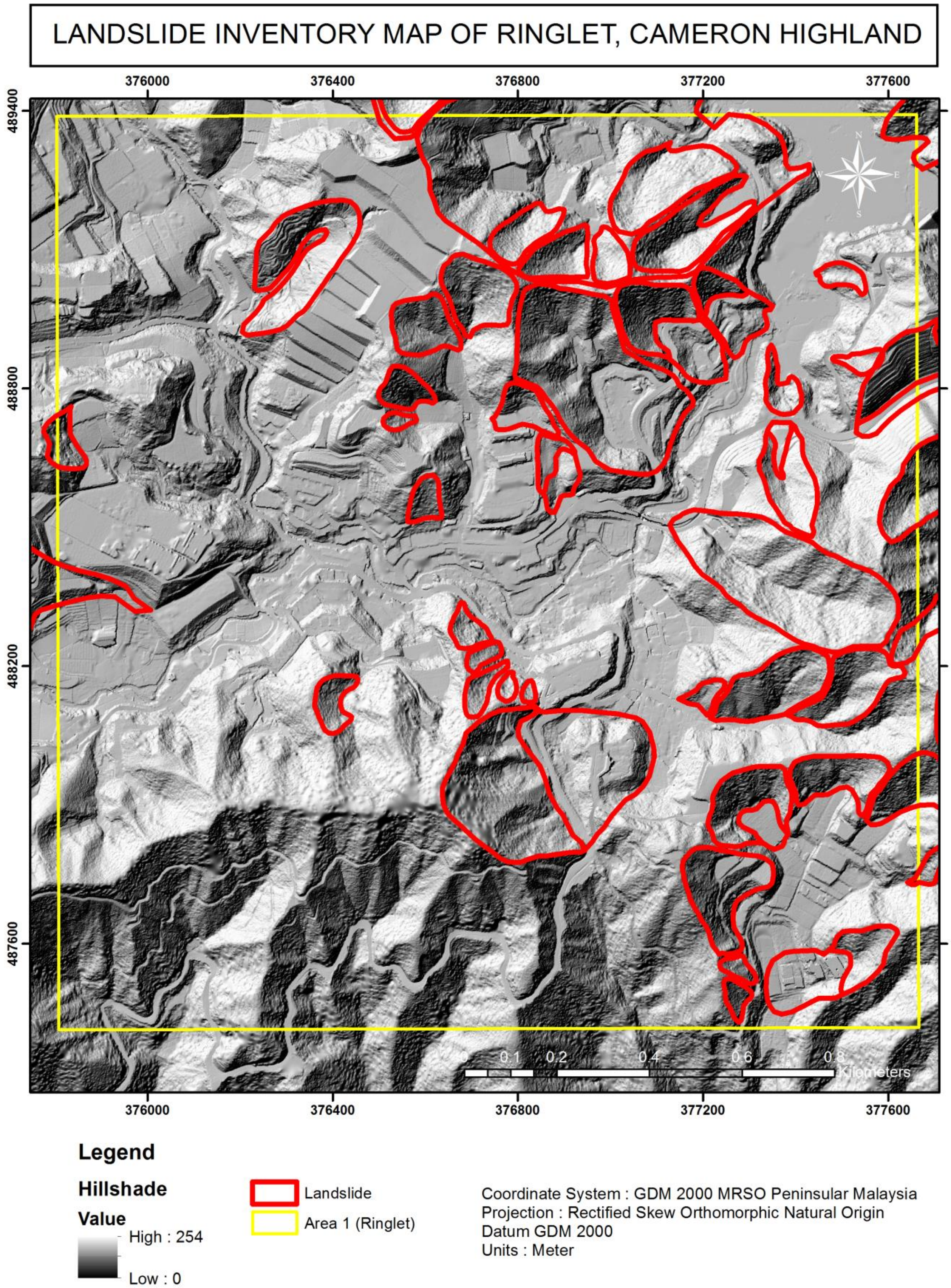


Figure 7.11: Landslide inventory map at Ringlet, Cameron Highlands.

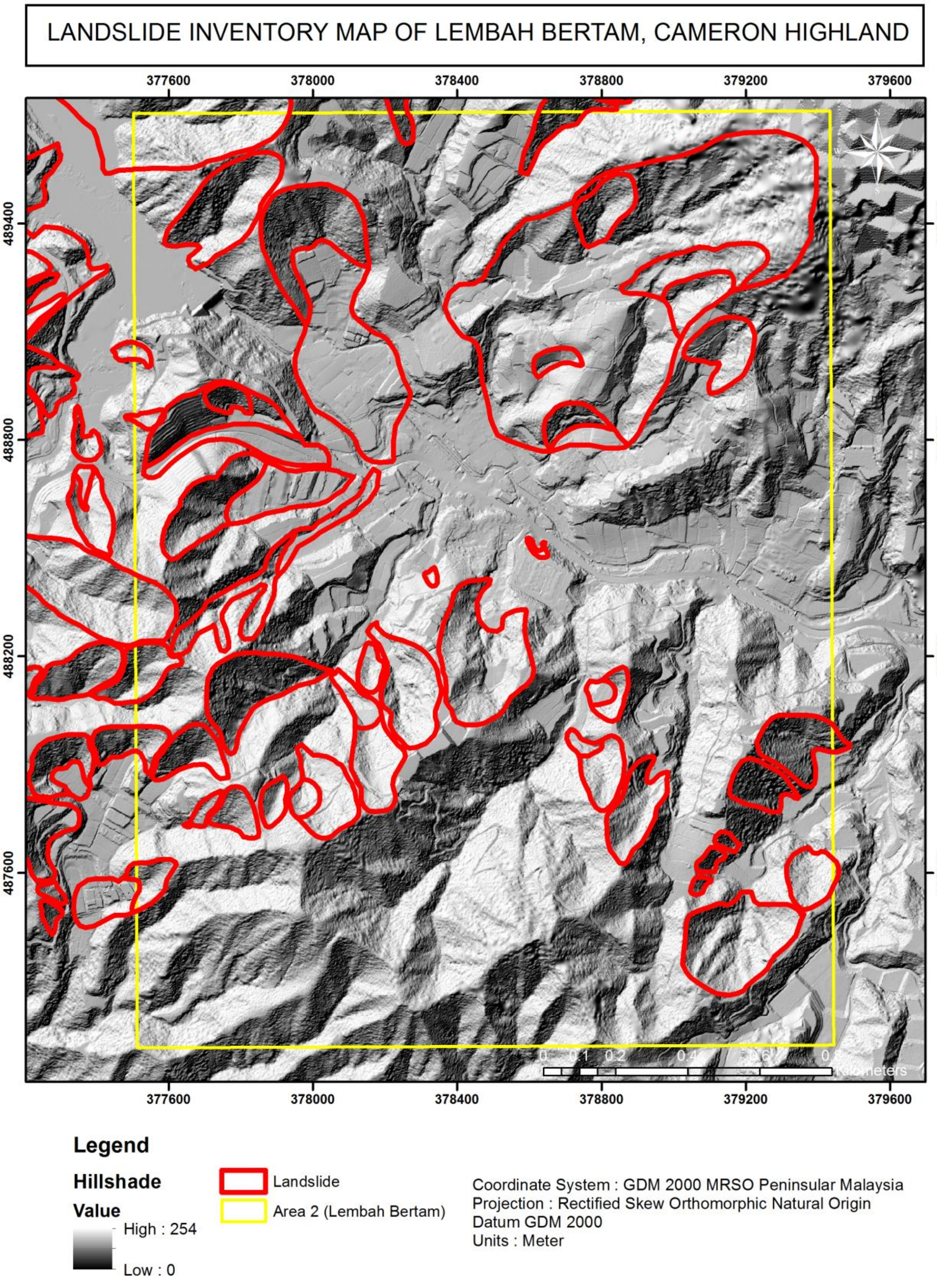


Figure 7.12: Landslide inventory map at Lembah Bertam, Cameron Highlands.

7.2.3 Acquisition of landslide hazard map

Landslide vulnerability and risk maps require hazard map to be generated at a specific level of details and quality. For example, vulnerability assessment method developed for different type of landslides may require landslide hazard maps to be generated for different landslide types at the same spatial scale. In addition, each landslide type should be accompanied by detailed information e.g. depth of landslide, run out area, velocity and etc. This information is required to combine the landslide hazard map and vulnerability map for landslide risk production. In this study, the landslide hazard map is obtained from the Department of Mineral and Geoscience of Malaysia (JMG). The usage of JMG's landslide hazard map is governed by JMG's practice, therefore the consultant does not have any control over how the hazard map is produced. However, due to the ultimate aim of this project to produce a guideline rather than a technical report, this is acceptable.

The hazard map has been developed with 0.5 meter spatial resolution that combines different types of landslide. Based on the landslide inventory map in the study area, the landslide hazard map has been developed based on the majority rotational/translational landslides (61%), followed by rockfall (18%) and debris flow (15%). Based on this information, the landslide hazard map can still be used for vulnerability and risk assessments, which relies on the fact that the selected area only contains rotational and translational landslides. The landslide hazard maps have been classified onto 5 classes namely very low, low, medium, high and very high hazard (Figure 7.13 and Figure 7.14). Based on the map, the worst-case landslide hazard class is assigned for each polygon of CI.

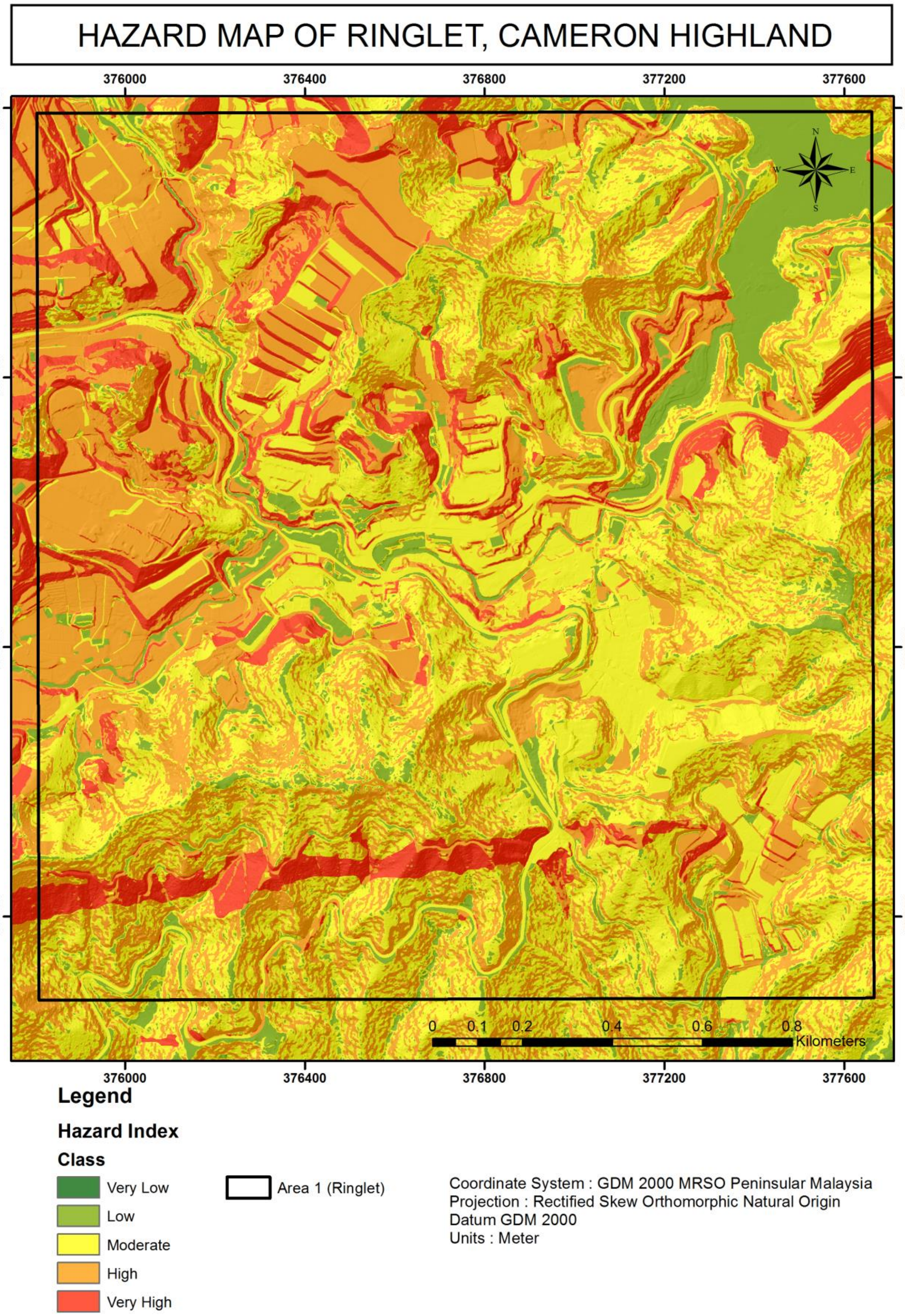


Figure 7.13: Landslide hazard map of Ringlet, Cameron Highlands (Source JMG).

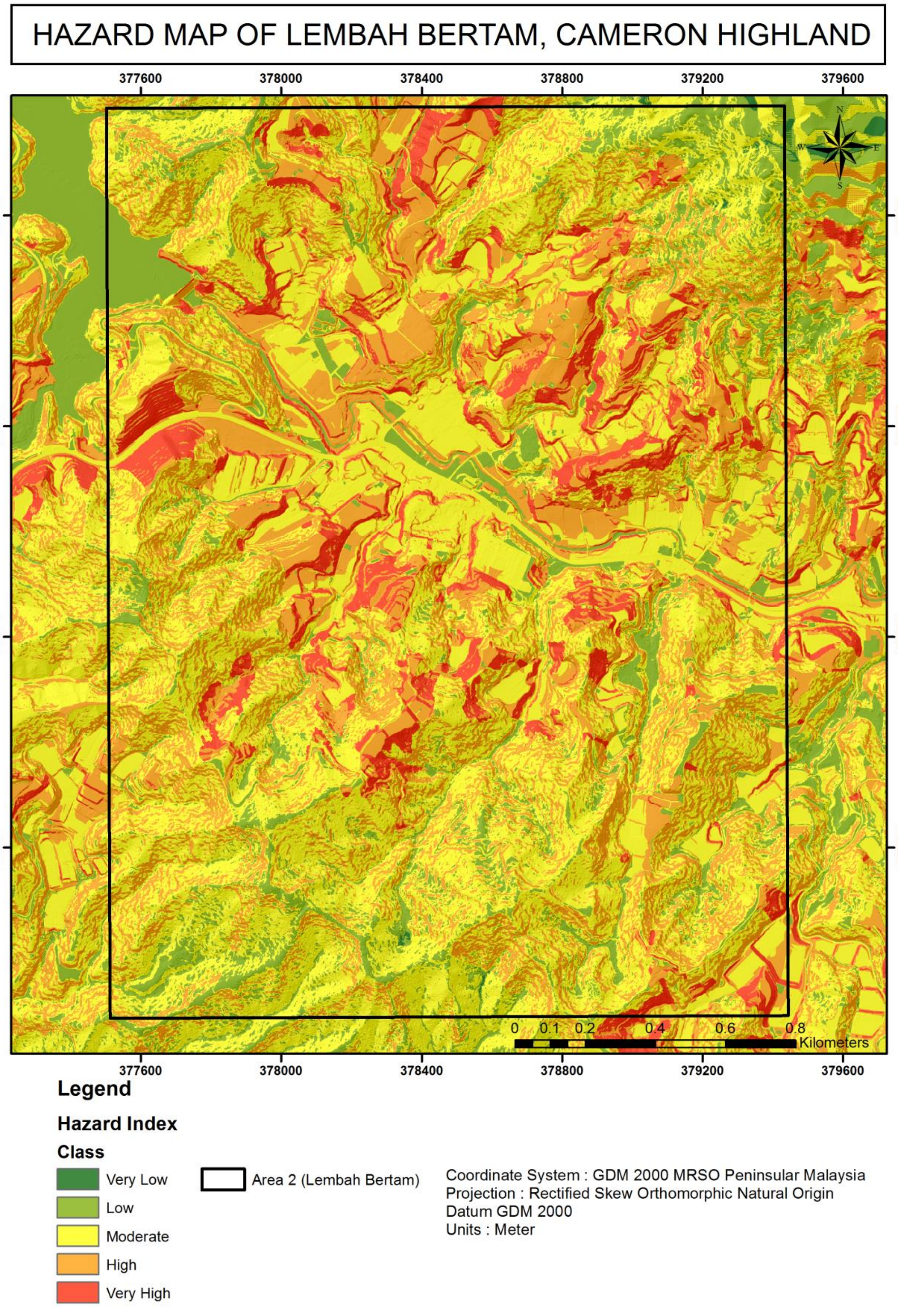


Figure 7.14: Landslide hazard map of Lembah Bertam, Cameron Highlands (Source JMG).

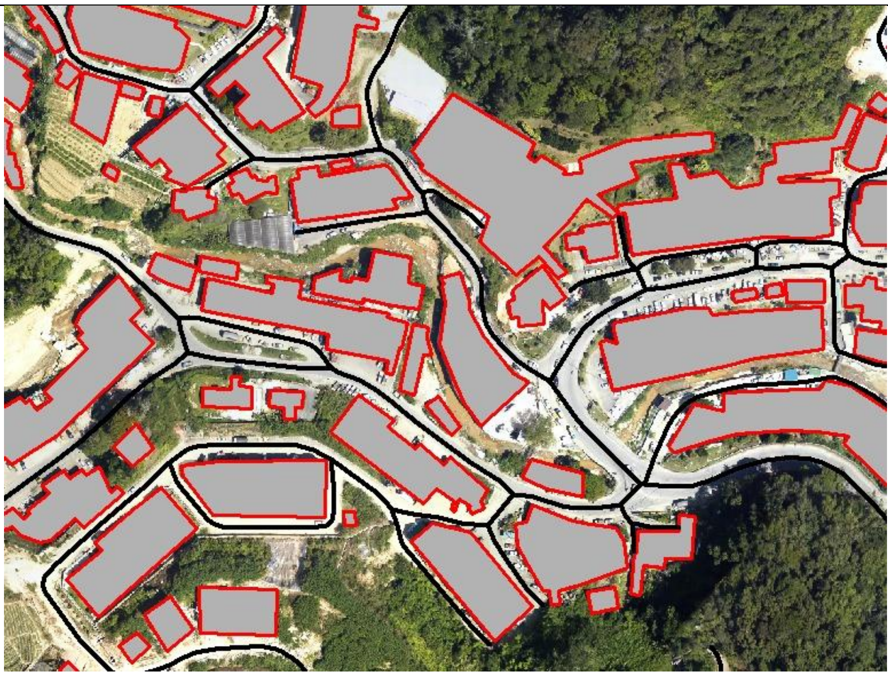
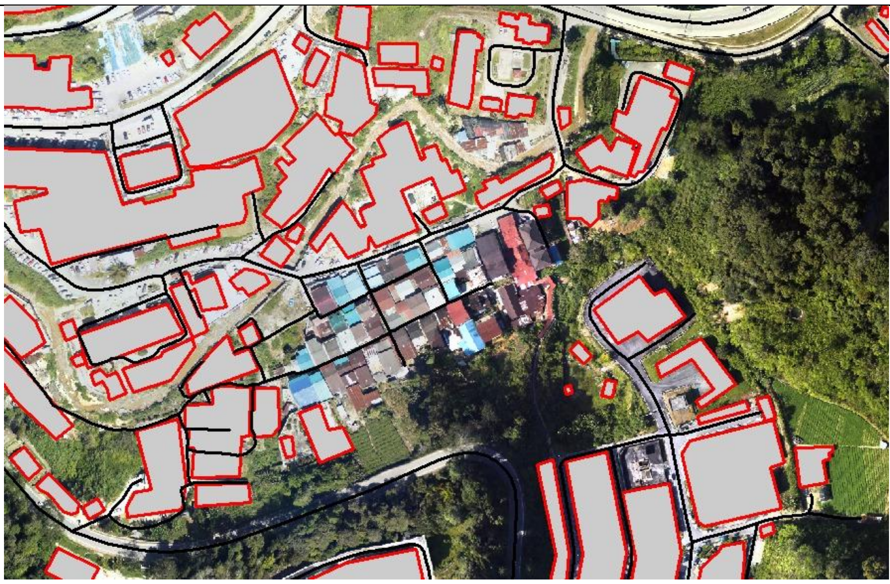
7.2.4 Development of critical infrastructure (CI) map for landslide vulnerability assessment

Subsequently, several CI maps are prepared for landslide vulnerability assessment for the area of Ringlet and Lembah Bertam. These CI comprise residential, building, road, utility and dam. Residential, building and road are one of the most considered CI pertaining to landslide vulnerability and risk assessment. For note, residential and building are combined as one single building CI. On another note, the selection of dam is due to its uniqueness to Cameron Highland while utility, particularly transmission tower or better known as electricity pylon is due to its vulnerability to existing landslide within Cameron Highland.

Several measures are carried out to prepare the CI maps. These measures are selected in consideration of existing CI geospatial data availability and its accuracy. The existing CI geospatial data is available from The Department of Mineral and Geoscience Malaysia (JMG) where the included CI are building and road. For producing this data, a geospatial approach for CI classification and mapping requires specific features obtained from high resolution satellite images and LiDAR data to be combined in digital feature extraction process. Several parameter features are extracted from high resolution satellite images for example vegetation indices (NDVI, DVI, TSAVI and etc.), occurrence and co-occurrence measure for texture and etc. In addition, structural features for example CHM, DSM and other statistical-based point clouds features are obtained from LiDAR data. Later on, these features are combined in the object-oriented image classification. The extracted land use/cover information is transformed into different CI.

Whenever the existing data is inaccurate, several improvements are made mostly in regards to the re-digitization of new CI such as new building which were not available in the JMG data. For this, the process of re-digitization is also supported by the high resolution orthophoto and DTM. Some CI data are not available at all such as dam and electricity pylon which requires a fresh round of digitization from scratch. Table 7.2 below listed the different measures of CI maps preparation.

Table 7.2: The different measures of CI maps preparation.

No.	Measure	Example
1	Using the exact existing data from JMG (**example: building and road**)	
2	Using the improved existing data **(example: building)**	 **Before**

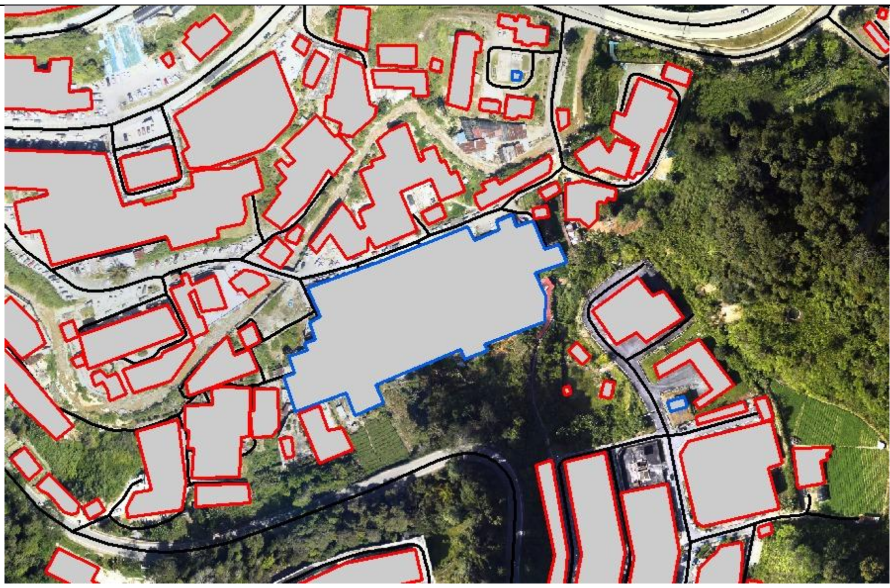
<table>
<tr><td></td><td></td><td>
After</td></tr>
<tr><td>3</td><td>Using freshly digitized new set of data from scratch **(example: electricity pylon and dam)**</td><td></td></tr>
</table>

Table 7.3 below provides the statistic of the overall CI within Cameron Highland.

Table 7.3: The statistic of the overall CI within Cameron Highland

No.	Critical Infrastructure	Statistic
1	Building	1,538 buildings
2	Road	180,318 m (total length)
3	Utility (electricity pylon)	18
4	Dam	1

Figures 7.15 and 7.16 in the next two pages detail the total CI for Cameron Highland specifically for the areas of Ringlet and Lembah Bertam.

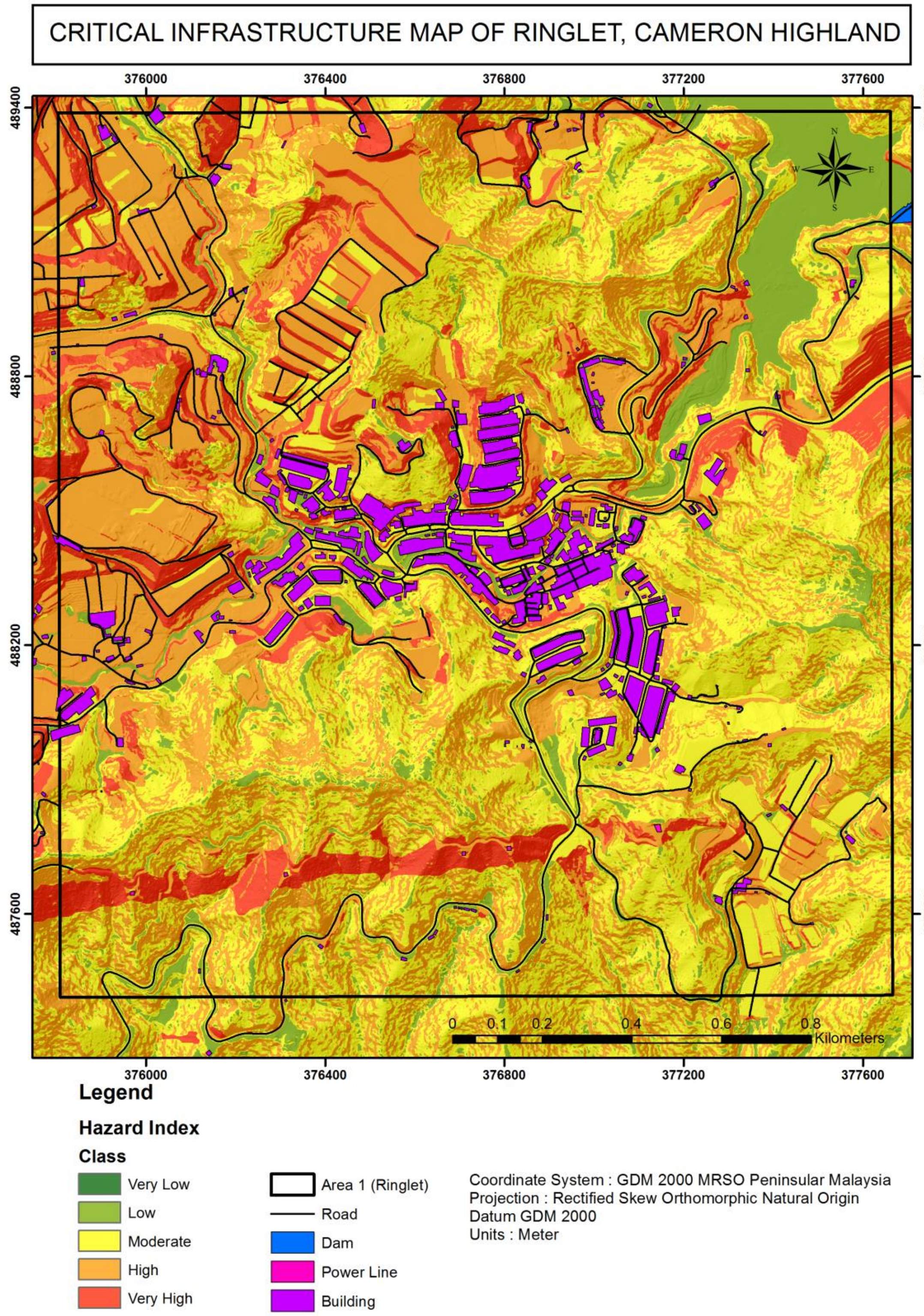


Figure 7.15: Landslide hazard map and distribution CI of Ringlet, Cameron Highlands.

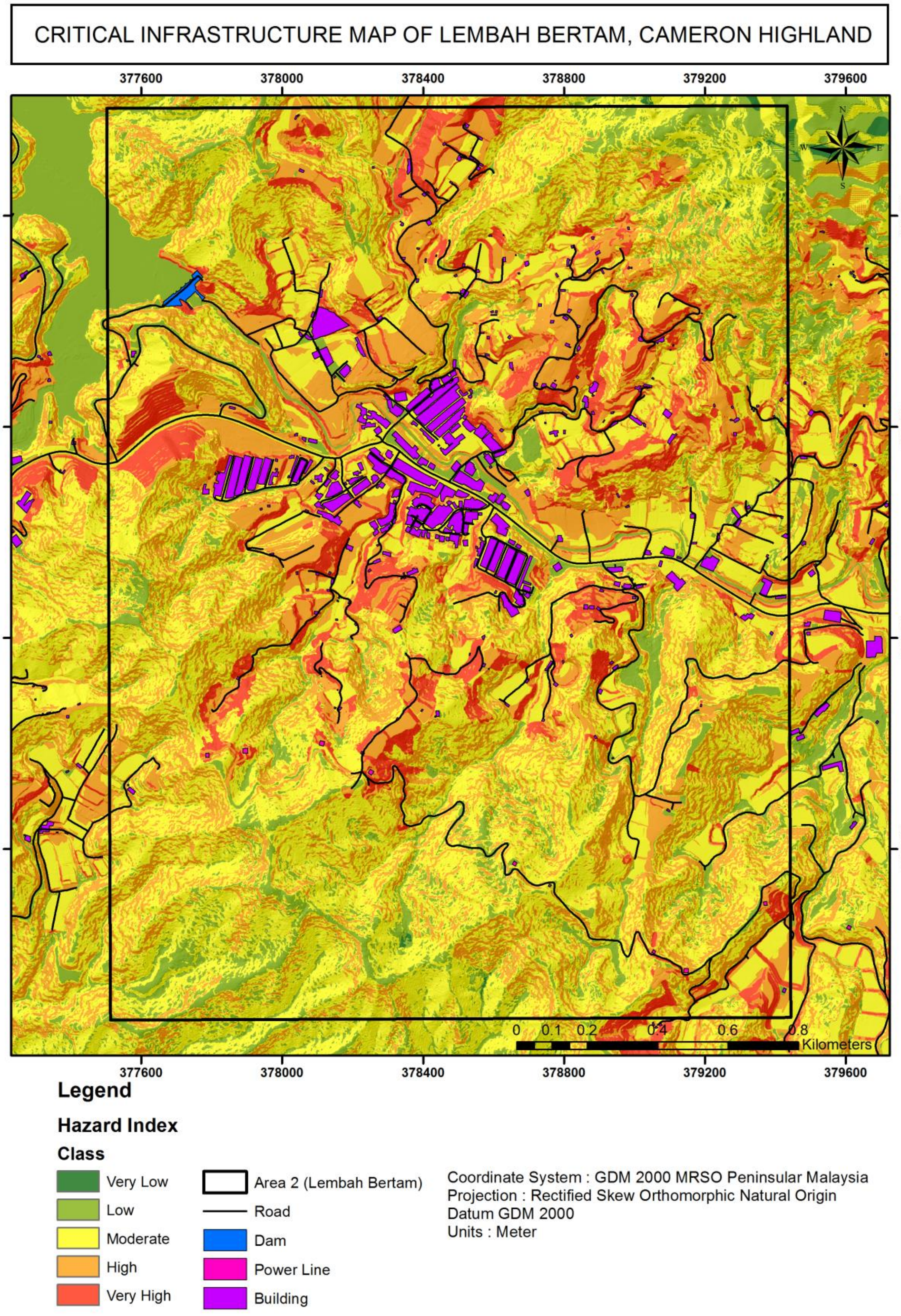


Figure 7.16: Landslide hazard map and distribution CI of Lembah Bertam, Cameron Highlands.

7.2.5 Development of surrounding environment (E) map for landslide vulnerability assessment

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 clearly will reduce the impact of landslide or vulnerability of CI. Various indicators and sub-indicators for this cluster have been observed during the field visit at Ringlet and Lembah Bertam. Indicators and sub-indicators of the surrounding environment (E) are observed within 50 meters from each of CI. The parameters include the presence of protection surrounding the CI, presence of warning system that alarms the people about the landslide occurrence, location of CI at the landslide area, drainage pattern built around CI, the slope morphology of the surrounding and the presence of erosion with its type. Each of the parameters are noted during the field visit and inserted into the database for the landslide vulnerability calculation.

7.2.6 Development of people density (P) map for landslide vulnerability assessment

The density of people is calculated differently for each CI. There are four indicators highlighted for building/residential which are population density, evacuation of alarm system, age of people and health condition. Meanwhile, CI of road only considers traffic volume indicator that implicates different road user volume based on type of road provided by JKR. As for dam, the population density indicator is divided into four classes, i.e. low, medium, high and very high. These classes reflect the population density that will be affected due to disrupted dam operation based on the function of that particular dam either serve as power supply or water supply. The last CI is TNB powerline which population density indicator is divided into three classes i.e., low, medium and high. This indicator also reflects the population density that will be affected due to disrupted TNB operation.

7.2.7 Field Survey

The field survey is necessary to update and validate the CI and landslide inventory map. The field survey is carried out following the conclusion of the output of FGD where specific weights for CI vulnerability indicators and sub-indicators are obtained. Additionally, the data collected in the field can be used to assist experts in evaluating the estimated landslide vulnerability and risk. The field survey is undertaken from 22nd until 24th November 2018 at Ringlet and Lembah Bertam, Cameron Highlands (Figure 7.17).

The main procedure of the field survey is by filling in a specific proforma to update information of the vulnerability indicators for individual CI and landslide inventory based on the manually assigned value of remotely sensed data. Furthermore, the field survey is also supported by aerial photos observed using UAV. Based on the characteristics of the CI and the corresponding landslide hazard, specific level of vulnerability and risk can be later on assigned by experts. Figure 7.17 below highlight some CI and landslide photos taken during the field survey.

Figure 7.17: CI and landslide photos taken during the field survey.

7.3 Estimation of Landslide Vulnerability and Risk for CI at Cameron Highlands

Vulnerability value for each CI will be determined by combining information obtained from landslide and map of CI and vulnerability estimation methods (Figure 2.1). The vulnerability value will be estimated for different CI by taking into account different landslide types, characteristics of landslides and selected indicators. Determination of vulnerability values for each CI required specific mathematical formulation (equations 1 and 2) to combine the selected indicators and different spatial analysis methods such as raster operator, shown in Figure 7.18 will be applied on the geospatial data. Finally, using the concept of qualitative risk, several risk maps are able to be derived from the cross-over of vulnerability map and hazard map, by only considering translational-rotational landslides, given the majority of the existing results of landslide hazard are from this type of landslide (Table 7.1).

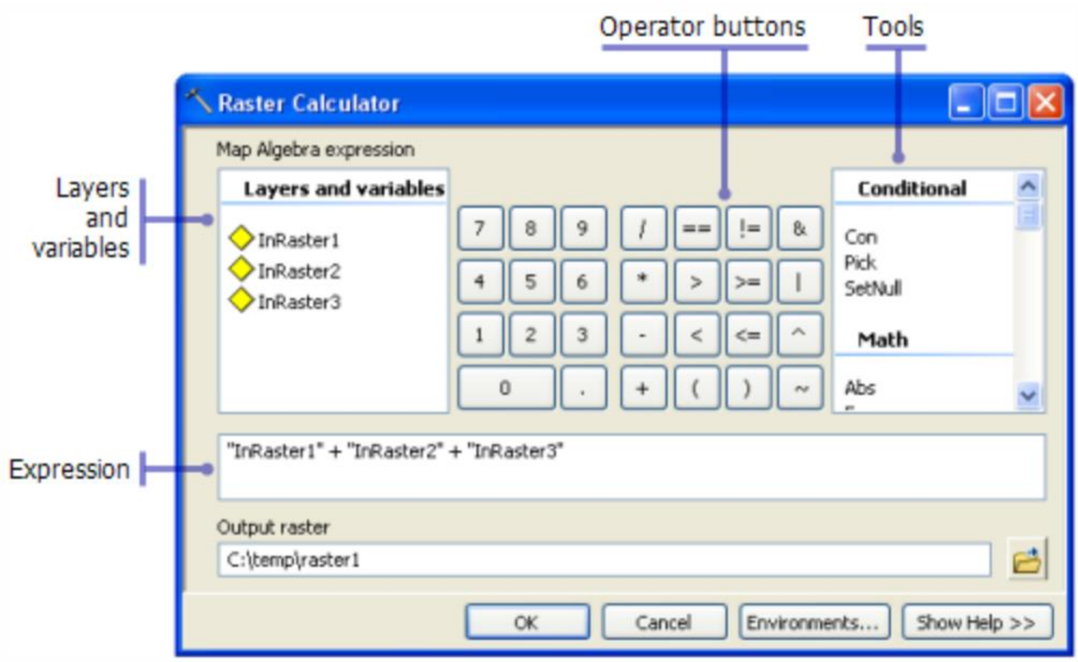


Figure 7.18: Raster operator using raster calculator.

7.3.1 Vulnerability and Risk Index for the Entire CI

The landslide vulnerability map produced for building at Ringlet (Figure 7.19) shows that most of the building were categorized as Moderate class. There were however, two (2) buildings (from a total of 334) that were categorized as High Vulnerability class (Table 7.4). For the landslide risk map, among all the building in this area, 91 were categorized as Medium risk while the rests (243 buildings) were identified as High risk.

Table 7.4: Statistics of buildings from Hazard, Vulnerability and Risk maps at Ringlet.

Building at Ringlet	No. of buildings
Total Building	334
Hazard	
Building at Hazard (Low)	12
Building at Hazard (Medium)	81
Building at Hazard (High)	164
Building at Hazard (Very High)	77
Vulnerability	
Building at Vulnerability (Moderate)	332
Building at Vulnerability (High)	2
Risk	
Building at Risk (Medium)	91
Building at Risk (High)	243

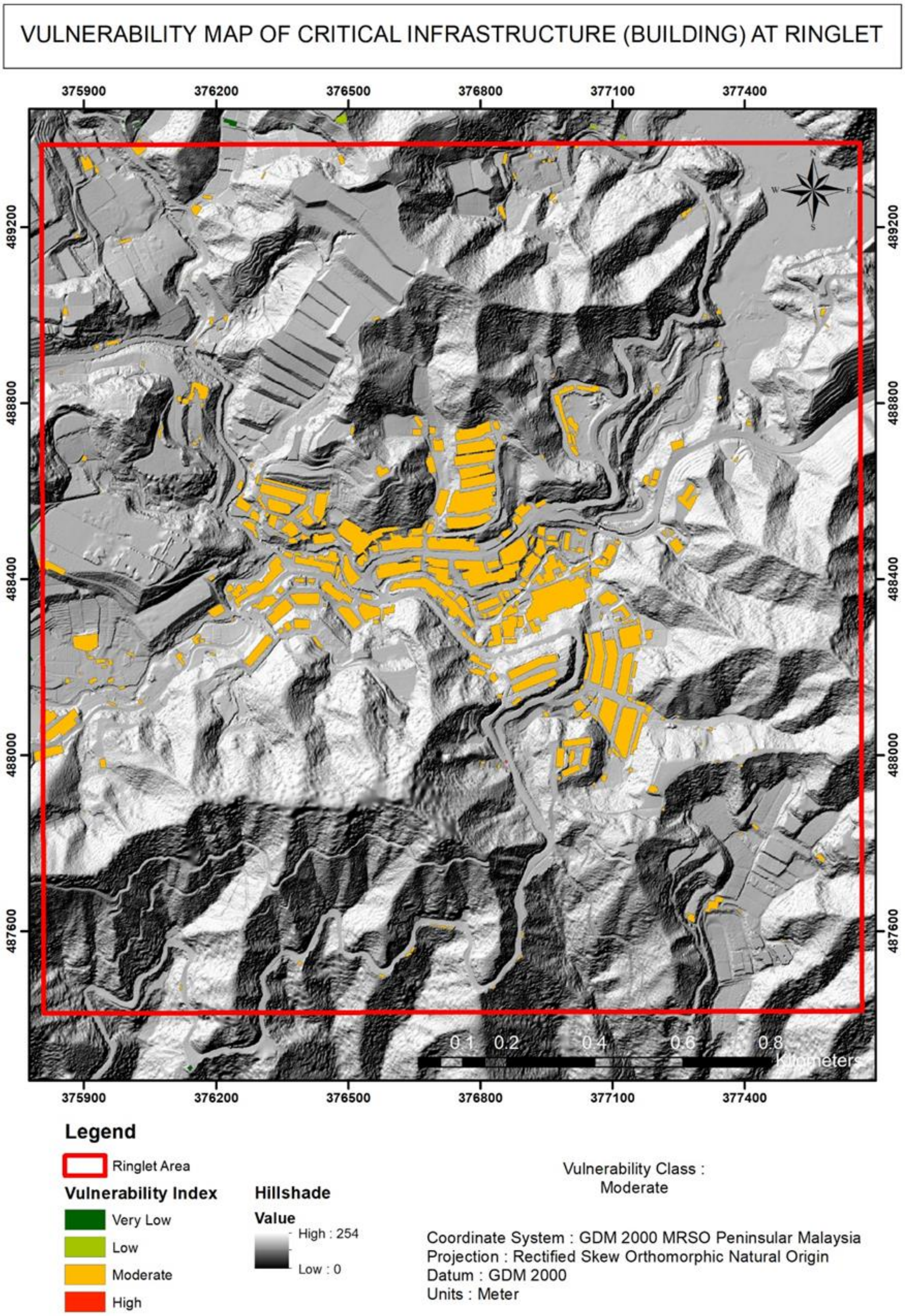


Figure 7.19: Landslide Vulnerability Map for Building, Ringlet, Cameron Highlands

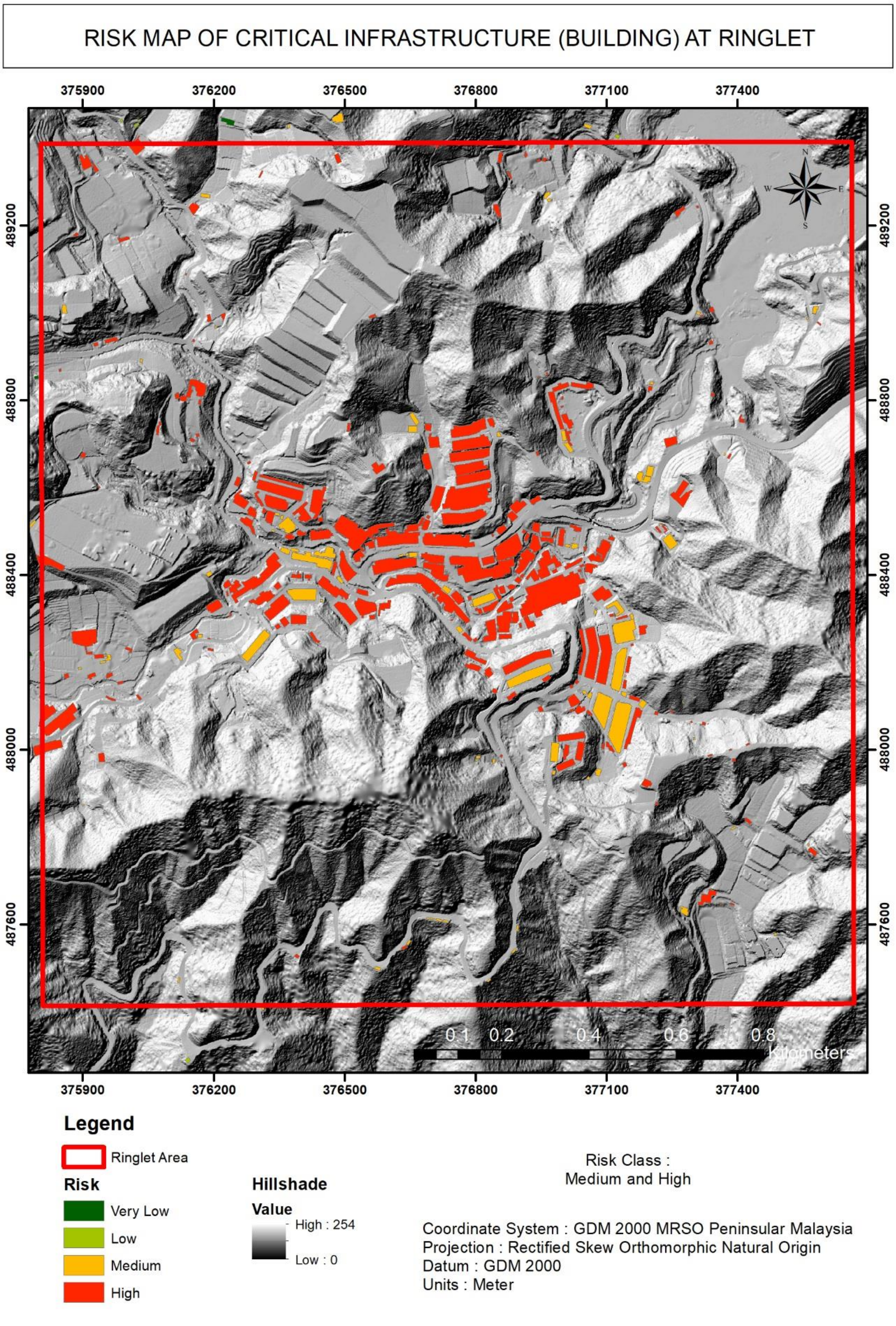


Figure 7.20: Landslide Risk Map for Building, Ringlet, Cameron Highlands

For Lembah Bertam, the results from the vulnerability map shows that all the buildings (a total of 358) were categorized as Moderate class (Figure 7.21 and Table 7.5). The Risk map however shows that, 117 of the buildings were categorized as Medium Risk while the rests of the buildings at this area (241) were categorized as High Risk. This looks almost similar at Ringlet which more buildings were categorized as High Risk compared to Moderate Risk (although most of the buildings were Moderate class for Vulnerability).

Table 7.5: 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

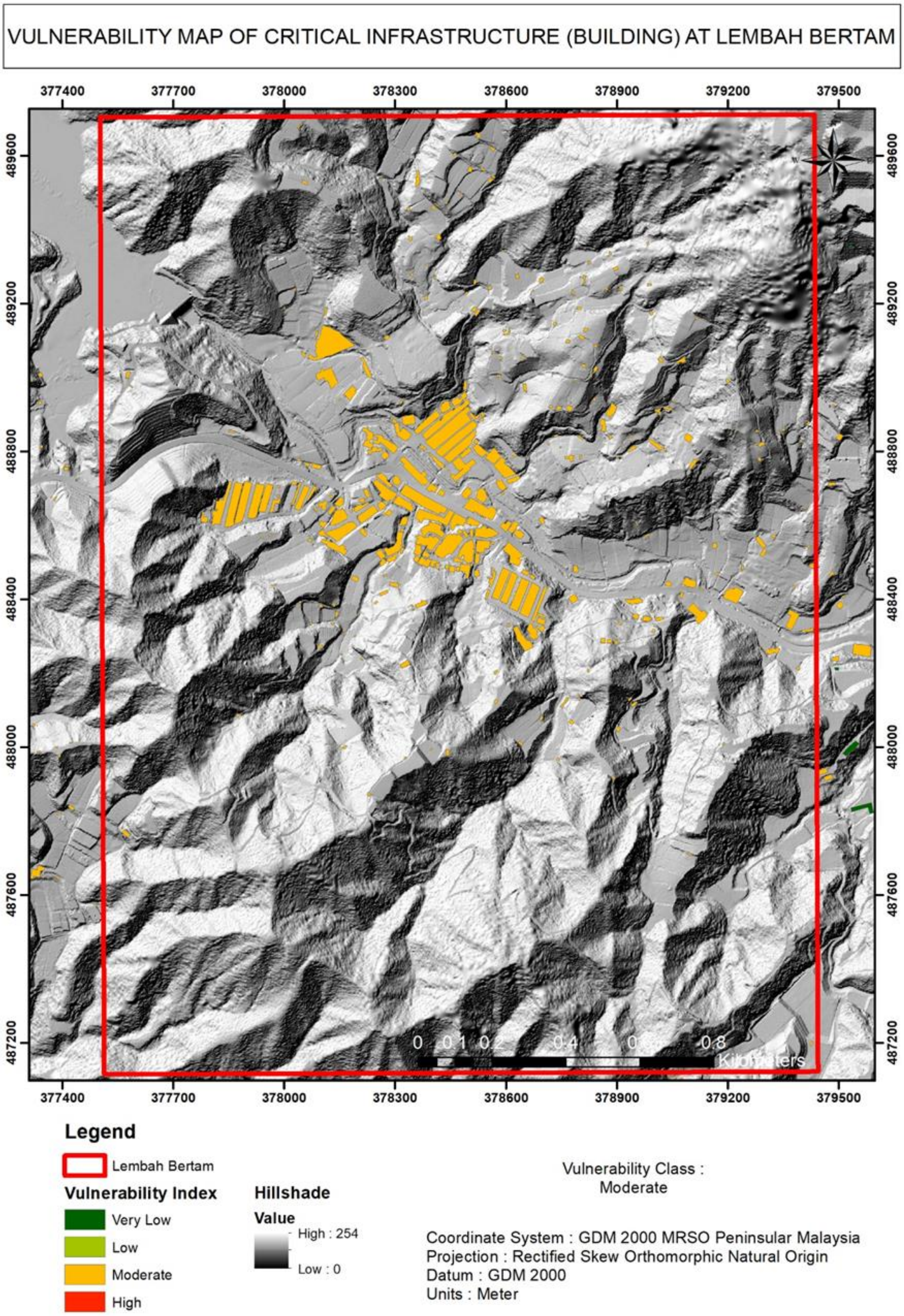


Figure 7.21: Landslide Vulnerability Map for Building, Lembah Bertam, Cameron Highlands.

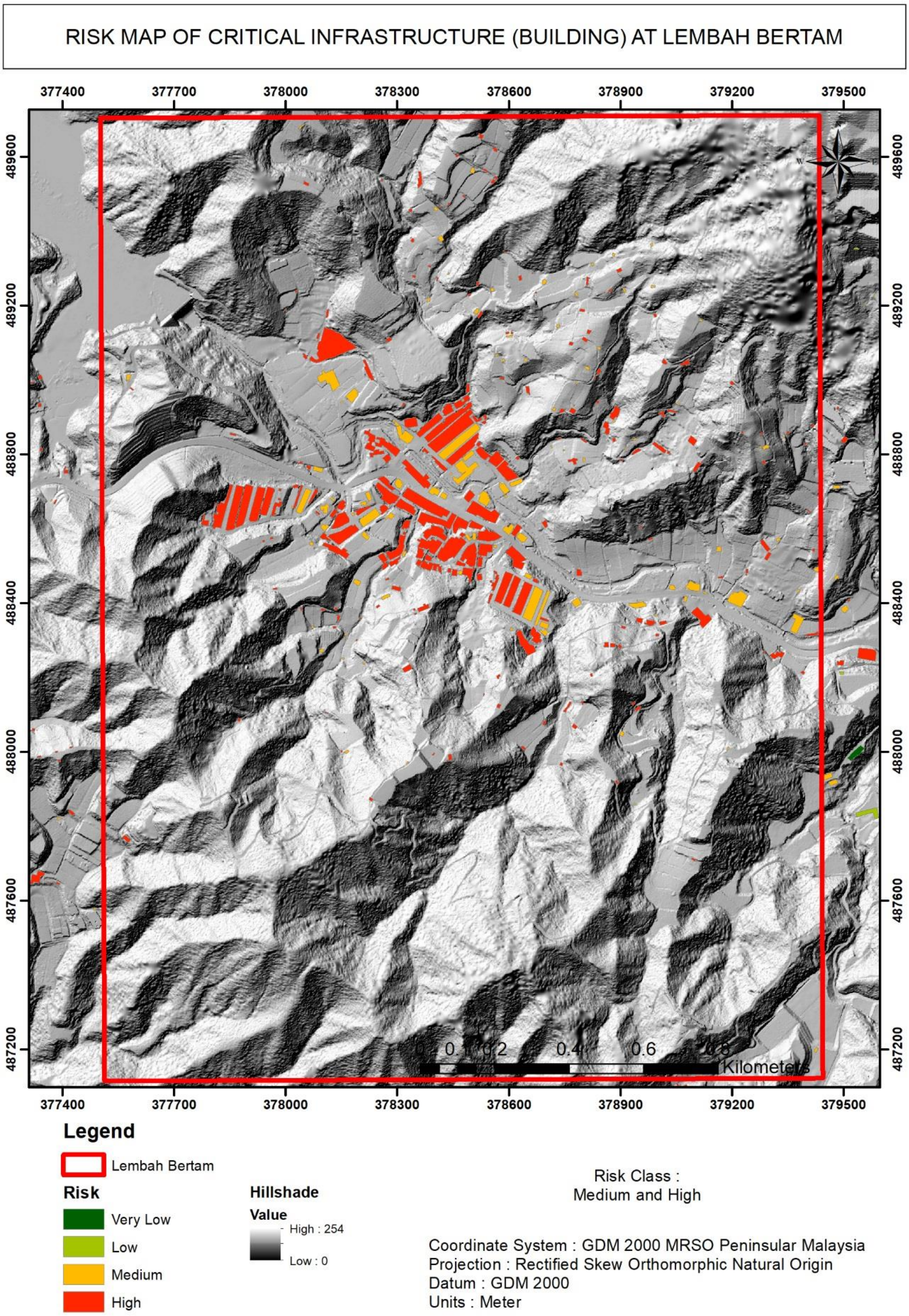


Figure 7.22: Landslide Risk Map for Building, Lembah Bertam, Cameron Highlands.

For the map of landslide vulnerability of road at Lembah Bertam, the analysis produced only two types of classes; Moderate and High classes. Among these, most of the roads here were categorized as Moderate and only small number of roads were having High Vulnerability (Figure 7.23). One possible explanation for this might be that most of the roads here were located outside or away from the landslide polygons at Lembah Bertam. Roads that have been categorized as having High Vulnerability were most likely located inside landslide polygon might have high hazard as well. The risk map of the roads at this area produced three types of risk classes: Medium, High and Very High. The roads at the flat area (i.e. centre of study area) were categorized as Medium Risk and the same roads that were having High Vulnerability appeared to be categorized as Very High of risk. Details of road length from each class for Hazard, Vulnerability and Risk maps can be found in Table 7.6.

Table 7.6: Statistics of road length from Hazard, Vulnerability and Risk maps at Lembah Bertam.

Lembah Bertam	**Length (meter)**
Total Road Length	30343
Hazard	
Road at Hazard (Medium)	6189
Road at Hazard (High)	11950
Road at Hazard (Very High)	12204
Vulnerability	
Road at Vulnerability (Moderate)	28282
Road at Vulnerability (High)	2061
Risk	
Road at Risk (Medium)	6159
Road at Risk (High)	22662
Road at Risk (Very High)	1521

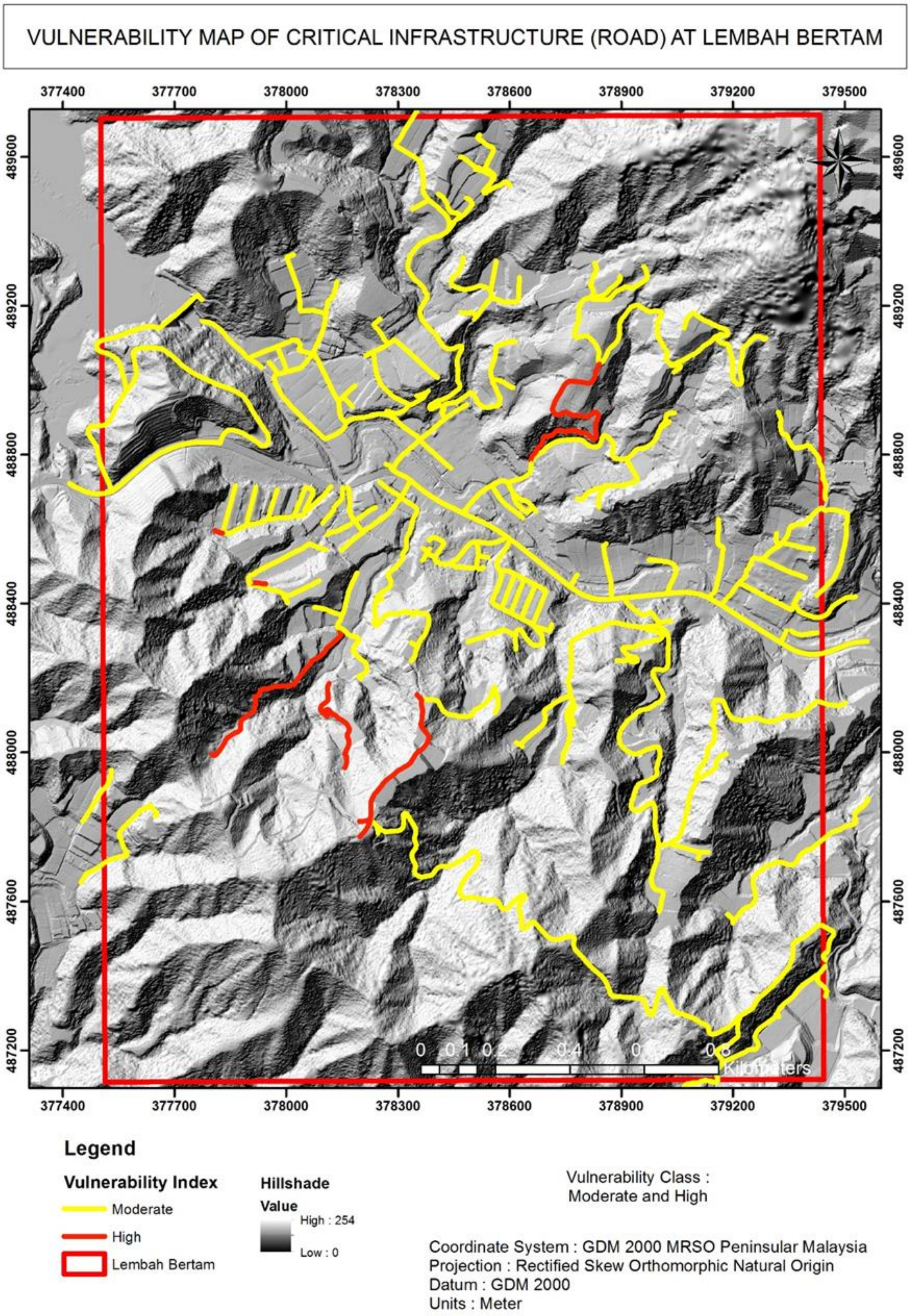


Figure 7.23: Landslide Vuln: erability Map for Road, Lembah Bertam, Cameron Highlands.

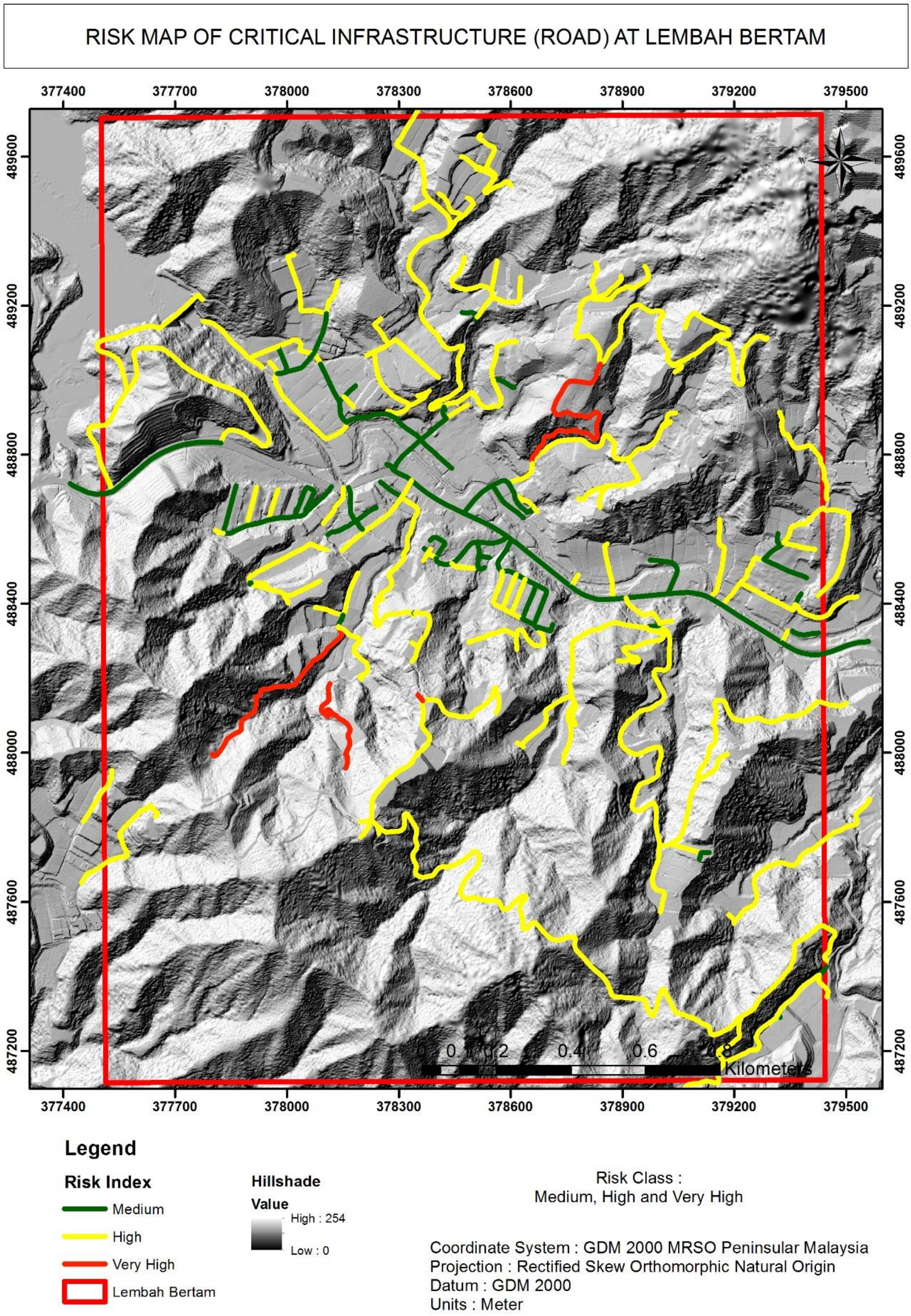


Figure 7.24: Landslide Risk Map for Road, Lembah Bertam, Cameron Highlands.

For the vulnerability of road at Ringlet (Figure 7.24), similar comments can be made that showing Moderate class dominated this area. However, there were three types of vulnerability classes which also include Low and High Vulnerability, apart from Moderate class. In addition, there were only few of roads that were categorized as Low and High classes. For example, only few of the roads were categorized as High Vulnerability which located in the northern region of the study area. For the risk map of the roads at this area (Figure 7.25), four (4) classes were produced; Low, Medium, High and Very High. Most of the roads were categorized as having High Risk, followed by Medium Risk and Low Risk, with Very High Risk appeared to be the lowest among all (i.e. only 816 meter in length from a total of 40,619 meter road length) (Table 7.7).

Table 7.7: Statistics of road length from Hazard, Vulnerability and Risk maps at Ringlet.

Ringlet	**Length (meter)**
Total Road Length	40619
Hazard	
Road at Hazard (Very Low)	197
Road at Hazard (Medium)	10455
Road at Hazard (High)	19502
Road at Hazard (Very High)	10466
Vulnerability	
Road at Vulnerability (Low)	868
Road at Vulnerability (Moderate)	38053
Road at Vulnerability (High)	1698
Risk	
Road at Risk (Low)	1036
Road at Risk (Medium)	9555
Road at Risk (High)	29211
Road at Risk (Very High)	816

Figure 7.25: Landslide Vulnerability Map for Road, Ringlet, Cameron Highlands.

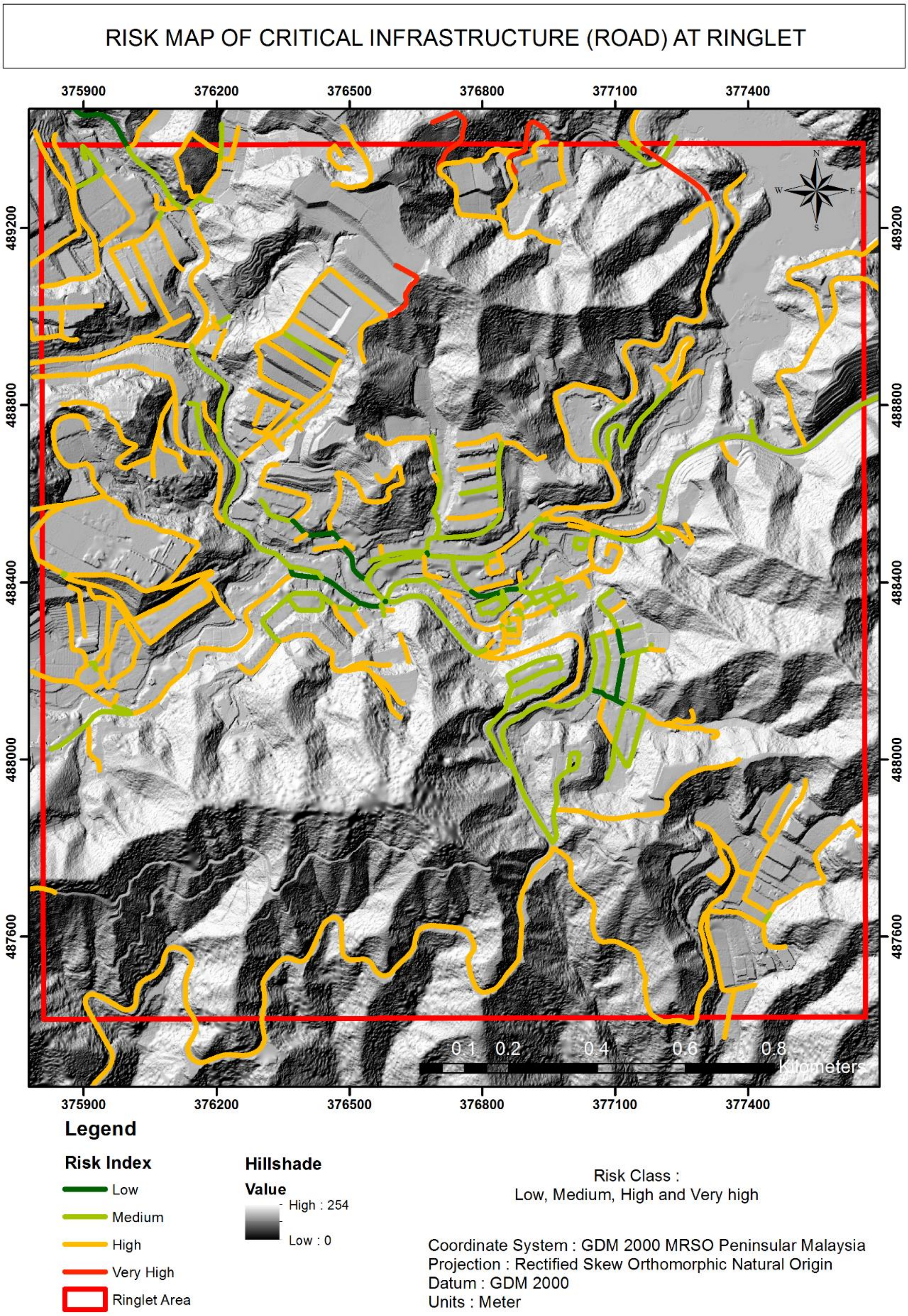


Figure 7.26: Landslide Risk Map for Road, Ringlet, Cameron Highlands.

For the vulnerability of TNB Powerline at Ringlet, only five (5) units of pylon were available and analysed in this study (all located at the southern region of study area). Among these five (5), all of them were categorized as Moderate class of vulnerability (Figure 7.27). As for risk, all these five (5) units were categorized as having High Risk (Figure 7.28). For the TNB powerline in Lembah Bertam, there were nine (9) units of pylon, and the results indicate that eight (8) of them were categorized as Moderate class of vulnerability and only one unit as High Vulnerability (Figure 7.29). For the risk, all the nine (9) pylon units at this study area were categorized as having High Risk (Figure 7.30).

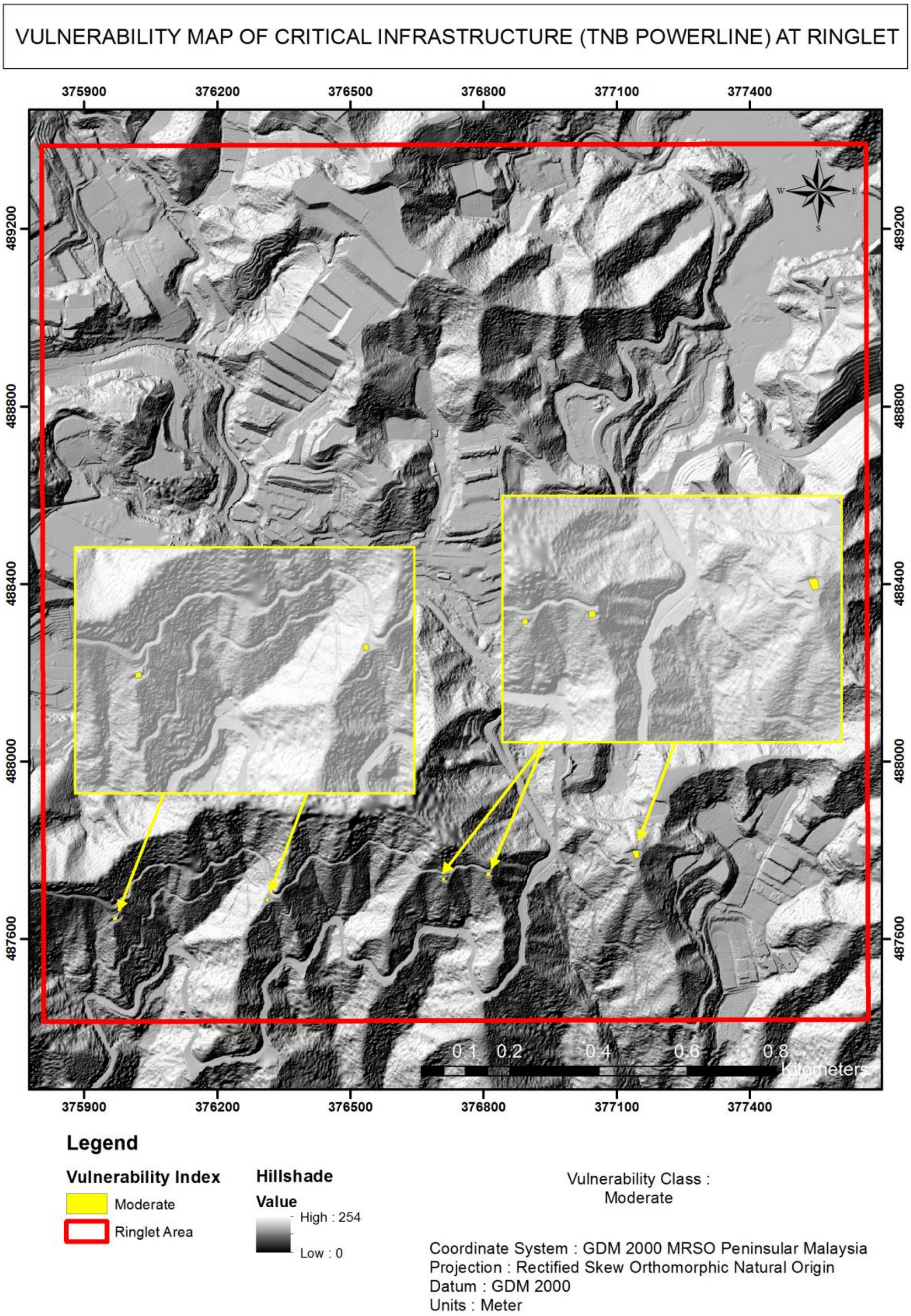


Figure 7.27: Landslide Vulnerability Map for Power Line, Ringlet, Cameron Highlands.

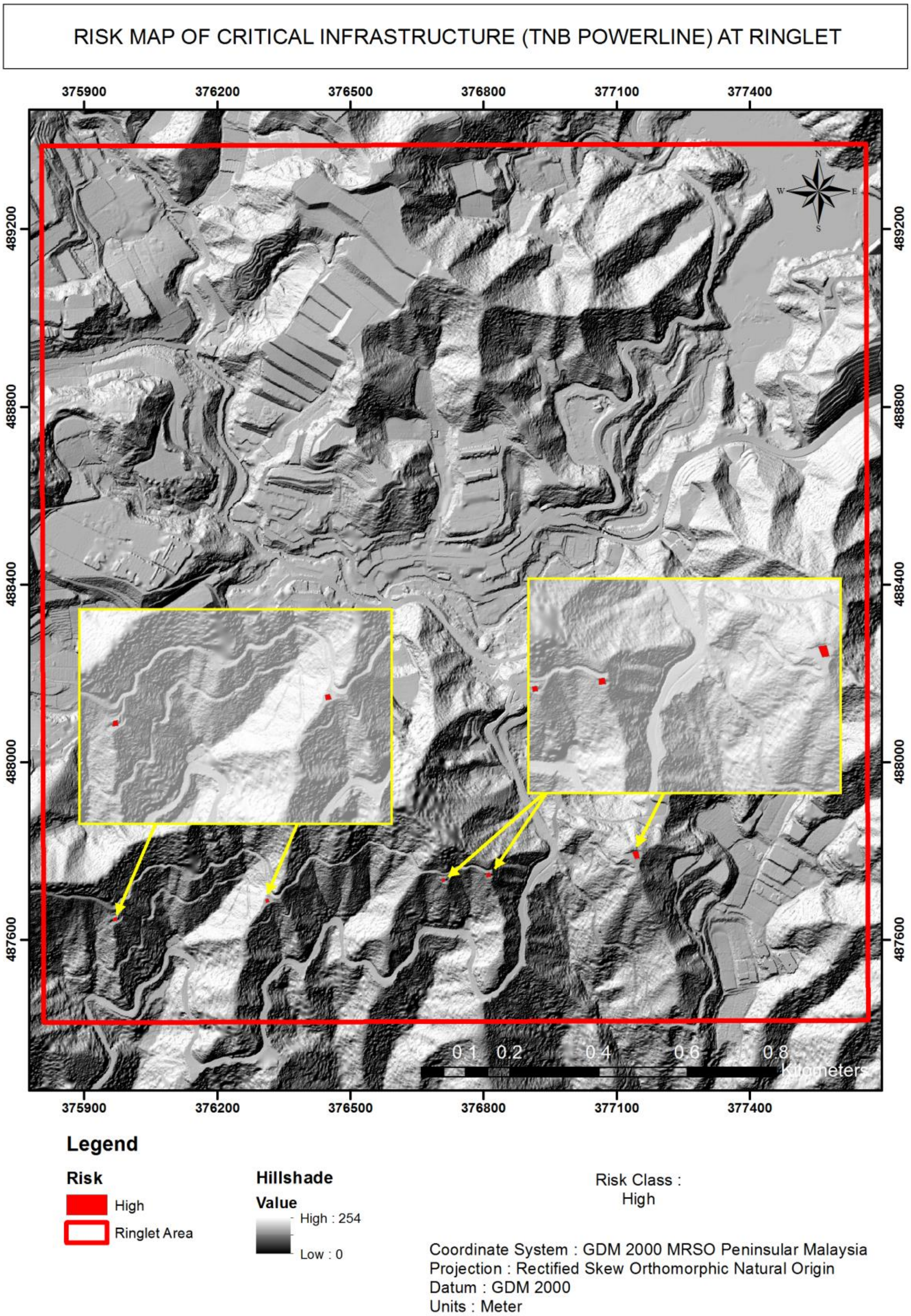


Figure 7.28: Landslide Risk Map for Power Line, Ringlet, Cameron Highlands.

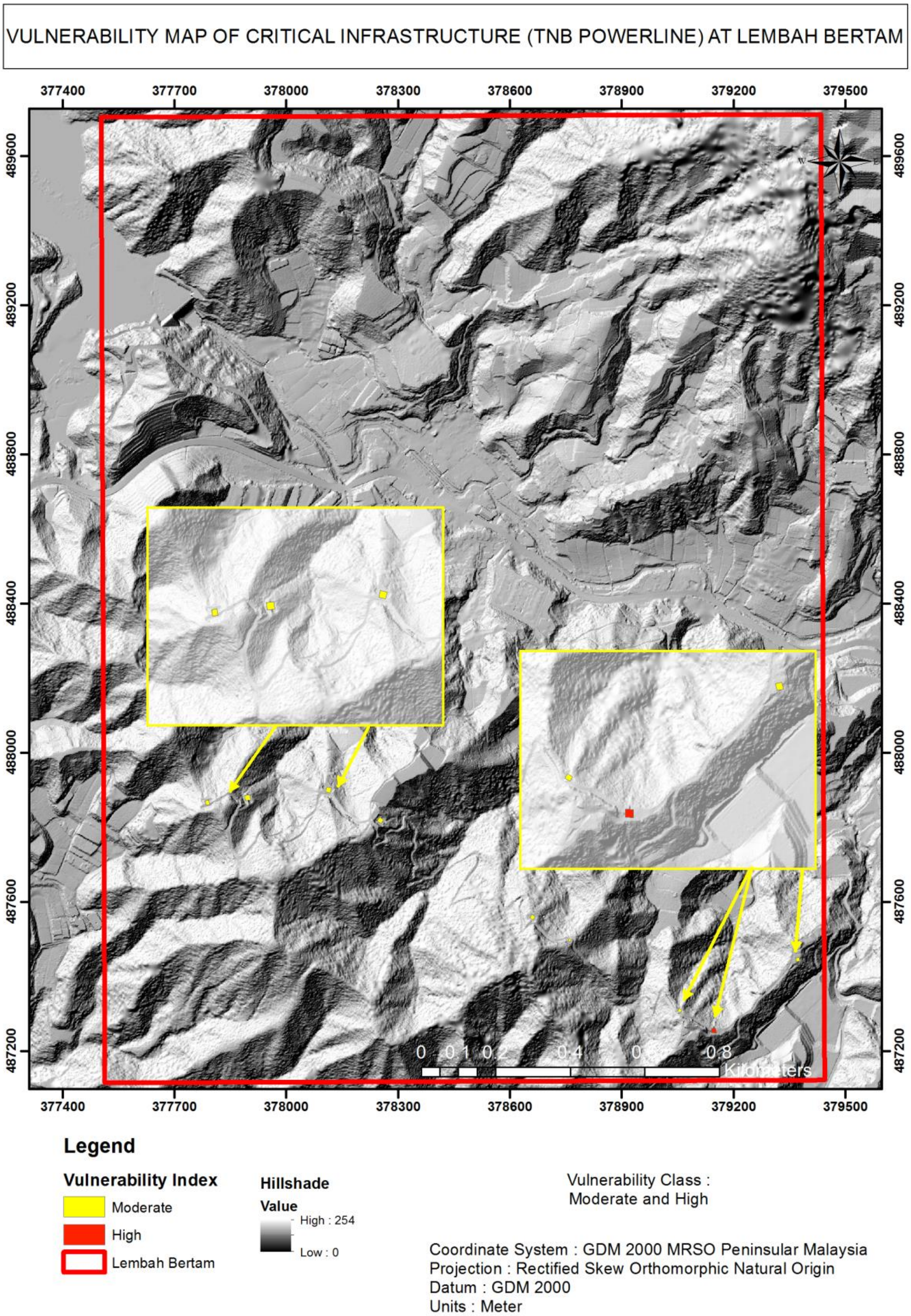


Figure 7.29: Landslide Vulnerability Map for Power Line, Lembah Bertam, Cameron Highlands.

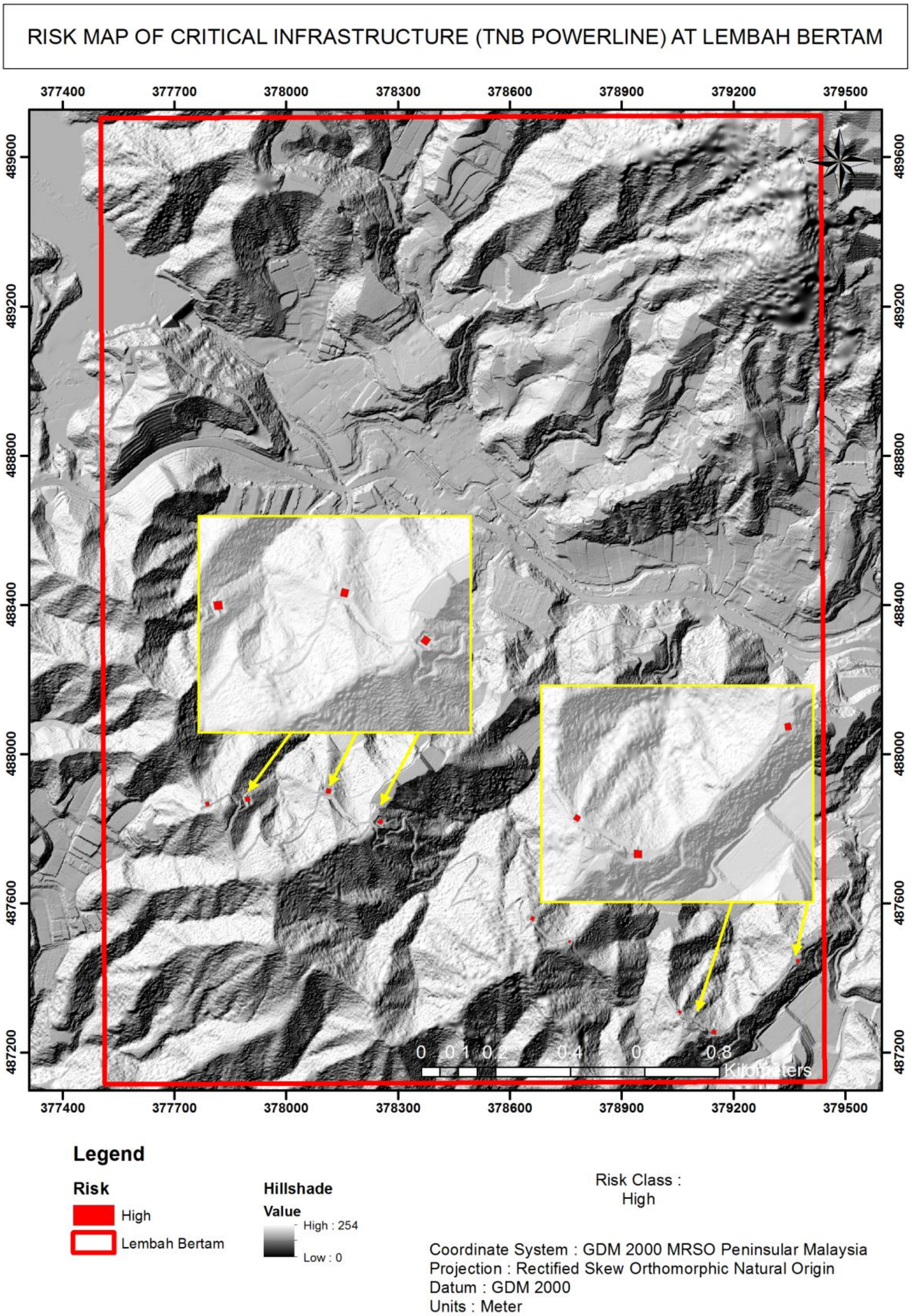


Figure 7.30: Landslide Risk Map for Power Line, Lembah Bertam, Cameron Highlands.

8.0 EVALUATION OF THE ESTIMATED VULNERABILITY AND RISK INDEX BASED ON EXPERT JUDGEMENTS

The conventional approach of study on landslide hazards has been emphasised on slope health and stability. The argument is because of the slope is the causal factor of landslide hazards and the mitigation measure should be made to stabilize the slope, but it may not economical and practical for huge scale. However, most of reported incidences of landslide hazards were beyond human capacity to mitigate, moreover when impact of climate change is to be considered. Moreover, this conventional method may not be applicable for natural slopes in Cameron Highland or perhaps any other highland area that is already densely populated with slopes all around. Despite that, so far no study is conducted in advance of landslide incidence on the effect of landslide hazards onto the infrastructure but instead only post disaster assessment was made.

The critical infrastructure vulnerability study approach is instead; focus on the effect of landslide hazards on the infrastructure, namely the vulnerability of the infrastructure on/near the slope.

Bear in mind the fundamental disaster scenario is adopted to guide the understanding of vulnerability study and logic and practically of the outcome value. The objective is perhaps in the future the engineering design, construction and maintenance approach of the infrastructures on highland maybe revisit for purpose of one of disaster risk mitigation of the element at risk.

8.1 Methodology Framework and Test

The study on the vulnerability and risk of critical infrastructure was conducted at Ringlet and Lembah Bertam, Cameron Highland has applied the vulnerability and risk methodological framework as explained in the earlier chapters.

The comprehensive study on vulnerability of CI cause by three types of landslide hazards, namely rotational/translational, debris flow and rock fall were carried out and applied on the test area of Ringlet and Lembah Bertam. The identification and determination of all four components (C,E,I,P) for a particular Critical Infrastructure is easily comprehend however the challenges are the allocation of weightage to each of the four components, identification of best fit indicators, sub-indicators and their respective weightage. Initially, the selection of indicators, sub-indicators and weightage for each CI were guided by previous work done and expert judgement from FGD and internal expert within the area of knowledge and experiences. To enhance the degree of variation, sensitivity analysis of indicators and sub-indicator for the respective weightage of four component C.E,I,P for a particular set of weightage were done by adopting standard deviation threshold value of 0.05 as the baseline, representing the degree of influence of each parameter to the vulnerability of infrastructure.

8.2 Landslide Vulnerability Indicators and Weightage

The two-weightage used for the four components were 0.25 of equal strength adopted by FGD (Table 4.1 to Table 4.5). Secondly, the internal experts suggested that base on the privilege of understanding the cause and effect and engineering judgement of vulnerability of CI, the unequal weightage should be adopted. The rationals were that, the causal factor is the landslide intensity (I), should carry the higher weightage, follow by critical infrastructure (C) as it is the effect of landslide hazards and focus element of study. While the environment factor E is a bonus component either there is a protection or none, moreover it influence is substantial to vulnerability of CI. The least weightage should be the people (P), as this component is mobile where the effect may or may not be presence. Therefore by random, the trial weightage used by internal experts are C = 0.38, I = 0.3, E= 0.2 and P = 0.12, a summation to 1.0, as highlighted (Table 12.9 to Table 12.22).

From the analysis, showed for the same indicators and sub-indicators that adopted equal weightage of 0.25 for all four components (C,E,I,P) and unequal weightage produced standard deviation of less than or equal to 0.05 , meaning the indicators are consistent. On the other hand, for sub-indicators, the deviation is higher where for building, road and dam are more than 90%, more than 93%, more than 38% respectively. A trial of reducing the number of sub-indicators resulted to a reduction of deviations. The findings indicated the influence of respondent knowledge and experiences on the indicators are acceptable. Consequently, when more variables of sub-indicators are introduced, the probability of double counting of the parameters are possible. The best is to use the easily identified, measurable and most significant indicators. These were proven scientifically from the analysis of sensitivity of indicators and sub-indicators for the particular critical infrastructure.

8.3 Vulnerability of CI Cause by Type of Landslides

Comparatively, the vulnerability of CI is evaluated with respect to the three types of landslide. One example of CI, namely building subjected to rotational/translational landslides, debris flow or rock fall is summarised below. Interestingly, the result shows how the mode of landslide effects the sensitivity of the indicators and the sequence of influential components to the vulnerability of CI itself. The approach of C,E,I,P which was documented from literature on debris flow produce the same output from these study. Whereas the rotational /translational produce C,E,I,P and rock fall is C,E,I,P. Nevertheless, further study needs to explore this initial summary.

Table 8.1: Evaluation of building vulnerability respected to three types of landslides

Type of landslides (causal factor)	Indicator	Influential component in sequence
Rotational/ translational	- Landslide volume is the most sensitive indicator - Least sensitive indicators are population density, age of people and health condition of people	The landslide intensity cluster (*I*) is the most sensitive cluster followed by the susceptibility of CI (*C*) and surrounding environment (*E*). The impact of landslide on the people inside the building has the lowest sensitivity value (P). I,C,E,P.

Debris flow	- Building foundation depth appeared to be the most sensitive vulnerability indicators, this can be related to the possible velocity of landslide - The least sensitive indicators landside thickness, population density, age of people and health of people	The vulnerability of the CI (C) is the most sensitive cluster followed by surrounding environment (E), landslide intensity (I) and impact of the building on people (P). C,E,P,I
Rockfall	- Building foundation depth appeared to be the most sensitive vulnerability indicators. - The least sensitive indicators, population density, age of people and health of people	The vulnerability of the CI (*C*) and landslide intensity (*I*) are the most sensitive clusters followed by surrounding environment (*E*), and impact of the building on people (*P*). C,I,E,P.

8.4 Landslide Vulnerability Assessment Based on Different Scenarios

Unfortunately, from the methodological framework, random respondents input and data processing tool, the trend and practical scenario of vulnerability of CI caused by landslide hazard is not significantly reflected to all four CIs. It is recommended that further analysis need to be carried out to improve the approach weightage, indicators and sub-indicators for all three scenarios. The possible two scenarios could be:

Scenario 1**:** Best scenario i.e. the vulnerability of CI is zero (safe) when landslide hazards is nil.

Scenario 2: Worst case scenario, i.e. the vulnerability of CI is very high when landslide hazard occurs.

The determination of the baseline weightage for C,E,I,P the vulnerability of CI versus Landslide Intensity scenarios need to be analysed again. The conclude baseline weightage shall be use later in the development of guideline.

8.5 Critical Infrastructure Vulnerability Index for Test Site – Ringlet and Lembah Bertam, Cameron Highland

Despite the issues highlight for further improvement, the method of classification of the vulnerability of CI is as shown. The outcome of the calculated vulnerability index is used to classify the class of vulnerability of the CI as summarised below. The JMG guideline and Table 4.8 are adopted to classify the vulnerability of CI from its respective calculated index.

8.6 Vulnerability of CI (Building and Road) In Lembah Bertam

Table 8.2 and 8.3 show the distribution of vulnerability class for buildings in the study area and those located inside the landslides. The entire buildings in the study area are classified as moderate vulnerability. Table 8.4 and 8.5 show the distribution of vulnerability class for roads in the study area and those located inside the landslides. Majority of the roads in Lembah Bertam were classified as moderate vulnerability. The results show 98.32% of buildings classified as moderate vulnerability are located inside the landslide area. About 92.50% of roads classified as moderate vulnerability are located inside the landslide area.

Table 8.2: Vulnerability of building in Lembah Bertam.

Classification	No of Building	Index
Building	358	
Vulnerability		VI (Range)
Very Low Vulnerability (VLV)	0	0
Low Vulnerability (LV)	0	0
Moderate Vulnerability (MV)	358	0.42 - 0.65
High Vulnerability (HV)	0	0
Very High Vulnerability (VHV)	0	0

Table 8.3: Vulnerability of building within landslides in Lembah Bertam.

Classification	No of Building	Index
Building within Landslides	119	
Vulnerability		VI (Range)
Very Low Vulnerability (VLV)	0	0
Low Vulnerability (LV)	0	0
Moderate Vulnerability (MV)	117	0.46 - 0.65
High Vulnerability (HV)	0	0
Very High Vulnerability (VHV)	0	0

Table 8.4: Vulnerability of road in Lembah Bertam.

Classification	No of Road	Length (meter)	Index
Road	241	30342.51	
Vulnerability			VI (Range)
Very Low Vulnerability (VLV)	0	0	0
Low Vulnerability (LV)	0	0	0
Moderate Vulnerability (MV)	232	28281.55	0.71 - 0.74
High Vulnerability (HV)	9	2060.96	0.42 - 0.70
Very High Vulnerability (VHV)	0	0	0

Table 8.5: Vulnerability of road within landslides in Lembah Bertam.

Classification	No of Road	Length (meter)	Index
Road within Landslides	120	18202.23	
Vulnerability			VI (Range)
Very Low Vulnerability (VLV)	0	0	0
Low Vulnerability (LV)	0	0	0
Moderate Vulnerability (MV)	111	16054.31	0.43 - 0.70
High Vulnerability (HV)	9	2060.96	0.70 - 0.74
Very High Vulnerability (VHV)	0	0	0

8.7 Vulnerability of CI (Building and Road) In Ringlet

Table 8.6 and 8.7 show the distribution of vulnerability class for buildings in the study area and those located inside the landslides. The entire buildings in the study area are classified as moderate vulnerability. Table 8.8 and 8.9 show the distribution of vulnerability class for roads in the study area and those located inside the landslides. Majority of the roads in Ringlet were classified as moderate vulnerability. The results show 98.32% and 1.68% of buildings classified as moderate and high vulnerability are located inside the landslide area respectively. About 96.27% and 3.73% of roads classified as moderate and high vulnerability are located inside the landslide area respectively.

Table 8.6: Vulnerability of building in Ringlet.

Classification	No of Building	Index
Building	334	
Vulnerability		VI (Range)
Very Low Vulnerability (VLV)	0	0
Low Vulnerability (LV)	0	0
Moderate Vulnerability (MV)	332	0.41 - 0.66
High Vulnerability (HV)	2	0.74
Very High Vulnerability (VHV)	0	0

Table 8.7: Vulnerability of building within landslides in Ringlet.

Classification	No of Building	Index
Building within Landslides	119	
Vulnerability		VI (Range)
Very Low Vulnerability (VLV)	0	0
Low Vulnerability (LV)	0	0
Moderate Vulnerability (MV)	117	0.41 - 0.66
High Vulnerability (HV)	2	0.74
Very High Vulnerability (VHV)	0	0

Table 8.8: Vulnerability of road in Ringlet.

Classification	No of Road	Length (meter)	Index
Road	241	30342.51	
Vulnerability			VI (Range)
Very Low Vulnerability (VLV)	0	0	0
Low Vulnerability (LV)	0	0	0
Moderate Vulnerability (MV)	232	28281.55	0.71 - 0.74
High Vulnerability (HV)	9	2060.96	0.42 - 0.70
Very High Vulnerability (VHV)	0	0	0

Table 8.9: Vulnerability of road within landslides in Ringlet.

Classification	No of Road	Length (meter)	Index
Road within Landslides	127	18202.23	
Vulnerability			VI (Range)
Very Low Vulnerability (VLV)	0	0	0
Low Vulnerability (LV)	0	0	0
Moderate Vulnerability (MV)	111	16054.31	0.43 - 0.70
High Vulnerability (HV)	9	2060.96	0.70 - 0.74
Very High Vulnerability (VHV)	0	0	0

9.0 VALIDATION OF LANDSLIDE VULNERABILITY INDEX BASED ON LANDSLIDE EVENT AT TAMAN BUKIT MEWAH, BUKIT ANTARABANGSA

9.1 Introduction

Validation of landslide vulnerability assessment method is carried out based on three important stages i.e. 1) extraction of landslide damage information from previous landslide occurences, 2) estimation of landslide vulnerability for each CI in the landslide area using the IBM's method and 3) comparison of the estimated landslide vulnerability index and class with the damage description obtained from the report (Figure 9.1). The first stage begins with detailed review on the landslide report. Based on the detailed landslide report, different types of CI is identified in the landslide area. With reference to the detailed information of each CI obtained from the report, suitable indicators, sub-indicators and weight value are selected for each CI. In the second stage landslide vulnerability index is calculated for each CI and any explanation or description of damage for each CI from the report is also extracted simultaneously. In the final stage the calculated landslide vulnerability index for each CI is converted into different classes of vulnerability and comparison is made betwen the description of landslide vulnerability class with the damage description obtained from the report.

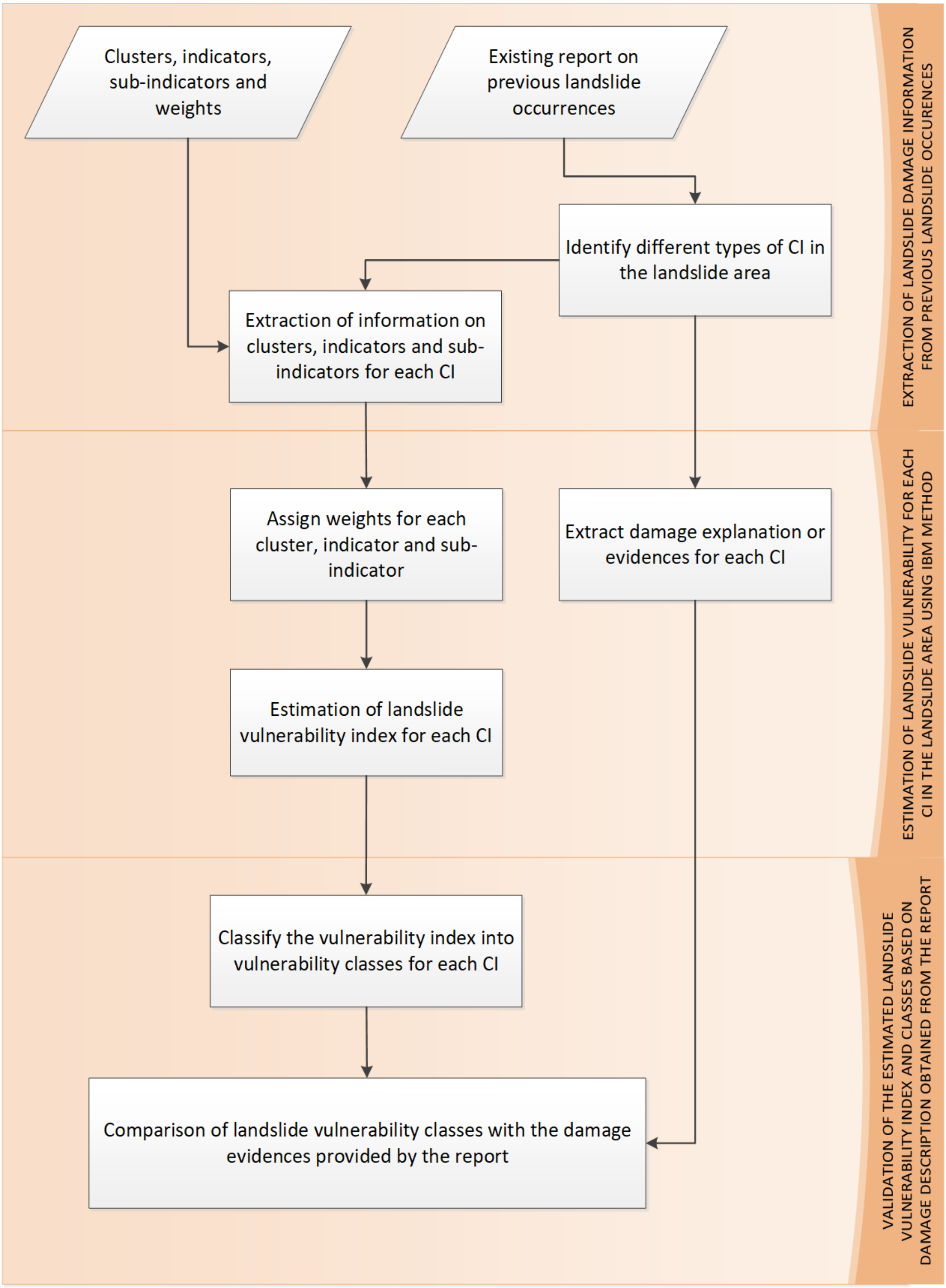


Figure 9.1: Comparison of the estimated landslide vulnerability index and class.

In this report, validation of landslide vulnerability assessment method is carried out at Taman Bukit Mewah, Bukit Antarabangsa, Hulu Kelang, Selangor. The landslide report has a complete information about each vulnerability cluster (C, E, I and P). Therefore, the landslide vulnerability can be calculated and its corresponding index can be estimated for this landslide event. The index and the description of the vulnerability will be compared with the damage and fatalities in this area as described in the report.

9.2 Simulation of Landslide Vulnerability Based on Landslide Event at Taman Bukit Mewah

The estimation of landslide vulnerability index and class at Taman Bukit Mewah is carried out as follows.

Scenario: Taman Bukit Mewah, Bukit Antarabangsa, Hulu Kelang, Selangor (6th December 2008)

Landslide type: Translational/Rotational

Susceptibility of CI (C) (0.36):

- *Building typology (0.14)*: Reinforced concrete structure (0.06)
- *Building Foundation Depth (Landslide Type Vs Deep Foundation Building (0.12)*: Accumulation height/landslide depth > 5 meter, shallow foundation (pad footing) (0.12)
- *Number of floor (0.10)*: Medium rise (2 - 5 storey) (0.05)

Surrounding Environment (E) (0.18):

- *Presence of protection (0.07)*: No protection (0.07)
- *Distance between building (0.05)*: 3-5 meter (0.02)
- *Building location (0.07)*: Building is located at the toe of slope (0.04)

Landslide intensity (I) (0.33):

- *Accumulation height (0.15)*: > 2.0 meter (0.15)
- *Landslide volume (0.18)*: Large, 50,000 - 250,000 meter3 (0.15)

People inside the building (P) (0.13):

- *Population density (0.04)*: High (0.04)
- *Evacuation of alarm system (0.03)*: No (0.03)
- *Age of people (0.03)*: Adults (0.01)
- *Health condition (0.03)*: Health (Good) (0.00)

Estimated vulnerability value: 0.74

Class of vulnerability: High

Class of vulnerability: Structural breaks, partly destructed, reconstruction of destructed parts, death is highly likely (severe injury) and evacuation necessary.

9.3 Description of the Event Based on Technical Report

Based on the technical report prepared by the JKR-CKC (Public Works Department of Malaysia), it was reported that on 6th December 2008, a landslide event occurred at Taman Bukit Mewah, Bukit Antarabangsa, Hulu Kelang, Selangor. The landslide debris has completely blocked Jalan Bukit Antarabangsa, the only road access to some other 5,000 residents. Fourteen (14) bungalow houses were destroyed by the failure debris. The landslide also resulted in five (5) fatalities and injury to fourteen (14) others.

The landslide took place at approximately 3.30 a.m, measuring 109 meter in width at the crest, 120 meter in length, 15 meter in depth and the angle of the scarp of the crown ranges from 45 to 50 degree. It was estimated that 101,500 cubic meter of earth had translated and the maximum run out distance of the failure debris was measured at approximately 210 meter from the toe of the slope.

Based on the investigation undertaken, the landslide can be classified as a deep seated slide. Deep seated slides are generally caused by high pore water pressure. From the investigations, the landslide is believed to have been contributed by a combination of factors such as poorly maintained/damaged drainage system on the failed slope and its surrounding, heavy leakage of an active water pipe along abandoned houses due to soil creep, prolonged soil creep that widened existing cracks and opened new tension cracks, etc. Based on the factors mentioned, the most probable triggering factor of the landslide is due to water leakage from the active pipe along the abandoned houses that caused a build up high pore water pressure within the slope. Figure 9.1 and 9.2 show the example of damaged buildings and scarp of the landslide. Figure 9.3 shows the geomorphological map of the landslide area and area of houses affected by the landslide.

Based on the landslide vulnerability seimulation, the estimated landslide vulnerability at Taman Bukit Mewah is 0.74 (High vulnerability) "Structural breaks, partly desructed, reconstruction of destructed parts, death is highly likely (severe injury) and evacuation necessary". The results show good agreement with the damage and fatalities as described in the technical report.

Figure 9.2: Damaged houses (JKR (CKC), 2008).

Figure 9.3: The failure side scarp masuring up to 20m in depth with gradient ranging from 30º to 50º (JKR (CKC), 2008).

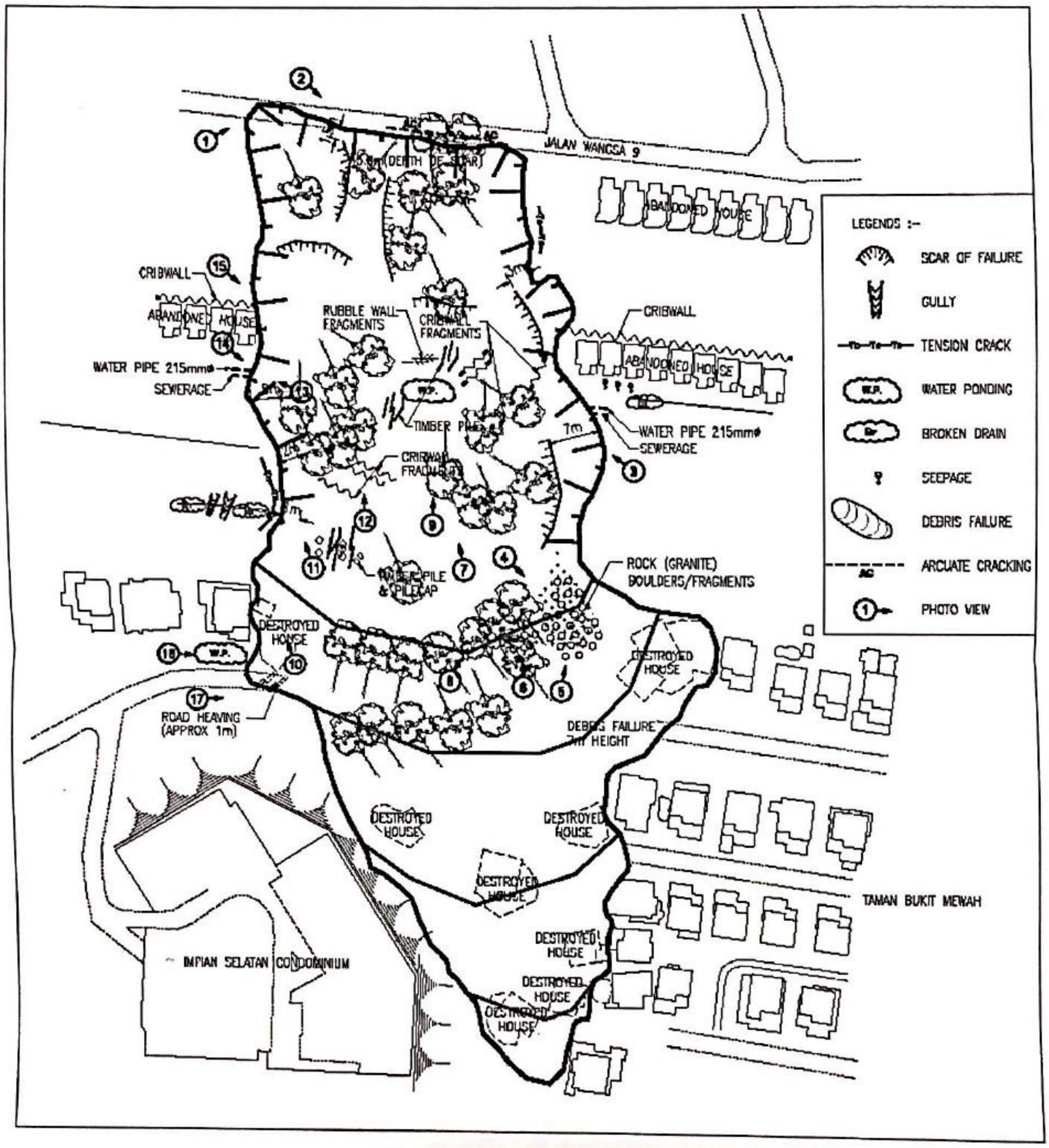


Figure 9.4: Geomorphological map of the landslide area and area of houses affected by the landslide (JKR (CKC), 2008).

10.0 CONCLUSIONS

The proposed landslide vulnerability assessment requires determination of 4 clusters i.e. susceptibility of CI (C), effect of surrounding environment or mitigation measures (E), susceptibility of people inside the residential building (P) and intensity of landslide hazard (I) (Equation 1). Based on intensive literature reviews, initial information on the landslide vulnerability clusters, indicators, sub-indicators, weights, vulnerability and risk classes were determined for further improvement in the Focus Group Discussion (FGD). Several FGDs have been carried out to improved this information. The FGDs with stakeholders have been used to improve the initial information obtained from the literature review. The outcomes from this FGDs are further improved by series of FGDs with the internal experts of the consultant project members. The initial landslide vulnerability clusters were treated equally in which all the group of indicators has the same influence towards the vulnerability value. In this case each group is given with 25% (or 0.25) weight value. The weight value was given equally among the indicators under each group or differently based on their level of importance in vulnerability estimation. However, the outcomes of the FGDs with sensititvity analysis and landslide vulnerability simulations found that this assumption should be changed, in which the cluster should be treated differently. Therefore, the final weight for each cluster has different different values (Table 4.7 to 4.17).

In the first FGD, a total of 23 landslide vulnerability survey forms were successfully completed by the respondents. The respondents have completed the survey form and determine the weightage value for each indicators and sub-indicators depending on the critical infrastructure given. The weight value was given differently among the indicators under each group based on their level of importance in vulnerability estimation.

In this study, the consistency level of weight values is determined based on the standard deviation value. Each weight value given for each indicator and its corresponding class has been analysed and the standard deviation value exceeding 0.05 marked as inconsistant. The results show that the entire weight values assigned for the indicator are consistent among the panels. However, the weight values assigned for the sub-indicators are not consistent, which implies strong deviation on the experience and understanding of the landslide vulnerability concept for CI among the participants. Therefore, the cluster, indicators, sub-indicators and weight values should be improved by the internal experts. In addition, the results show that the weight values assigned by the internal experts are more sensitive to the variations of vulnerability value compared to the weight assigned by the stakeholders.

More sensitive cluster/indicator can be achieved by assigning high weight value for cluster and indicator with good variation or distribution of weight of sub-indicator (0.1 to 1.0). Based on the best, medium and worst case landslide vulnerability scenarios, the set of weight assigned by the internal experts has produced more reasonable value expected for very low, moderate and very high vulnerability classes compared to the weights obtained from the stakeholders. The final landslide cluster, indicators, sub-indicators and weight values obtained from the internal experts have successfully improved the initial data. The key approach towards development of a reliable and practical landslide vulnerability assessment is to use the easily identified, measurable and most significant indicators. These were proven scientifically from the analysis of sensitivity of indicators and sub-indicators for the particular critical infrastructure. The estimated landslide vulnerability for building at Taman Bukit Mewah was 0.72 (High vulnerability) “Structural breaks, partly desructed, reconstruction of destructed parts, death is highly likely (severe injury) and evacuation necessary”. The results show good agreement with the reports of the landslide produced by the Slope Engineering Division (CKC), Public Works Department (JKR).

In conclusion, the study has successfully achieved the objective to assess and develop the parameters/indicators of landslide vulnerability assessment of critical infrastructures (CI) and assigning level for each parameter is addressed. The landslide vulnerability indicators, sub-indicators and its corresponding weights were tested in Ringlet and Lembah Bertam, Cameron Highland with supports from various remotely sensed data, field data and other ancillary geospatial data.

11.0 REFERENCES

Abdul Ghani Rafek, Ibrahim Komoo & Tan, T. H., 1989. Influence of geological factors on slope stability along the East-West Highway, Malaysia. *Proc. Int. Conf. Engineering Geology in Tropical Terrain. Bangi*: 79-93.

Abella, E. C. & Van Westen, C. 2007. Generation of a landslide risk index map for Cuba using spatial multi-criteria evaluation. *Landslides,* 4**,** 311-325.

Aliabadi, S. F., Sarsangi, A. & Modiri, E. 2015. The social and physical vulnerability assessment of old texture against earthquake (case study: Fahadan district in Yazd City). *Arabian Journal of Geosciences,* 8**,** 10775-10787.

Anbalagan, R. & Singh, B. 1996. Landslide hazard and risk assessment mapping of mountainous terrains — a case study from Kumaun Himalaya, India. *Engineering Geology,* 43**,** 237-246.

Azami, S. M., Mohamed, Z. & Samad, A. M. (2006). Sistem Pengurusan Georisiko dan Reliabiliti Untuk Pencegahan Geobencana. Persidangan Bersama Geosains UKM-ITB, 127-129.

Bendimerad, F. (2001). Loss estimation: a powerful tool for risk assessment and mitigation. *Soil Dynamics and Earthquake Engineering, 21*, 467-472

Bin, Y., Lihong, Q., Zuowei, Z., and Muqi, W. (2016). A Metamodel for the Manufacturing Process Information Modeling. *Procedia CIRP*, 56, 332–337

Birkmann, J. (2006). *"Indicators and criteria for measuring vulnerability: theoretical bases and criteria"*.

Birkmann, J., Cardona, O.D., Carreño, M.L., Barbat, A.H., Pelling, M., Schneiderbauer, S., Kienberger, S., Keiler, M., Alexander, D., Zeil, P., & Welle, T. (2013). Framing vulnerability, risk and societal responses: the MOVE framework. *Natural Hazards, 67*, 193-211

Blaikie, P., Cannon, T., Davis, I., Wisner, B., 1994. At Risk: Natural Hazards, People's Vulnerability, and Disasters. Routledge, New York.

B. Ngo, E. 2001. *When Disasters and Age Collide: Reviewing Vulnerability of the Elderly*.

Bolin, R. 1993. Household and Community Recovery After Earthquakes. Institute of

Behavioral Science: University of Colorado.

Bolin, R. & Stanford, L. 1991. Shelter, Housing and Recovery: A Comparison of U.S. Disasters. *Disasters,* 15**,** 24-34.

Bolin, R. & Stanford, L. 1998. *The Northridge Earthquake: Vulnerability and Disaster,* London, Routledge.

Bono, D.A. & Mora, M.G. (2014). A global exposure model for disaster risk assessment. *International Journal of Disaster Risk Reduction* **10**: 442–451

Burton, I., Kates, R. W. & White, G. F. 1993. *The Environment as Hazard (2nd ed.),* New York, Guildford.

Cardinali, M., Reichenbach, P., Guzzetti, F., Ardizzone, F., Antonini, G., Galli, M., Cacciano, M., Castellani, M., & Salvati, P. (2002). A geomorphological approach to the estimation of landslide hazards and risks in Umbria, Central Italy. *Nat. Hazards Earth Syst. Sci., 2*, 57-72

Carribean Handbook On Risk Information Management. n.d. *Scales of landslide susceptibility assessment* [Online]. Available: http://www.charim.net/methodology/42 [Accessed August 8, 2018].

Ciurean, R.L., Schröter, D., & Glade, T. (2013). Conceptual frameworks of vulnerability assessments for natural disasters reduction. *Approaches to disaster management-Examining the implications of hazards, emergencies and disasters*: InTech

Cimne (2009). Method and indicator systems for assessing vulnerability and risk: detailed
literature review. Deliverable to WT 1.2, MOVE (Methods for the Improvement of Vulnerability Assessment in Europe).

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.J., 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, 73, 209-263

Cova, T. J. & Church, R. L. 1997. Modelling community evacuation vulnerability using GIS.
International Journal of Geographical Information Science, 11**,** 763-784.

Cruden, D. & Fell, R. (1997). Quantitative risk assessment for slopes and landslides–the state of the art. *Landslide Risk Assessment***,** 3-12.

Cutter, S. L. 1996. Vulnerability to environmental hazards. *Progress in Human Geography,*
20**,** 529-539.

Cutter, S. L., Mitchell, J. T. & Scott, M. S. 2000. Revealing the Vulnerability of People and
Places: A Case Study of Georgetown County, South Carolina. *Annals of the Association of American Geographers,* 90**,** 713-737.

Cutter, S., Boruff, B.J., Shirley, W.L., (2003). Social vulnerability to environmental hazards. Soc. Sci. Q. 84, 242-261.

Dai, F.C., Lee, C.F., & Ngai, Y.Y. (2002). Landslide risk assessment and management: an overview. *Engineering Geology, 64*, 65-87

Doornkamp, J. C. 1989. Hazards. *In* McCall,G. J. H. & Marker, B. R. (eds.) Earth Science Mapping for Planning, Development and Conservation. Graham & Trotman, London, 157-173.

Drabek, T. E. 1996. Disaster Evacuation Behavior: Tourists and Other Transients. Boulder,
Colorado: Institute of Behavioral Science, University of Colorado.

Eidsvig, U.M.K., Papathoma-Köhle, M., Du, J., Glade, T., & Vangelsten, B.V. (2014). Quantification of model uncertainty in debris flow vulnerability assessment. *Engineering Geology, 181*, 15-26

Eidsvig, U. M. K., McLean, A., Vangelsten, B. V., Kalsnes, B., Ciurean, R. L., Argyroudis, S.,
Winter, M. G., Mavrouli, O. C., Fotopoulou, S., Pitilakis, K., Baills, A., Malet, J.-P. & Kaiser, G. 2014. Assessment of socioeconomic vulnerability to landslides using an indicator-based approach: methodology and case studies. *Bulletin of Engineering Geology and the Environment,* 73**,** 307-324.

Enarson, E. & Scanlon, J. 1999. Gender patterns in flood evacuation: A case study in Canada's Red River Valley. *Applied Behavioral Science Review,* 7**,** 103-124.

Enarson, E. P. & Morrow, B. H. 1998. *The Gendered Terrain of Disaster: Through Women's Eyes*, Praeger.

Erener, A., & Sebnem Düzgün, I.H.B. (2012). A regional scale quantitative risk assessment for landslides: case of Kumluca watershed in Bartin, Turkey. *Landslides.*

Federation Emergency Management Agency (FEMA). 1997. Multi Hazards – Identification and risk assessment. A cornerstone of the National Strategy. USA. 370p

Fell, R. (2000). Landslide Risk Management Concepts and Guidelines–Australian Geomechanics Society Sub-Committee On Landslide Risk Management. *Landslides, International Union of Geological Sciences, Cardiff, UK***,** 51-93.

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, 85-98

Flageolett, J.-C. (1999). Landslide hazard - a conceptual approach in risk viewpoint. In R. Casale, & C. Margottini (Eds.), *Floods and Landslides: Integrated Risk Assessment.* (pp. 3-18). Berlin: Springer-Verlag

Fothergill, A. 1996. Gender, Risk, and Disaster. *International journal of mass emergenciesband disasters,* 14**,** 33-56.

Fotopoulou, S.D., & Pitilakis, K.D. (2017). Vulnerability assessment of reinforced concrete buildings at precarious slopes subjected to combined ground shaking and earthquake induced landslide. *Soil Dynamics and Earthquake Engineering, 93*, 84-98

Frédéric, L., P. Asté, J., & Leroi, E. (1996). *Vulnerability assessment of elements exposed to mass-movement: Working toward a better risk perception*.

Fuchs, S., Heiss, K., & Hübl, J. (2007). Towards an empirical vulnerability function for use in debris flow risk assessment. *Nat. Hazards Earth Syst. Sci., 7*, 495-506

Fuchs, S., Kuhlicke, C., & Meyer, V. (2011). Editorial for the special issue: vulnerability to natural hazards—the challenge of integration. *Natural Hazards, 58*, 609-619

Fuchs, S., Tsao, T.-C., & Keiler, M. (2012). *Quantitative vulnerability functions for use in mountain hazard risk management - the challenge of transfer*.

Gems, B., Mazzorana, B., Hofer, T., Sturm, M., Gabl, R., & Aufleger, M. (2016). 3-D hydrodynamic modelling of flood impacts on a building and indoor flooding processes. *Nat. Hazards Earth Syst. Sci., 16*, 1351-136

Geotechnical Control Office. (1991). Geotechnical Manual for Slopes. Hong Kong: Hong Kong Government.

Glade, T. (2004). Vulnerability assessment in landslide risk analysis. *Die Erde, 134*, 121-138

Glade, T. n.d. *Generation of quantitative landslide risk maps - advances and pit falls* [Online]. Available: http://www.adpc.net/casita/pdf/03-Qualitative-landslide-risk-maps.pdf [Accessed August 22, 2018].

Gue, S. S. & Tan, Y. C. 2002. Mitigating the risk of landslide on Hill-Site Development in Malaysia. *2nd World Engineering Congress, Sarawak, Malaysia, 22-25 July 2002*

Guillard-Gonçalves, C., Zêzere, J.L., Pereira, S., & Garcia, R.A.C. (2016). Assessment of physical vulnerability of buildings and analysis of landslide risk at the municipal scale: application to the Loures municipality, Portugal. *Nat. Hazards Earth Syst. Sci., 16*, 311-331

Haliza Abdul Rahman & Jabil Mapjabil. 2017. Landslides Disaster in Malaysia: an Overview. *Health and the Environment Journal, vol 8, No.1.* p.58-71.

Heinz Center for Science, E. a. t. E. 2000. *The Hidden Costs of Coastal Hazards: Implications For Risk Assessment And Mitigation*, Island Press.

Heinz Center for Science, E. a. t. E. 2002. *Human Links to Coastal Disasters*, H. John Heinz III Center for Science, Economics and the Environment.

Hencher, S. R.; Su. G. L., & Malone, A. Back analysis of landslides to allow the design of cost-effective mitigation measures

Hewitt, K. 1997. *Regions of Risk: A Geographical Introduction to Disasters,* Essex, U. K, Longman.

Hewitt, K. 2000. Safe place or 'catastrophic society'? Perspectives on hazards and disasters in Canada. *The Canadian Geographer / Le Géographe canadien,* 44**,** 325-341.

Hu, K.H., Cui, P., & Zhang, J.Q. (2012). Characteristics of damage to buildings by debris flows on 7 August 2010 in Zhouqu, Western China. *Natural Hazards, 12*, 2209-2217

Hungr, O. (1997). Some methods of landslide intensity mapping. In D.M. Cruden, & R. Fell (Eds.), *International Workshop on Landslide Risk Assessment* (pp. 215–226). Honolulu: Balkema

Ibrahim Komoo & Abdul Ghani Rafek, 1988. Faktor penyebab utama kegagalan cerun di Lebuhraya Timur-Barat, Malaysia. Laporan Teknik FSFG. 2(1):36-47.

Ibrahim Komoo, 1995. Tragedi Gelinciran Tanah di Jalan Susur Genting Highland pada 30 Jun 1995. *Laporan terbuka, Institut Alam Sekitar dan Pembangunan, Universiti Kebangsaan Malaysia*.

Ibrahim Komoo, 1997. Slope failure disasters – A Malaysian predicament. *In*: Marinos, Koukis, Tsiambaos & Stournaras (eds.). *Engineering Geology and the Environment*. 1: 777-781.

Ibrahim Komoo, 1998. Deep weathering: Major cause of slope failure in wet tropical terrain. *8th International IAEG Congress, Balkema, Rotterdam.* 1773-1778

IUGS (1997). Quantitative risk assessment for slopes and landslides – the State of the Art. IUGS Working Group on Landsldies, Committee on Risk Assessment, in *Landslide risk assessment*, Cruden and Fell (eds), Balkema, Rotterdam, 3-12

Isaza-Restrepo, P.A., Martínez Carvajal, H.E., & Hidalgo Montoya, C.A. (2016). Methodology for quantitative landslide risk analysis in residential projects. *Habitat International, 53*, 403-412

Jabatan Mineral dan Geosains (2002), *Laporan gelonsoran tanah serta batuan di Kampong Sri Gunung Pulai, Pontian, Johor Darul Takzim*, Laporan No. JMG.JHR: (GS) 1/2002, JMG Negeri Johor, Jun 2002

Jabatan Kerja Raya (CKC) (2008), *Final Landslide Investigation Report-Investigation of Slope Failure at Taman Bukit Mewah, Bukit Antarabangsa, Hulu Klang, Selangor*, Laporan No. JKR 21500-0008-09, December 2008

Jakob, M., Stein, D., & Ulmi, M. (2011). *Vulnerability of buildings to debris flow impact*.

Jamaludin, S., Huat, B. K., Omar, H., et al. (2004), Landslide Hazard and Risk Assessment in Malaysia. Malaysian-Japan Symposium on Geohazards and Geoenvironmental Engineering Recent Advances. 55-62.

Kang, H.-s., & Kim, Y.-t. (2016). The physical vulnerability of different types of building structure to debris flow events. *Natural Hazards, 80*, 1475–1493

Kappes, M.S., Papathoma-Köhle, M., & Keiler, M. (2012). Assessing physical vulnerability for multi-hazards using an indicator-based methodology. *Applied Geography, 32*, 577-590

Kaynia, A.M., Papathoma-Köhle, M., Neuhäuser, B., Ratzinger, K., Wenzel, H., & Medina-Cetina, Z. (2008). Probabilistic assessment of vulnerability to landslide: Application to the village of Lichtenstein, Baden-Württemberg, Germany. *Engineering Geology, 101*, 33-48

Kloos, J., Asare-Kyei, D., Pardoe, J. & Renaud, F. G. 2015. Towards the development of an adapted multi-hazard risk assessment framework for the West Sudanian Savanna zone.

Ko Ko, C., Flentje, P. N. & Chowdhury, R. N. 1999. Landslide risk assessment-development of a hazard consequence approach.

Kumpulan IKRAM Sdn. Bhd. (2002), *Soil Investigation Work & Soil Instrumentation Work Gunung Pulai Slope Failure Johor Bahru, Johor Darul Takzim*, Bil. Laporan 080/02, IKRAM Selatan, Julai 2002.

Lacass, S., & Nadim, F. (2006). Hazard and Risk Assessment of Slope. International Conference on Slope, 3-35.

Li, Z., Nadim, F., Huang, H., Uzielli, M., & Lacasse, S. (2010). Quantitative vulnerability estimation for scenario-based landslide hazards. *Landslides, 7*, 125–134

Lo, W.-C., Tsao, T.-C., & Hsu, C.-H. (2012). *Building vulnerability to debris flows in Taiwan: A preliminary study*.

Majlis Perbandaran Ampang Jaya (MPAJ), 1994. Report of the Technical Committee of Investigation on the Collapse Block 1 and the stability of Blocks 2 and 3 Highland Towers Condominium, Hulu Klang, Selangor Darul Ehsan.

Malone, A. 2017. Understanding the movement behaviour of the Pos Selim Landslide Malaysia. Session Keynote. 30th National Geoscience Conference and Exhibition. Geological Society of Malaysia (Abstract).

Malone, A. W., Hansen, A., Hencher, S.R., and Fletcher, C.J.N. 2008. Post-failure movements of a large slow rock slide in schist near Pos Selim, Malaysia. *In*: Chen *et al.* (eds). Landslides and Engineered Slopes. Taylor & Francis Group, London, p.457-461.

Martha, T. R., Van Westen, C. J., Kerle, N., Jetten, V. & Vinod Kumar, K. 2013. Landslide hazard and risk assessment using semi-automatically created landslide inventories. *Geomorphology,* 184**,** 139-150.

Mazzorana, B., Simoni, S., Scherer, C., Gems, B., Fuchs, S., & Keiler, M. (2014). A physical approach on flood risk vulnerability of buildings. *Hydrol. Earth Syst. Sci., 18*, 3817-3836

Mazzorana, B., & Fuchs, S. (2010). Fuzzy Formative Scenario Analysis for woody material transport related risks in mountain torrents. *Environmental Modelling & Software, 25*, 1208-1224

McCall, 1992. Natural and mad-made hazards: their increasing importance in the end-20th century world. *In* McCall, G. J. H., Lamming, D. J. S. & Scott, S. C. (eds.) Geohazards – Natural and Man-made. Chapman & Hall. London, 1-4.

Mileti, D. 1999. *Disasters by Design: A Reassessment of Natural Hazards in the United States*,
National Academies Press.

Mitchell, J. K. 1999. *Crucibles of Hazard: Mega-cities and Disasters in Transition,* Tokyo,
United Nations University Press.

Mohd Asbi & Associates Sdn Bhd. (2005). Surface investigation report on proposed cut slope between Ch 23+000 and Ch 24+560 Simpang Pulai - Gua Musang - Kuala Berang package 2, Malaysia. Report to Ministry of works Malaysia

Mohd Shamiruddin Mahamad Azami.(2009), Slope Risk Assessment using GIS

Technique: Study Area-Section U10 Shah Alam,Selangor. Unpublished master thesis Universiti Teknologi MARA

Morrow, B. & Phillips, B. 1999. *What's gender "got to do with it"?*

Morrow, B. H. 1999. Identifying and Mapping Community Vulnerability. *Disasters,* 23**,** 1-18.

Nisha & Punia, M. 2014. Socio-economic vulnerability and sustainable development in context of Development vs. Conservation debate: A study of Bhagirathi Basin, Uttarakhand, INDIA. *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.,* XL-8**,** 77-84.

O'Brien, P. W. & Mileti, D. 1992. *Citizen Participation in Emergency Response following the Loma Prieta Earthquake*.

Othman, S. H., & Beydoun, G. (2010). Metamodel-based decision support system for disaster management. *The 5th International Conference on Software and Data Technologies (ICSOFT'2010)*

Othman S.H., Beydoun G. (2013). Model-driven disaster management. Volume 50, Issue 5, July 2013, Pages 218-228. https://doi.org/10.1016/j.im.2013.04.002

Papathoma-Köhle, M., Keiler, M., Totschnig, R., & Glade, T. (2012). *Improvement of vulnerability curves using data from extreme events: a debris flow event in South Tyrol*.

Papathoma-Köhle, M. (2016). *Vulnerability curves vs. Vulnerability indicators: Application of an indicator-based methodology for debris-flow hazards*.

Papathoma-Köhle, M., Zischg, A., Fuchs, S., Glade, T., & Keiler, M. (2015). Loss estimation for landslides in mountain areas – An integrated toolbox for vulnerability assessment and damage documentation. *Environmental Modelling & Software, 63*, 156-169

Papathoma-Köhle, M., Keiler, M., Totschnig, R., & Glade, T. (2012b). A new vulnerability function for debris flow - the importance of physical vulnerability assessment in alpine areas. In, *12th Congress INTERPRAEVENT 2012*. Grenoble / France: INTERPRAEVENT

Papathoma-Köhle, M., Gems, B., Sturm, M., & Fuchs, S. (2017). Matrices, curves and indicators: A review of approaches to assess physical vulnerability to debris flows. *Earth-Science Reviews, 171*, 272-288

Park, Y., Pradhan, A. M. S., Kim, U., Kim, Y.-T. & Kim, S. 2016. Development and Application
of Urban Landslide Vulnerability Assessment Methodology Reflecting Social and Economic Variables. *Advances in Meteorology,* 2016**,** 13.

Peacock, W. G., Morrow, B. H. & Gladwin, H. 1997. Hurricane Andrew: Ethnicity, Gender
and the Sociology of Disasters. *In:* Peacock, W. G., Morrow, B. H. & Gladwin, H. (eds.) *DISASTERS AND SOCIAL CHANGE: HURRICANE ANDREW AND THE RESHAPING OF MIAMI?* Gainesville, Florida: University Press of Florida

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.

Pereira, S., Garcia, R.A.C., Luís Zêzere, J., Oliveira, S.C., & Silva, M. (2017). Landslide quantitative risk analysis of buildings at the municipal scale based on a rainfall triggering scenario. *Geomatics, Natural Hazards and Risk, 8*, 624-648

Petrie, G. & Toth, C.K (2008). Introduction to laser ranging, profiling, and scanning. In: J. Shan, C. K. Toth (Eds.), Topographic Laser Ranging and Scanning: Principles and Processing. Boca Raton: CRC/Taylor & Francis, pp. 1-27

Platt, R. 1991. Lifelines: An Emergency Management Priority for the United States in the
1990s. *Disasters,* 15**,** 172-176.

Platt, R. 1999. *Disasters and Democracy: The Politics of Extreme Natural Events,* Washington,
D.C., Island Press.

Puente, S. 1999. Social Vulnerability to Disaster in Mexico City. *In:* Mitchell, J. K. (ed.) *Crucibles of Hazard: Mega Cities and Disasters in Transitions.* Tokyo: United Nations University Press.

Pulido, L. 2000. Rethinking Environmental Racism: White Privilege and Urban Development in Southern California. *Annals of the Association of American Geographers,* 90**,** 12-40.

Quan Luna, B., Blahut, J., vanWesten, C.J., Sterlacchini, S., van Asch, T.W.J., & Akbas, S.O.
(2011). The application of numerical debris flow modelling for the generation of physical vulnerability curves. *Natural Hazards, 11*, 2047–2060

Ratemo, S. & Bamutaze, Y. 2017. Spatial analysis of elements at risk and household vulnerability to landslide hazards on Mt. Elgon, Uganda. *African Journal of Environmental Science and Technology* 11**,** 438-447.

Reinhold, T., Sedlacek, W., & Fuchs, S. (2011). A quantitative vulnerability function for fluvial
sediment transport. *Natural Hazards, 58*, 681–703

Remondo, J., Bonachea, J., & Cendrero, A. (2008). Quantitative landslide risk assessment and mapping on the basis of recent occurrences. *Geomorphology, 94*, 496-507

Roberds, W.J. (2005). Estimating temporal and spatial variability and vulnerability – State of the Art Paper 5. Landslide Risk Management, Hungr, Fell, Couture & Eberhardt (eds), Taylor & Francis, London: 129-158

S., Tofani, V., Hervás, J., & Smith, J.T. (2014). Recommendations for the quantitative analysis
of landslide risk. *Bulletin of Engineering Geology and the Environment, 73*, 209-263

Safeland (2012). Living with landslide risk in Europe: Assessment, effects of global change,
and risk management strategies: 7th Framework Programme, Cooperation Theme 6 Environment (including climate change), Sub-Activity 6.1.3 Natural Hazards. In

Sagarejo Municipality 2010. Landslide Hazard, Social-Economic Vulnerability and Physical
(Buildings) Risk Assessment. Sagarejo, Georgia.

Samodra, G., Chen, G., Sartohadi, J., Kasama, K. & Hadmoko, D. S. Spatial Pattern of Socio
economic Landslide Vulnerability and its Spatial Prediction by means of GIS-Fuzzy Logic in Kayangan Catchment, Indonesia. International Conference on

Disaster Management 2012, The 8th Annual Conference of IIIRR, 2012 Kumamoto, Japan.

Shu, Y.K. & Lai, K. H., 1980. Rockfall at Gunung Cheroh, Ipoh. *Geological Survey Malaysia, Prof. Papers, 3:* 1-9.

Shu, Y.K., Chow, W. S. & Zakaria, M. 1981. Rockfall danger related to limestone hills in the Kinta Valley, Perak. *Annual Report 1981, Geological Survey of Malaysia:* 184-197.

Silva, M., & Pereira, S. (2014). Assessment of physical vulnerability and potential losses of buildings due to shallow slides. *Natural Hazards*, 1029–1050

Steinführer, A., De Marchi B, Kuhlicke C, Scolobig A, Tapsell S & Tunstall S 2009. Vulnerability, resilience and social constructions of flood risk in exposed communities. FLOODsite report T11-07-12: http://www.floodsite.net

Tajul Anuar Jamaluddin. (2006). Human factors and slope failures in Malaysia. *Bull. Geol. Soc. Malaysia*, 52: 75-84. Tajul Anuar JAmaluddin & Ibrahim Komoo. *2007. Structurally-controlled landslide in Weathered Rock Masses – Typical Examples from Malaysia. Proc. 2nd Malaysia-Japan Symposium on Geohazards & Geoenvironmental engineering. 20-22 Nov. 2007. Langkawi. P.137-148.*

Tajul Anuar Jamaludin. (2015). Large-Scale landslides in mountainous terrain of Malaysia – Some case studies. Paper presented at International Symposium on Multi Hazard and Risk. 23-24 March 2015, Kuala Lumpur.

Tajul Anuar Jamaluddin, Ibrahim Komoo, Mohd asbi Othman, Lee, S. M. 2006. Characteristics of a structurally-controlled landslide at the Pos Selim – Cameron Higland Highway, Perak, Malaysia. *Proc. International Symposium on Geotechnical Hazards: Prevention, Mitigation and Response. Yogyakarta, Indonesia, 24-27 Apr. 2006.*

Tajul Anuar, J. 1990. Geologi Kejuruteraan Lebuhraya Timur-Barat, Gerik-Jeli Semenanjung Malaysia – Dengan Penekanaan Terhadap Kegagalan Cerun Batuan. *MSc Thesis, Universiti Kebangsaan Malaysia, Bangi.*

Tajul Anuar, J. 2002. Engineering Geology and slope failures along the Pos Selim-Cameron Highland Highway. *Proc. Seminar Penyelidikan Vot F, University Malaya*. (in CD-ROM).

Tapsell S M, Tunstall S M, Green C & A, F. 2005. Task 11 Social Indicator Set, FLOODsite report T11-07-01. (http://www.floodsite.net)

Tarbotton, C., Dall'Osso, F., Dominey-Howes, D., & Goff, J. (2015). The use of empirical vulnerability functions to assess the response of buildings to tsunami impact: Comparative review and summary of best practice. *Earth-Science Reviews, 142*, 120-134

Technical Committee on Risk Assessment and Management (2004) Glossary of Risk Assessment Terms. Version 1, *International Society of Soil Mechanics and Geotechnical Engineering* TC32, 7 p., http://www.engmath.dal.ca/tc32/2004Glossary_Draft1.pdf

Tobin, G. & C. Ollenburger, J. 1992. *Natural hazards and the elderly*.

Totschnig, R., Sedlacek, W., & Fuchs, S. (2011). A quantitative vulnerability function for fluvial sediment transport. *Natural Hazards, 58*, 681-703

UN, 2007. Hyogo Framework for Action 2005–2015: Building the Resilience of Nations and Communities to Disasters. (Kyoto).

UN-ISDR, 2004. Terminology of disaster risk reduction. United Nationas, International Strategy for Disaster Reduction, Geneva, Switzerland http://www.unisdr.org/eng/library/lib-terminology-eng%20home.htm

Universiti Teknologi Malaysia (UTM), 2002. Laporan Penilaian Geologi, Geoteknik dan Hidrologi di Persekitaran Tadahan Sungai Air Hitam Besar, Gunung Pulai, Johor Darul Takzim. Oktober 2002.

Uzielli, M., Nadim, F., Lacasse, S., & Kaynia, A.M. (2008). A conceptual framework for quantitative estimation of physical vulnerability to landslides. *Engineering Geology, 102*, 251-256

Van Westen, C., Van Asch, T. W. & Soeters, R. 2006. Landslide hazard and risk zonation—why is it still so difficult? *Bulletin of Engineering geology and the Environment,* 65**,** 167-184.

Varnes, D. J. 1984. *Landslide hazard zonation: a review of principles and practice*.

Vega, J. A. & Hidalgo, C. A. 2016. Quantitative risk assessment of landslides triggered by earthquakes and rainfall based on direct costs of urban buildings. *Geomorphology,* 273**,** 217-235.

Visconti, M. and Cook, C.R., 2002, December. A meta-model framework for software process modeling. In International Conference on Product Focused Software Process Improvement (pp. 532-545). Springer, Berlin, Heidelberg.

W.K. Kong (2002) Risk assessment of slopes. Quarterly *Journal of Engineering Geology and Hydrogeology*, 35, 213–222. 1470-9236/02. 2002 Geological Society of London

W.Y. KO (2015). Recent Initatives for Enhancing Landslide Risk Management in Hong Kong.Florence.*Geotechnical Safety and Risk V* 99 *T.* Schweckendiek et al. (Eds.)© 2015 The authors and IOS Press.This article is published online with Open Access by IOS Press and distributed under the terms of the Creative Commons Attribution Non-Commercial License. doi:10.3233/978-1-61499-580-7-99

Webb, G. R., Tierney, K. J. & Dahlhamer, J. M. 2000. Businesses and Disasters: Empirical
Patterns and Unanswered Questions. *Natural Hazards Review,* 1**,** 83-90.

Winter, M.G., Shearer, B., Palmer, D., Harmer, C. & Sharpe, J. (2016). The Economic Impact of Landslides and Floods on the Road Network. Procedia Engineering, 143, 1425-1434

Yadav, D. K. & Barve, A. 2017. Analysis of socioeconomic vulnerability for cyclone-affected
communities in coastal Odisha, India. *International Journal of Disaster Risk Reduction,* 22**,** 387-396.

Youssef, A., Maerz, N. H., & Fritz, M., A. (2003). A Risk-Consequence Hazard Rating System for Missouri Highways. 54th Highway Geology Symposium, Burlington, 175 - 195.

Zêzere, J.L., Garcia, R.A.C., Oliveira, S.C., & Reis, E. (2008). Probabilistic landslide risk analysis considering direct costs in the area north of Lisbon (Portugal). *Geomorphology, 94*, 467-495.

12.0 APPENDIX

Table 12.1: Table of building indicators.

COMPONENT	INDICATOR	WEIGHT
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	STRUCTURAL TYPOLOGY / STRUCTURE CONSTRUCTION MATERIALS	0.06
	BUILDING FOUNDATION DEPTH	0.05
	BUILDING CATEGORIES	0.04
	FUNCTION OF BUILDING	0.05
	NUMBER OF FLOOR	0.05
SURROUNDING ENVIRONMENT [E]	PRESENCE OF PROTECTION	0.06
	PRESENCE OF WATER CHANNEL	0.06
	BUILDING ORIENTATION FROM THE RIVER	0.06
	DISTANCE BETWEEN BUILDING	0.05
	BUILDING LOCATION	0.06
LANDSLIDE INTENSITY [I]	ACCUMULATION HEIGHTS	0.08
	DEPOSIT THICKNESS	0.08
	LANDSLIDE VOLUME	0.09
PEOPLE INSIDE BUILDING [P]	POPULATION DENSITY	0.04
	EVACUATION OF ALARM SYSTEM	0.04
	AGE OF PEOPLE	0.04
	HEALTH CONDITION	0.04
	TIMES OF DAY	0.04
	DAY	0.04

Table 12.2: Table of building sub-indicators.

COMPONENT	INDICATOR	SUB-INDICATOR	WEIGHT
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	STRUCTURAL TYPOLOGY / STRUCTURE CONSTRUCTION MATERIALS	Light weight	0.76
		Semi light weight	0.74
		Timber Structure	0.74
		Masonry structure	0.64
		Reinforced concrete structure	0.52
		IBS structures	0.52
		Steel structure	0.48
	BUILDING FOUNDATION DEPTH (LANDSLIDE TYPE VS SHALLOW FOUNDATION BUILDING)	For landslide depth <1.5 meter, depth of building foundation ≤3 meter	0.64
		For landslide depth 1.5 - 5 meter, depth of building foundation ≤3 meter	0.66
		For landslide depth 5 - 10 meter, depth of building foundation ≤3 meter	0.68
		For landslide depth > 10 meter, depth of building foundation ≤3 meter	0.70
	BUILDING FOUNDATION DEPTH (LANDSLIDE TYPE VS DEEP	For landslide depth <1.5 meter, depth of building foundation >3 meter	0.40
		For landslide depth 1.5 - 5 meter, depth of	0.50

	FOUNDATION BUILDING)	building foundation >3 meter	
		For landslide depth 5 - 10 meter, depth of building foundation >3 meter	0.60
		For landslide depth 10 - 20 meter, depth of building foundation >3 meter	0.68
		For landslide depth >20 meter, depth of building foundation >3 meter	0.72
	BUILDING CATEGORIES	Original building	0.48
		Original building with certified extension	0.52
		Original building with non certified extension	0.74
	FUNCTION OF BUILDING	Commercial building (factory)	0.64
		Commercial building (malls)	0.66
		Commercial building (office)	0.64
		Hospitals	0.78
		Schools	0.76
		Residential	0.76
	NUMBER OF FLOOR	Low rise (<3 storey)	0.48
		Medium rise (4 to 5 storey)	0.58
		High rise (>6 storey)	0.74

SURROUNDING ENVIRONMENT [E]	PRESENCE OF PROTECTION	Engineered protection system	0.78
		Non- engineered protection system	0.68
		Natural /vegetation protection	0.53
		No protection	0.45
	PRESENCE OF WATER CHANNEL	Exist	0.83
		Non-Exist	0.35
	BUILDING ORIENTATION FROM THE RIVER	First row from the river	0.80
		Second row from the river	0.58
		Third row and above from the river	0.50
	DISTANCE BETWEEN BUILDING	<3 meter	0.68
		3- 5 meter	0.56
		>5 meter	0.56
	BUILDING LOCATION	Building is located at a distance more than height of slope	0.48
		Building is located at a distance within height of slope	0.62
		Building is located at the toe of slope	0.72
		Building is located at the crest of slope	0.80
		Building is located at the mid-height of slope	0.96
		Height <0.5 meter	0.43

LANDSLIDE INTENSITY [I]	ACCUMULATION HEIGHTS	0.5 meter < height < 2 meter	0.63
		Height > 2 meter	0.80
	DEPOSIT THICKNESS	< 1.5 meter	0.34
		1.5 meter - 5 meter	0.52
		5 meter - 20 meter	0.72
		>20 meter	0.92
	LANDSLIDE VOLUME	Very Small, <0.001 - 0.5 meter3	0.26
		Very Small , <500 meter3	0.40
		Small, 500 - 10, 000 meter3	0.54
		Medium, 10,000 - 50,000 meter3	0.68
		Large, >500,000 meter3	0.84
		Very Large, >>500,000 meter3	0.96
PEOPLE INSIDE BUILDING [P]	POPULATION DENSITY	Low rise (<3 storey)	0.34
		Medium	0.62
		High	0.86
	EVACUATION OF ALARM SYSTEM	Yes	0.28
		No	0.72
	AGE OF PEOPLE	Children	0.74
		Teenagers	0.52
		Adults	0.50
		Senior Citizen (Tua-muda - 65-74 tahun)	0.80
		Senior Citizen (Tua-tua – 75-84 tahun)	0.84

		Senior Citizen (Paling tua-tua - >85 tahun)	0.86
	HEALTH CONDITION	Health (Good)	0.32
		Health (Poor)	0.62
		Disabled person	0.90
	TIMES OF DAY	Peak hour	0.83
		Non- peak hour	0.60
	DAY	Weekend/ Public holiday	0.68
		Weekdays	0.60

Table 12.3: Table of Road indicators.

COMPONENT	INDICATOR	WEIGHT
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	ROAD CATEGORY (JKR STANDARD DESIGN)	0.06
	LOCATION OF ROAD	0.07
	ROAD MATERIAL	0.06
	ROAD MAINTENANCE	0.05
SURROUNDING ENVIRONMENT [E]	PRESENCE OF PROTECTION	0.11
	PRESENCE OF WARNING SYSTEM	0.09
	ROAD DRAINAGE SYSTEM	0.04
LANDSLIDE INTENSITY [I]	ACCUMULATION HEIGHTS	0.06
	DEPOSIT THICKNESS	0.09
	LANDSLIDE VOLUME	0.10
PEOPLE INSIDE BUILDING [P]	TRAFFIC VOLUME	0.25

Table 12.4: Table of road sub-indicators.

COMPONENT	INDICATOR	SUB-INDICATOR	WEIGHT
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	ROAD CATEGORY (JKR STANDARD DESIGN)	R1 / R1a / R2 (minor rural road)	0.70
		R3 / R4 (secondary rural road)	0.66
		R4 / R5 (primary rural road)	0.62
		R5 (highway)	0.52
		R6 (Expressway)	0.48
		U1 / U1a / U2 / U3 (urban local street)	0.64
		U3 / U4 (urban collector road)	0.58
		U4 / U5 (urban arterial road)	0.50
		U6 (urban expressway)	0.42
	LOCATION OF ROAD	Road is located at a distance more than height of slope	0.44
		Road is located at a distance within height of slope	0.60
		Road is located at the toe of slope	0.76
		Road is located at the crest of slope	0.84
		Road is located at the mid-height of slope	0.94
	ROAD MATERIAL	Flexible Pavement / Bituminous Road	0.60

		Rigid Pavement / Concrete Road	0.60
		Unpaved Road	0.70
	ROAD MAINTENANCE	Yes	0.46
		No	0.70
SURROUNDING ENVIRONMENT [E]	PRESENCE OF PROTECTION	Engineered protection system	0.36
		Non- engineered protection system	0.74
		Natural / vegetation protection	0.72
		No protection	0.88
	PRESENCE OF WARNING SYSTEM	Yes	0.38
		No	0.80
	ROAD DRAINAGE SYSTEM	Yes	0.50
		No	0.73
LANDSLIDE INTENSITY [I]	ACCUMULATION HEIGHTS	Height <0.5 meter	0.43
		0.5 meter < height < 2 meter	0.63
		Height > 2 meter	0.80
	DEPOSIT THICKNESS	1.5 meter	0.40
		1.5 meter – 5 meter	0.54
		5 meter - 20 meter	0.72
		>20 meter	0.90
	LANDSLIDE VOLUME	Very Small, 0.001- 0.5 meter3	0.28
		Very Small, <500 meter3	0.42
		Small, 500 - 10,000 meter3	0.54
		Medium, 10,000 - 50,000 meter3	0.70

		Large, >500,000 meter3	0.84
		Very Large, >>500,000 meter3	0.96
PEOPLE INSIDE BUILDING [P]	TRAFFIC VOLUME	(R2 / R1 / R1a / U2 / U1/ U1a (less than 1000 ADT))	0.46
		(R3 / U3 – 3000 to 1000 ADT)	0.56
		(R4 / U4 – 10,000 to 3000 ADT)	0.66
		(R5 / U5 – more than 10,000 ADT)	0.78
		(R6 / R5/ U6 – all traffic volume)	0.88

Table 12.5: Table of dam indicators.

COMPONENT	INDICATOR	WEIGHT
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	SIZE	0.0752
	DAM TYPOLOGY/CATEGORIES	0.0888
	DAM CONSTRUCTION MATERIALS	0.0860
SURROUNDING ENVIRONMENT [E]	PRESENCE OF PROTECTION	0.1818
	PRESENCE OF WARNING SYSTEM	0.0682
LANDSLIDE INTENSITY [I]	ACCUMULATION HEIGHTS	0.0749
	LANDSLIDE VOLUMELANDSLIDE THICKNESS / DEPTH (BODY OF LANDSLIDE)	0.0876
	LANDSLIDE VOLUME	0.0876
PEOPLE INSIDE BUILDING [P]	POPULATION DENSITY	0.2500

Table 12.6: Table of dam sub-indicators.

COMPONENT	INDICATOR	SUB-INDICATOR	WEIGHT
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	SIZE	Basin / catchment (km2)	0.90
		Reservoir (m3)	0.90
		> 100 meter	0.18
		51 meter - 99 meter	0.38
		25 meter - 50 meter	0.52
		5 meter - 24 meter	0.82
		< 5 meter	1.00
	DAM TYPOLOGY/CATEGORIES	Water Supply	1.00
		Power Generation	0.77
		Irrigation	0.58
		Flood Mitigation	0.45
		Sedimentation / Recreational	0.22
	DAM CONSTRUCTION MATERIALS	Earthfill	0.83
		Rockfill	0.67
		Reinforced Concrete	0.28
		Composite	0.47
SURROUNDING ENVIRONMENT [E]	PRESENCE OF PROTECTION	No protection	0.95
		Natural protection (e.g vegetation)	0.78
		Partially man-made protection system	0.57
		Fully engineered protection system	0.15
	PRESENCE OF WARNING SYSTEM	Yes	0.22
		No	0.92
LANDSLIDE INTENSITY [I]	ACCUMULATION HEIGHTS	Height ≤0.5 meter	0.32
		0.5 meter < Height ≤ 2 meter	0.55

		2 meter < Height ≤ 3.5 meter	0.83
		>3.5 meter	0.97
	LANDSLIDE VOLUMELANDSLIDE THICKNESS / DEPTH (BODY OF LANDSLIDE)	Surficial landslide, 1.5 meter	0.25
		Shallow landslide, 1.5 meter – 5 meter	0.47
		Deep seated landslide, 5 meter - 20 meter	0.70
		Very deep seated landslide, >20 meter	1.00
	LANDSLIDE VOLUME	Very Small, 0.001- 0.5 meter3	0.28
		Very Small, <500 meter3	0.42
		Small, 500 - 10,000 meter3	0.54
		Medium, 10,000 - 50,000 meter3	0.70
		Large, >500,000 meter3	0.84
		Very Large, >>500,000 meter3	0.96
PEOPLE INSIDE BUILDING [P]	POPULATION DENSITY	Low (0)	0.18
		Medium (1-10)	0.47
		High (11 - 100)	0.70
		Very High (> 100)	0.95

Table 12.7: Table of TNB power line indicators.

COMPONENT	INDICATOR	WEIGHT
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	TOWER STRUCTURAL	0.06
	TYPOLOGY OF UTILITIES	0.06
	TOWER MATERIAL	0.06
	TOWER STRUCTURE FOUNDATION LENGTH	0.07
SURROUNDING ENVIRONMENT [E]	PRESENCE OF PROTECTION	0.04
	ENVIRONMENT	0.04
	RIGHT OF WAY (ROW)	0.04
	CIVIL	0.04
	SLOPE MORPHOLOGY (SHAPE)	0.04
	PRESENCE OF WARNING SYSTEM	0.04
LANDSLIDE INTENSITY [I]	ACCUMULATION HEIGHTS	0.08
	LANDSLIDE THICKNESS / DEPTH (BODY OF LANDSLIDE)	0.10
	LANDSLIDE VOLUME	0.08
PEOPLE INSIDE BUILDING [P]	POPULATION DENSITY	0.25

Table 12.8: Table of TNB power line sub-indicators.

COMPONENT	INDICATOR	SUB-INDICATOR	WEIGHT
SUSCEPTIBILITY OF CRITICAL INFRASTRUCTURE [C]	TOWER STRUCTURAL	Conductor	0.04
		Crossarm	0.05
		Damper	0.04
		Bracing	0.05
	TYPOLOGY OF UTILITIES	GRID 500KV (Height 46-67 meter) (Width 10.5 -19 meter)	0.05
		GRID 275KV (Height 34 meter) (Width 7.5 meter)	0.05
		GRID 132KV (Height 29 meter) (Width 5.7 meter)	0.05
		GRID 33KV	0.04
		PMU	0.05
		TELCO TOWER	0.04
	TOWER MATERIAL	Wood	0.05
		Steel	0.04
		Composite	0.05
	TOWER STRUCTURE FOUNDATION LENGTH (LANDSLIDE TYPE VS SHALLOW FOUNDATION TOWER (TELCO, PMU, 33KV))	For landslide depth <1.5 meter, length of tower foundation ≤3 meter	0.03
		For landslide depth 1.5 - 5 meter, length of tower foundation ≤3 meter	0.04
		For landslide depth 5 - 10 meter, length of tower foundation ≤3 meter	0.05
		For landslide depth > 10 meter, height of tower foundation ≤3 meter	0.06

	TOWER STRUCTURE FOUNDATION LENGTH (LANDSLIDE TYPE VS DEEP SEATED FOUNDATION TOWER (500KV, 275KV, 132KV) - TOP, STRAIGHT)	For landslide depth <1.5 meter, length of tower foundation >3 meter	0.05
		For landslide depth 1.5 - 5 meter, length of tower foundation >3 meter	0.05
		For landslide depth 5 - 10 meter, length of tower foundation >3 meter	0.06
		For landslide depth > 10 meter, height of tower foundation >3 meter	0.07
	TOWER STRUCTURE FOUNDATION LENGTH (LANDSLIDE TYPE VS DEEP SEATED FOUNDATION TOWER (500KV, 275KV, 132KV) - TOP, CONCAVE)	For landslide depth <1.5 meter, length of tower foundation >3 meter	0.05
		For landslide depth 1.5 - 5 meter, length of tower foundation >3 meter	0.06
		For landslide depth 5 - 10 meter, length of tower foundation >3 meter	0.07
		For landslide depth > 10 meter, height of tower foundation >3 meter	0.07
	TOWER STRUCTURE FOUNDATION LENGTH (LANDSLIDE TYPE VS DEEP SEATED FOUNDATION TOWER (500KV,	For landslide depth <1.5 meter, length of tower foundation >3 meter	0.05
		For landslide depth 1.5 - 5 meter, length of tower foundation >3 meter	0.05
		For landslide depth 5 - 10 meter, length of tower foundation >3 meter	0.06

	275KV, 132KV) - TOP, CONVEX)	For landslide depth > 10 meter, height of tower foundation >3 meter	0.07
	TOWER STRUCTURE FOUNDATION LENGTH (LANDSLIDE TYPE VS DEEP SEATED FOUNDATION TOWER (500KV, 275KV, 132KV) - FACE, STRAIGHT)	For landslide depth <1.5 meter, length of tower foundation >3 meter	0.05
		For landslide depth 1.5 - 5 meter, length of tower foundation >3 meter	0.06
		For landslide depth 5 - 10 meter, length of tower foundation >3 meter	0.07
		For landslide depth > 10 meter, height of tower foundation >3 meter	0.07
	TOWER STRUCTURE FOUNDATION LENGTH (LANDSLIDE TYPE VS DEEP SEATED FOUNDATION TOWER (500KV, 275KV, 132KV) - FACE, CONCAVE)	For landslide depth <1.5 meter, length of tower foundation >3 meter	0.06
		For landslide depth 1.5 - 5 meter, length of tower foundation >3 meter	0.06
		For landslide depth 5 - 10 meter, length of tower foundation >3 meter	0.07
		For landslide depth > 10 meter, height of tower foundation >3 meter	0.07
	TOWER STRUCTURE FOUNDATION LENGTH (LANDSLIDE TYPE VS DEEP	For landslide depth <1.5 meter, length of tower foundation >3 meter	0.06
		For landslide depth 1.5 - 5 meter, length of tower foundation >3 meter	0.06

	SEATED FOUNDATION TOWER (500KV, 275KV, 132KV) - FACE, CONVEX)	For landslide depth 5 - 10 meter, length of tower foundation >3 meter	0.07
		For landslide depth > 10 meter, height of tower foundation >3 meter	0.07
	TOWER STRUCTURE FOUNDATION LENGTH (LANDSLIDE TYPE VS DEEP SEATED FOUNDATION TOWER (500KV, 275KV, 132KV) - TOE, STRAIGHT)	For landslide depth <1.5 meter, length of tower foundation >3 meter	0.03
		For landslide depth 1.5 - 5 meter, length of tower foundation >3 meter	0.04
		For landslide depth 5 - 10 meter, length of tower foundation >3 meter	0.05
		For landslide depth > 10 meter, height of tower foundation >3 meter	0.05
	TOWER STRUCTURE FOUNDATION LENGTH (LANDSLIDE TYPE VS DEEP SEATED FOUNDATION TOWER (500KV, 275KV, 132KV) - TOE, CONCAVE)	For landslide depth <1.5 meter, length of tower foundation >3 meter	0.04
		For landslide depth 1.5 - 5 meter, length of tower foundation >3 meter	0.05
		For landslide depth 5 - 10 meter, length of tower foundation >3 meter	0.05
		For landslide depth > 10 meter, height of tower foundation >3 meter	0.06
	TOWER STRUCTURE FOUNDATION	For landslide depth <1.5 meter, length of tower foundation >3 meter	0.05

	LENGTH (LANDSLIDE TYPE VS DEEP SEATED FOUNDATION TOWER (500KV, 275KV, 132KV) - TOE, CONVEX)	For landslide depth 1.5 - 5 meter, length of tower foundation >3 meter	0.06
		For landslide depth 5 - 10 meter, length of tower foundation >3 meter	0.07
		For landslide depth > 10 meter, height of tower foundation >3 meter	0.07
SURROUNDING ENVIRONMENT [E]	PRESENCE OF PROTECTION	No Protection	0.04
		Natural protection (e.g vegetation)	0.04
		Partially man-made protection system	0.04
		Moderately man-made protection system	0.03
		Fully engineered protection system	0.03
	ENVIRONMENT	Normal	0.02
		Jungle	0.03
		Industries	0.04
		Farm	0.03
		Coastal	0.03
		Tower Location (Top)	0.03
		Tower Location (Face)	0.04
		Tower Location (Toe)	0.03
		Distance From Slope (≥5 meter)	0.04
		Distance From Slope (<5 meter)	0.04
	RIGHT OF WAY (ROW)	Encroachment (Rentice)	0.05
		Encroachment (Logging)	0.04
		132KV (20 meter radius from center)	0.04

		275KV (20 meter radius from center)	0.04
		500KV (25 meter radius from center), (Town)	0.04
		500KV (30 meter radius from center), (Jungle)	0.04
	CIVIL	Type of soil	0.04
		Foundation (Depth)	0.04
		Foundation (Area)	0.04
	SLOPE MORPHOLOGY (SHAPE)	Concave	0.04
		Convex	0.04
		Straight	0.04
	PRESENCE OF WARNING SYSTEM	Yes	0.02
		No	0.03
LANDSLIDE INTENSITY [I]	ACCUMULATION HEIGHTS (TOP, STRAIGHT)	Height ≤0.5 meter	0.02
		0.5 meter < Height ≤ 2 meter	0.02
		2 meter > Height ≤3.5 meter	0.02
		>3.5 meter	0.02
	ACCUMULATION HEIGHTS (TOP, CONCAVE)	Height ≤0.5 meter	0.04
		0.5 meter < Height ≤ 2 meter	0.04
		2 meter > Height ≤3.5 meter	0.04
		>3.5 meter	0.04
	ACCUMULATION HEIGHTS (TOP, CONVEX)	Height ≤0.5 meter	0.05
		0.5 meter < Height ≤ 2 meter	0.05
		2 meter > Height ≤3.5 meter	0.05
		>3.5 meter	0.05
	ACCUMULATION HEIGHTS (FACE, STRAIGHT)	Height ≤0.5 meter	0.05
		0.5 meter < Height ≤ 2 meter	0.05
		2 meter > Height ≤3.5 meter	0.05
		>3.5 meter	0.05
		Height ≤0.5 meter	0.06

	ACCUMULATION HEIGHTS (FACE, CONCAVE)	0.5 meter < Height ≤ 2 meter	0.06
		2 meter > Height ≤3.5 meter	0.06
		>3.5 meter	0.06
	ACCUMULATION HEIGHTS (FACE, CONVEX)	Height ≤0.5 meter	0.07
		0.5 meter < Height ≤ 2 meter	0.07
		2 meter > Height ≤3.5 meter	0.07
		>3.5 meter	0.07
	ACCUMULATION HEIGHTS (TOE, STRAIGHT)	Height ≤0.5 meter	0.03
		0.5 meter < Height ≤ 2 meter	0.04
		2 meter > Height ≤3.5 meter	0.05
		>3.5 meter	0.06
	ACCUMULATION HEIGHTS (TOE, CONCAVE)	Height ≤0.5 meter	0.03
		0.5 meter < Height ≤ 2 meter	0.04
		2 meter > Height ≤3.5 meter	0.05
		>3.5 meter	0.06
	ACCUMULATION HEIGHTS (TOE, CONVEX)	Height ≤0.5 meter	0.05
		0.5 meter < Height ≤ 2 meter	0.05
		2 meter > Height ≤3.5 meter	0.07
		>3.5 meter	0.08
	LANDSLIDE THICKNESS / DEPTH (BODY OF LANDSLIDE) (TOP, STRAIGHT)	Surficial deposit, 1.5 meter	0.04
		Shallow landslide, 1.5 meter – 5 meter	0.05
		Deep seated landslide, 5 meter - 20 meter	0.08
		Very deep seated landslide, >20 meter	0.09
	LANDSLIDE THICKNESS / DEPTH (BODY OF LANDSLIDE) (TOP, CONCAVE)	Surficial deposit, 1.5 meter	0.04
		Shallow landslide, 1.5 meter – 5 meter	0.05
		Deep seated landslide, 5 meter - 20 meter	0.08

		Very deep seated landslide, >20 meter	0.09
	LANDSLIDE THICKNESS / DEPTH (BODY OF LANDSLIDE) (TOP, CONVEX)	Surficial deposit, 1.5 meter	0.06
		Shallow landslide, 1.5 meter – 5 meter	0.07
		Deep seated landslide, 5 meter - 20 meter	0.08
		Very deep seated landslide, >20 meter	0.09
	LANDSLIDE THICKNESS / DEPTH (BODY OF LANDSLIDE) (FACE, STRAIGHT)	Surficial deposit, 1.5 meter	0.08
		Shallow landslide, 1.5 meter – 5 meter	0.09
		Deep seated landslide, 5 meter - 20 meter	0.10
		Very deep seated landslide, >20 meter	0.10
	LANDSLIDE THICKNESS / DEPTH (BODY OF LANDSLIDE) (FACE, CONCAVE)	Surficial deposit, 1.5 meter	0.08
		Shallow landslide, 1.5 meter – 5 meter	0.09
		Deep seated landslide, 5 meter - 20 meter	0.10
		Very deep seated landslide, >20 meter	0.10
	LANDSLIDE THICKNESS / DEPTH (BODY OF LANDSLIDE) (FACE, CONVEX)	Surficial deposit, 1.5 meter	0.09
		Shallow landslide, 1.5 meter – 5 meter	0.10
		Deep seated landslide, 5 meter - 20 meter	0.10
		Very deep seated landslide, >20 meter	0.10
		Surficial deposit, 1.5 meter	0.08

	LANDSLIDE THICKNESS / DEPTH (BODY OF LANDSLIDE) (TOE, STRAIGHT)	Shallow landslide, 1.5 meter – 5 meter	0.09
		Deep seated landslide, 5 meter - 20 meter	0.10
		Very deep seated landslide, >20 meter	0.10
	LANDSLIDE THICKNESS / DEPTH (BODY OF LANDSLIDE) (TOE, CONCAVE)	Surficial deposit, 1.5 meter	0.08
		Shallow landslide, 1.5 meter – 5 meter	0.09
		Deep seated landslide, 5 meter - 20 meter	0.10
		Very deep seated landslide, >20 meter	0.10
	LANDSLIDE THICKNESS / DEPTH (BODY OF LANDSLIDE) (TOE, CONVEX)	Surficial deposit, 1.5 meter	0.08
		Shallow landslide, 1.5 meter – 5 meter	0.09
		Deep seated landslide, 5 meter - 20 meter	0.10
		Very deep seated landslide, >20 meter	0.10
	LANDSLIDE VOLUME	Very Small, 0.001- 0.5 meter3	0.04
		Very Small, <500 meter3	0.05
		Small, 500 - 10,000 meter3	0.05
		Medium, 10,000 - 50,000 meter3	0.06
		Large, >500,000 meter3	0.07
		Very Large, >>500,000 meter3	0.08
PEOPLE INSIDE BUILDING [P]	POPULATION DENSITY	Low	0.20
		Medium	0.23
		High	0.25