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Landslide vulnerability and risk assessment: A guideline for critical infrastructure in Malaysia

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Abstract

Landslide vulnerability is a crucial element that connects hazard and risk for a specific element-at-risk. Currently, landslide vulnerability study in Malaysia is limited and attention is given to susceptibility and hazard assessments. Ideally, vulnerability assessment should address various aspects of element-at-risk including physical, social, economic, and environmental. In 2018, a guideline for landslide vulnerability and risk assessment for critical infrastructure in Malaysia was developed for the Construction Research Institute of Malaysia (CREAM). The guideline aimed at developing large-scale landslide vulnerability and risk assessment methods for local authorities as a level of basic and supporting information for land-use plan, landslide mitigation purposes, and risk assessment for any development of the critical infrastructure (CI) i.e. road, dam, building and electricity pylon. The aim of this study is to develop a simple methodology to support more detailed on-site landslide vulnerability and risk assessment. Using a case study from the Cameron Highlands District in northern Malaysia remotely sensed and field data were combined to create a detailed landslide inventory and element-at-risk mapping. Due to the limited landslide damage records, a vulnerability model was developed using the qualitative indicator-based method (IBM). The indicators and the corresponding sub-indicators are divided into four clusters i.e. 1) the susceptibility of element-at-risk (C), 2) surrounding environment (E), 3) intensity of landslide hazard (I), and 4) affected community (P). Suitable indicators and sub-indicators were selected and proposed based on a thorough literature review and a series of focus group discussions (FGD) with agencies involved with landslide hazard management in Malaysia. The FGD sessions also focused on experts assigning scores for each indicator and sub-indicator based on their relationship to the likelihood of landslide vulnerability. The final scores were then converted to final weighting values and a landslide vulnerability map was generated by combining the individual vulnerability cluster maps i.e. C, E, I and P. The resulting landslide vulnerability index was classified into five classes; very high, high, medium, low, and very low with a clear definition of the potential damage to CI and the community. Using a qualitative risk-matrix approach a landslide risk map was generated by combining the landslide hazard and vulnerability maps and was then validated against past landslide event in the Bukit Antarabangsa, Selangor, Malaysia. The results confirm good agreement between the derived vulnerability and risk maps and actual landslide damage in the area. The methodology proposed here is however strongly dependent on several key elements including, the quality of landslide hazard map, the landslide inventory map and the experience of the experts.

Keywords: geospatial, Landslide vulnerability and risk, LiDAR

1. Introduction

Risk can be defined as ‘‘the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular damaging phenomenon for a given area and reference period’’ (Varnes et al., 1984). On a simpler note, International Union of Geological Sciences similarly defines landslide risk as a measure of the probability and severity of an adverse effect to health, property and the environment (Cruden and Fell, 1997). Both definitions highlight three different impacts of landslide risk including, critical physical infrastructure, socio-economic and environment. Therefore, any map of landslide risk should typically present the subdivision of the terrain into zones that are characterized by different probabilities of losses that might occur due to landslides of a given type within a given period of time.

Two common methods are available for landslide risk assessment, qualitative or quantitative. Qualitative risk analysis refers to an analysis that uses word form (descriptive) or numerical scales to describe the magnitude of potential consequences and the likelihood that those consequences will occur. Whereas quantitative risk analysis is based on numerical values of the probability, vulnerability, and consequences, resulting in a numerical value of risk (Cruden and Fell, 1997; Technical Committee on Risk Assessment and Management, 2004; UN-ISDR, 2004; Fell et al., 2008). Depending on the completeness of data, a semi-quantitative approach can be devised to provide an indicative probability via qualitative terms given to a team of expert for a heuristic assessment (Van Westen et al., 2006).

Vulnerability is a fundamental component in risk assessment, which defines the relationship between level of potential damage for specific hazard intensity and element-at-risk (Dai et al., 2002; Uzielli et al., 2008; Kappes et al., 2012). It 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). Furthermore, vulnerability can be defined in a more integrative approach as “a characteristic of human behavior, social and physical environments, describing the degree of susceptibility (or resistance) to the impact of e.g., natural hazards’’ (Kappes et al., 2012). Although previous studies have shown that there is no general or universal approach in vulnerability assessment (Fuchs et al., 2011) and idea vulnerability assessment should account for various criteria including physical, economic, environmental, institutional, and human factors. Papathoma-Köhle et al. (2015) has defined three dominant approaches to express the vulnerability of element-at-risk i.e., vulnerability matrices, vulnerability indicators (Birkmann et al., 2013) and vulnerability curves (Totschnig et al., 2011). These approaches can be further classified into qualitative, semi-quantitative and quantitative vulnerability assessment methods.

Previous studies have shown that landslide vulnerability assessment can be accomplished using qualitative, semi-quantitative and quantitative approaches. The qualitative approach requires suitable vulnerability values for a specific element-at-risk based on the landslide type (Cardinali et al., 2002; Kappes et al., 2012). The vulnerability values (between 0.0 and 1.0) are assigned by experts based on their experience and historical records of landslide degree of damage. Vulnerability matrix and indicator-based vulnerability assessment are flexible and require less landslide damage information compared to the quantitative approach. Furthermore, the matrix and indicator-based methods are easy to use and comprehend by decision makers.

However, there is no direct (quantified) relationship between hazard intensities and degree of damage (Uzielli et al. 2008) and instead relies on expert judgments. Meanwhile, the semi-quantitative approach is more flexible with reduced level of generalization and subjectivity (Dai et al., 2002). For instance, based on this method, the damage matrices are populated by classified intensities and stepwise levels of damage. In a previous study by Frédéric et al. (1996), damage matrices were developed based on damaging factors and the resistance of the elements at risk to the impact of landslides. The applicability of this method requires statistical analysis of detailed records on landslides and their consequences (Dai et al. 2002). It still requires detailed information on the impact of a specific landslide hazard towards a specific element-at-risk. Finally, the quantitative vulnerability assessment approach requires detailed and complex information applied on the local scale or individual infrastructure (Fuchs et al., 2011, Kaynia et al., 2008, Li et al., 2010b, Uzielli et al., 2008) and is usually employed by engineers involved in the technical decision making where a more explicit objective output is required. The results can be directly used in a quantitative risk assessment with detailed analysis on the uncertainty analysis of the vulnerability assessment.

In Malaysia, landslide vulnerability studies are still very limited. This is due to insufficient of landslide inventory and damage records among agencies related to landslide hazard management. In 2018, the Construction Research Institute of Malaysia (CREAM) has proactively created national guidance for landslide vulnerability and risk assessments for critical infrastructure in Malaysia. This guideline includes the role of geospatial technology and in deriving important indicators and sub-indicators for the vulnerability model and the in the mapping aspect of landslide risk for different critical infrastructure types in Malaysia.

In this paper, we present a more detailed methodology for landslide vulnerability and risk mapping based on the qualitative approach and illustrate its use in an area of the Cameron Highlands District in northern Malaysia. The vulnerability model was developed using indicator method, in which the indicators are carefully selected and combined based on different critical infrastructure and landslide types in Malaysia. The guideline can be used by various agencies and authorities to evaluate the vulnerability and risk of existing and future infrastructures under their jurisdiction. The outcome of this analysis can be used to further decrease the risk and vulnerability of the infrastructure towards landslide hazard. Furthermore, the guideline comes with a simple non-geospatial tool to support on-site landslide vulnerability and risk assessment.

2. Materials and method

The 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 weighting values, 3) landslide vulnerability and risk mapping in Cameron Highlands and 4) evaluation of the landslide vulnerability and risk assessment method (Fig. 1).

2.1 Description of study area

The study site is at Lembah Bertam located in Cameron Highlands, which cover about 3.66 km2 and 5.00 km2 respectively. 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 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. 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 no 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.

Schist in Cameron Highlands formed as roof pendant, which is a body of schist left

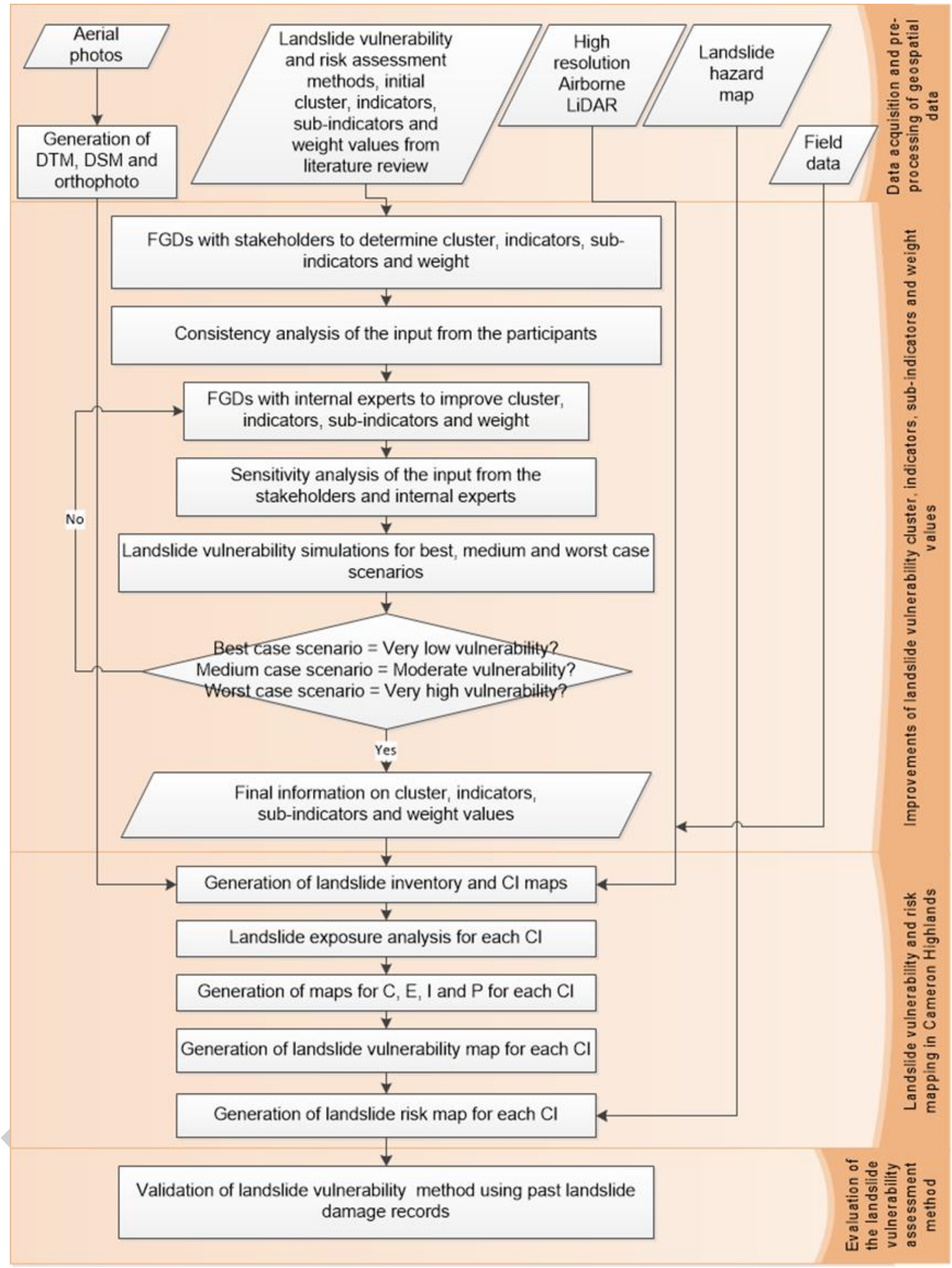


Fig. 1: Overall methodology of landslide vulnerability and risk assessments (DTM – digital terrain model; DSM – digital surface model; LiDAR – light detection and ranging; FGD – focus group discussion; CI – critical infrastructure; C - susceptibility of element-at-risk; E - surrounding environment; I - intensity of landslide hazard; and P - affected community.

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. Distribution of schist is limited to west part of Cameron Highlands. 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.

Cameron highlands is undergoing rapid development that involves land clearing for hotels, residential area, shop lots, agricultural activities etc. This has become one of the main causes for landslides occurrences in Cameron Highlands.

2.2 Acquisition and pre-processing of geo--spatial data

The first stage focuses on data acquisition that includes geospatial and non-geospatial data. The geospatial data includes high-resolution aerial photographs and airborne LiDAR survey at Lembah Bertam, Cameron Highlands. The LiDAR and aerial photos were processed to produce digital terrain model (DTM), digital surface model (DSM) and orthophotos with 0.5-m spatial resolution. In addition, several other ancillary data were also obtained from different agencies for example landslide hazard map, high resolution DTM and orthophotos from the Mineral and Geoscience Department of Malaysia (JMG). The landslide hazard map was produced using high-resolution airborne LiDAR data and the final map was classified into 5 hazard classes namely, very high, high, moderate, low and very low with its spatial resolution of 0.5 m. All the data were compiled into the same map projection system and datum and stored in the GIS database. Several field visits were made in Lembah Bertam to collect information related to landslide inventory and characteristics of critical infrastructures. The field data was used to support parameterization of landslide vulnerability indicators and sub-indicators especially for the information that cannot be directly measured from the remotely sensed data. Furthermore, intensive literature review is used to define the suitable landslide vulnerability and risk assessment method for the scenario in Malaysia.

2.3 Determination of landslide vulnerability cluster, indicators and sub-indicators

Based on the proposed method for landslide vulnerability and risk assessments, the second stage focuses on determination and improve--ments of landslide vulnerability clusters, indi--cators, sub-indicators and weighting values. The landslide vulnerability model for different element-at-risk i.e., building, road, electricity dam and electricity pylon were developed based on their vulnerability cluster (C, E, I and P), indicators and sub-indicators. Cluster C determines the susceptibility of infrastructure towards landslide. Cluster E reflects the impact of surrounding environment either in reducing or increasing the vulnerability of the critical infrastructure towards landslide. Furthermore, cluster I and P represent intensity of landslide hazard and the impact to the surrounding people respectively. Each indicator under specific cluster consists of several sub-indicators.

This process was conducted via few series of expert focus group discussions (FGD) with different stakeholders. Each participant is required to fill a specially designed survey form for landslide vulnerability and risk assessments and was followed by detailed explanation on the concept of landslide vulnerability and risk assessment including a step-by-step explanation on the procedure in determining the clusters, indicators, sub-indicators and the weighting values.

A series of sensitivity analysis based on one-at-a-time (OAT) method were carried out to determine the consistency of 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 was aimed at analyzing the consistency of weighting values assigned by the stakeholders for the indicators and sub-indicators through the analysis of standard deviation value of weight between participants. A separate sensitivity analysis focused 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. A series of sensitivity analysis based on one-at-a-time (OAT) method, were then carried out to determine the sensitivity of each cluster, indicators and sub-indicators leading to a final value of landslide vulnerability for each CI. This method varies the value of a specific indicators and sub-indicators (V) while the rest of sub-indicators remains unchanged (Equation 1)

$$V = \{a_1, a_2, a_3, a_4 \ldots . a_n\} \quad (1)$$

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.

The Sen_{Ind} is defined as the sensitivity of the estimated vulnerability value with the weight changes of sub-indicators (Equation 2) and is estimated by the standard deviation of the estimated vulnerability value produced by the simulation. Higher Sen_{Ind} value indicates a more sensitive indicator compared to an indicator with a 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 3). Sen_{Clus} is estimated by the average of the Sen_{Ind} for indicators that belong to a specific cluster. Higher Sen_{Clus} values indicate a more sensitive cluster compared to other cluster with lower index value.

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

where *n* is the number of indicators for each cluster.

$$Sen_{Clus} = \frac{\sum_{i=1}^{m} Sen_{Ind_i}}{m} \quad (3)$$

where *m* is the number of clusters.

In addition, several simulations on the vulnerability calculation were made for three different scenarios i.e. best-case, moderate-case and the worst-case landslide vulnerability. The simulation analyzes the reliability of weighting values given by the stakeholders and internal experts (for each CI and landslide type). The best-case landslide scenario, with the combination of indicators with the lowest weight is expected to produce the very low landslide vulnerability. The moderate landslide vulnerability scenario with the combination of moderate weight of indicators is expected to produce "moderate vulnerability" and in the worst-case landslide scenario with the highest vulnerability values is classified as "very high vulnerability".

2.4 Landslide vulnerability and risk mapping

The landslide vulnerability mapping in--volves generation of several maps representing different clusters, indicators, sub-indicators and weighting values as defined in the landslide vulnerability. The vulnerability index for CI is defined as in Equation 4.

$$V = \sum_{i=1}^{m} w_i \times S_j \quad (4)$$

where w_i is the *i-th* weight of m indicators under different indicator groups and S_i is *i-th* score for a specific class of the indicators. The weight for each group ranges from 0.1 (low influence to increase vulnerability) to 1.0 (high influence to increase vulnerability).

The C cluster map is based on inter-pretation and classification of high resolution orthophoto, LiDAR -derived DTM and intensive fieldwork in the study area and characterized based on the indicators and sub-indicators in this cluster. The map for cluster E accounts for the surrounding environment that might increase and decrease the impact of landslide hazard. The P cluster 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 airborne 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 JMG, 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.

2.5 Validation of landslide vulnerability and risk results

Evaluation of the landslide vulnerability and risk assessment method is then carried out over other area 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 can then be compared with the damage records and damage descriptions in the report.

3. Results and discussion

3.1 Landslide vulnerability indicators

The landslide vulnerability clusters, indicators (C, E, I and P) and the specific sub-indicators (or classes) have been assigned with suitable weighting values obtained from expert input. Figure 2 to Figure 5 show the sensitivity analysis of FGD with the stakeholders regarding the indicators and clusters for each of the critical infrastructure. In the first and second FGD sessions the discussions were only focussed on the rotational and translational landslides.

The final weight for each indicator and its sub-indicator is then 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 a very low landslide vulnerability value is expected. The second scenario focuses on simulating landslide vulnerability in which a medium value of landslide vulnerability is expected. Finally, the highest vulnerability value is expected for the worst-case scenario of landslide vulnerability.

Discussion during the FGD sessions allowed substantial improvement and modifications of the proposed indicator, sub-indicator as well as their corresponding weighting values. The final set of clusters, indicators, sub-indicators and their weights were generated based on the output of the FDG with the stakeholders and internal experts. The indicators, sub-indicators were fine-tuned based on the locality of the particular environment. **Fig. 6** to **Fig. 9** show the list of recommended cluster indicators and sub--indicators for the guidelines of landslide vulnerability and risk assessment for critical infrastructure in Malaysia

3.2 Landslide vulnerability and risk assessments in Lembah Bertam, Cameron Highland

The landslide inventory map was produced based on the manual interpretation of DTM derived from the LiDAR data. The elevation model 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

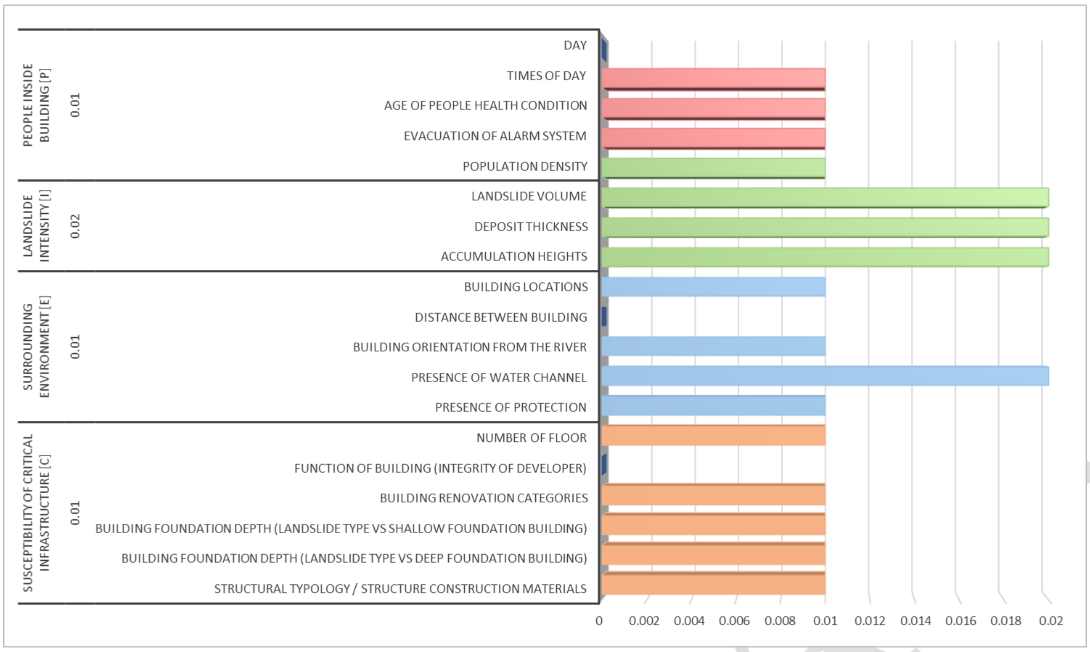


Fig. 2: Sensitivity of cluster (Sen_{Clus}) and Sensitivity of indicator (Sen_{Ind}) calculated for each indicator for building and rotational/translational landslide.

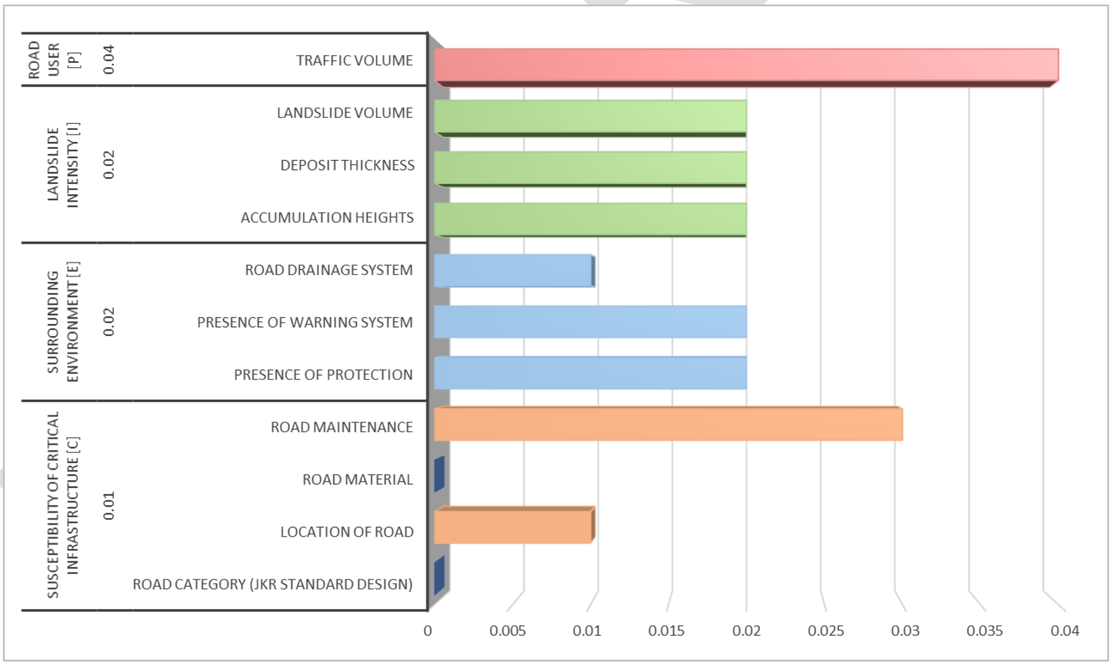


Fig. 3: Sensitivity of cluster (Sen_{Clus}) and Sensitivity of indicator (Sen_{Ind}) calculated for each indicator for road and rotational/translational landslide.

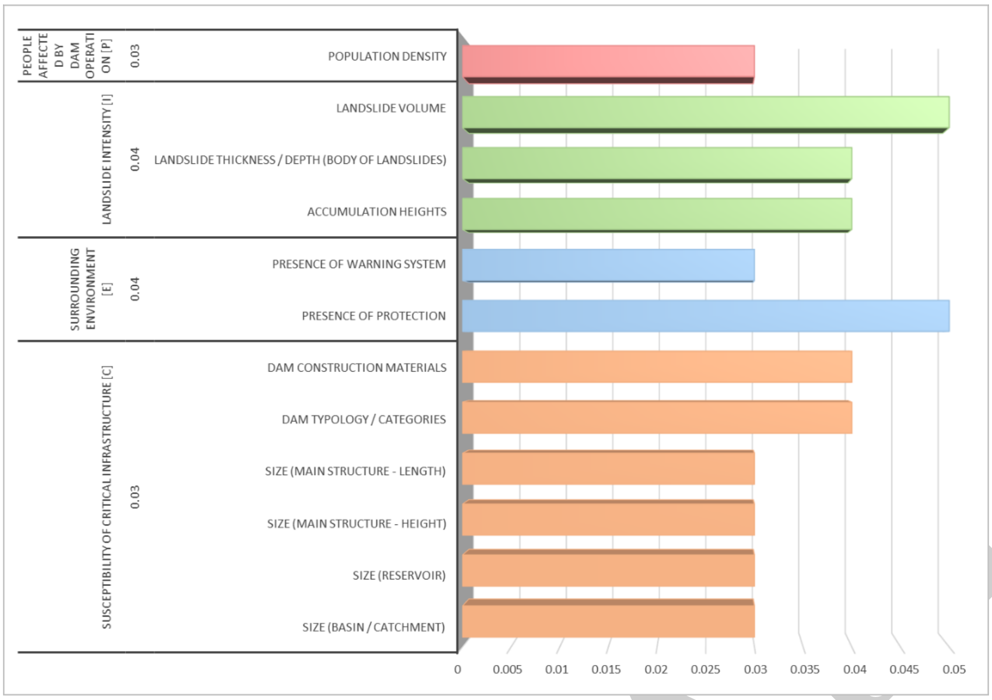


Fig. 4: Sensitivity of cluster (Sen_{Clus}) and Sensitivity of indicator (Sen_{Ind}) calculated for each indicator for dam and rotational/translational landslide.

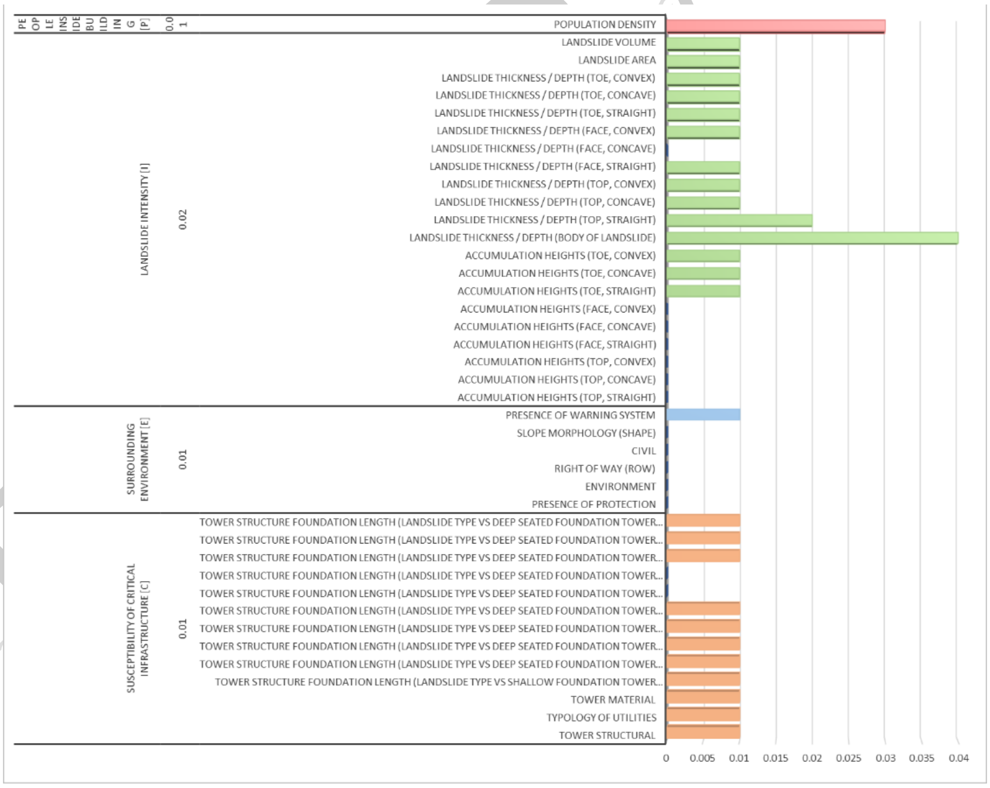


Fig. 5: Sensitivity of cluster (Sen_{Clus}) and Sensitivity of indicator (Sen_{Ind}) calculated for each indicator for pylon and rotational/translational landslide

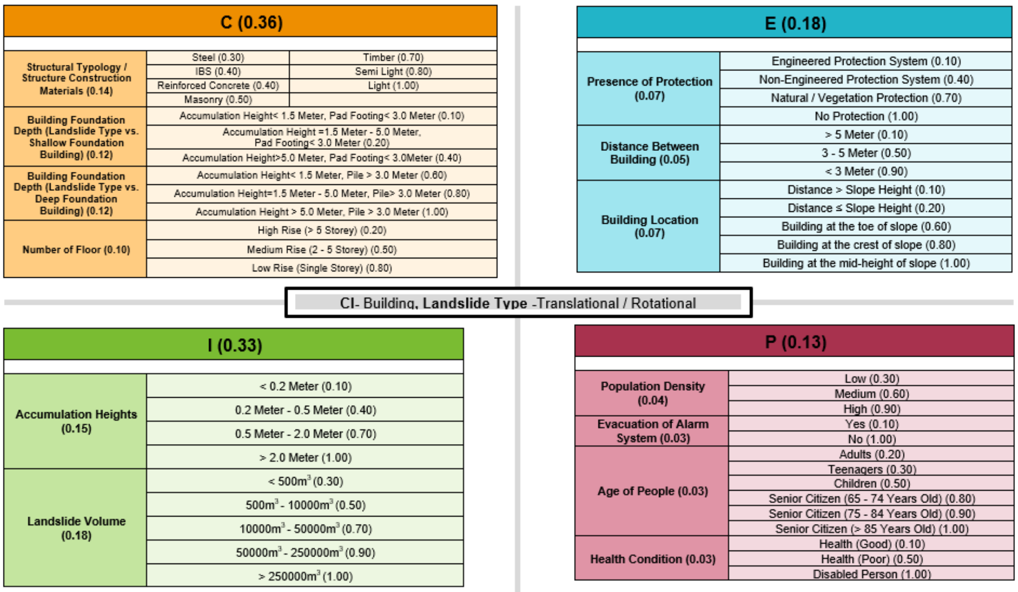


Fig. 6: Clusters, indicators and sub-indicators (C, E, I and P) and its weighting values for critical infrastructure (building) with translational/rotational as the type of landslide.

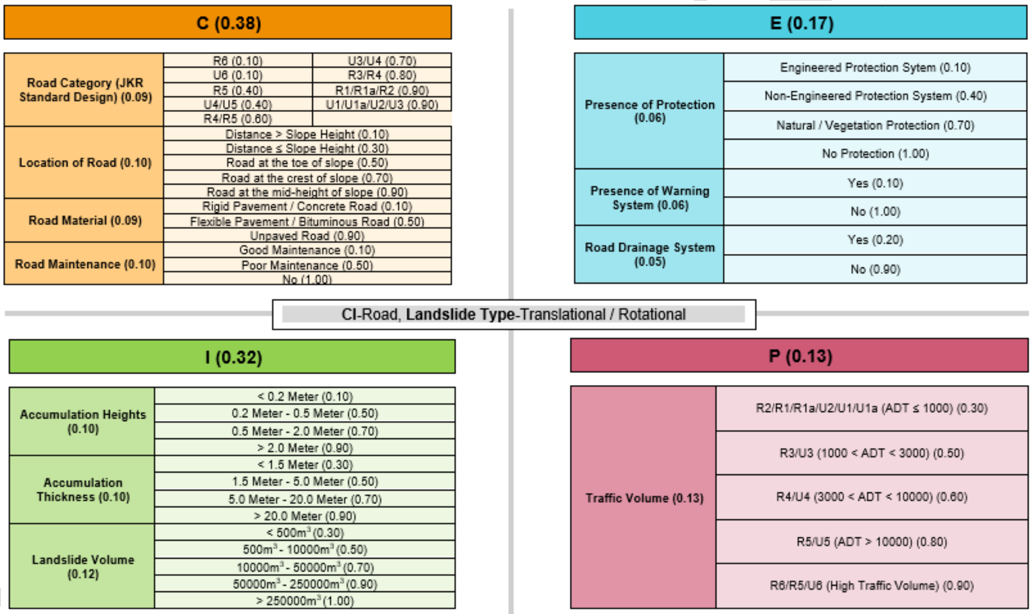


Fig. 7: Clusters, indicators and sub-indicators (C, E, I and P) and its weighting values for critical infrastructure (road) with translational/rotational as the type of landslide.

(I) indicator i.e. landslide volume, landslide velocity and accumulation height. There are in total about 54 landslides identified at Lembah Bertam. 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. The resulted landslide inventory map for the Lembah Bertam area is shown in Fig. 10

The landslide vulnerability maps for the respective CI were then generated by combining all cluster maps C, E, I and P spatially. The resulting landslide vulnerability index for each of CI was categorized into its specific vulnerability class as shown in Fig.11(a). Most of the critical infrastructures are at moderate vulnerability while the dam remains under low vulnerability class. The landslide risk map was generated by the com-

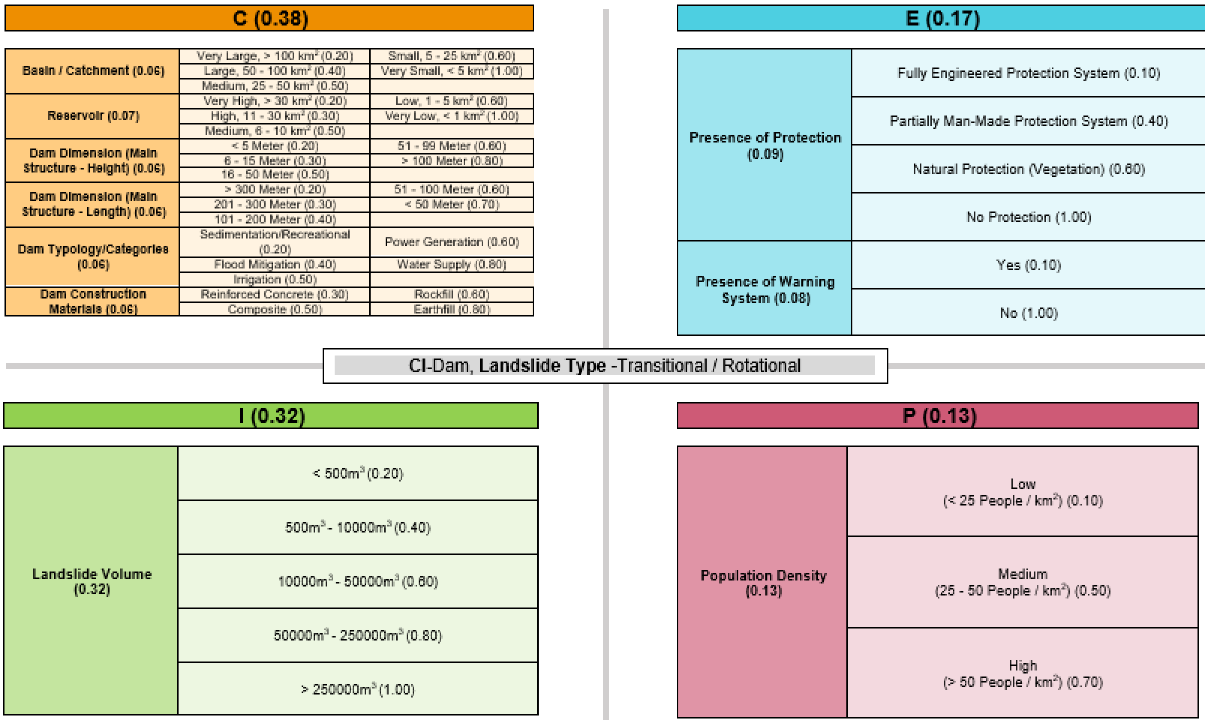


Fig. 8: Clusters, indicators and sub-indicators (C, E, I and P) and its weighting values for critical infrastructure (dam) with translational/rotational as the type of landslide.

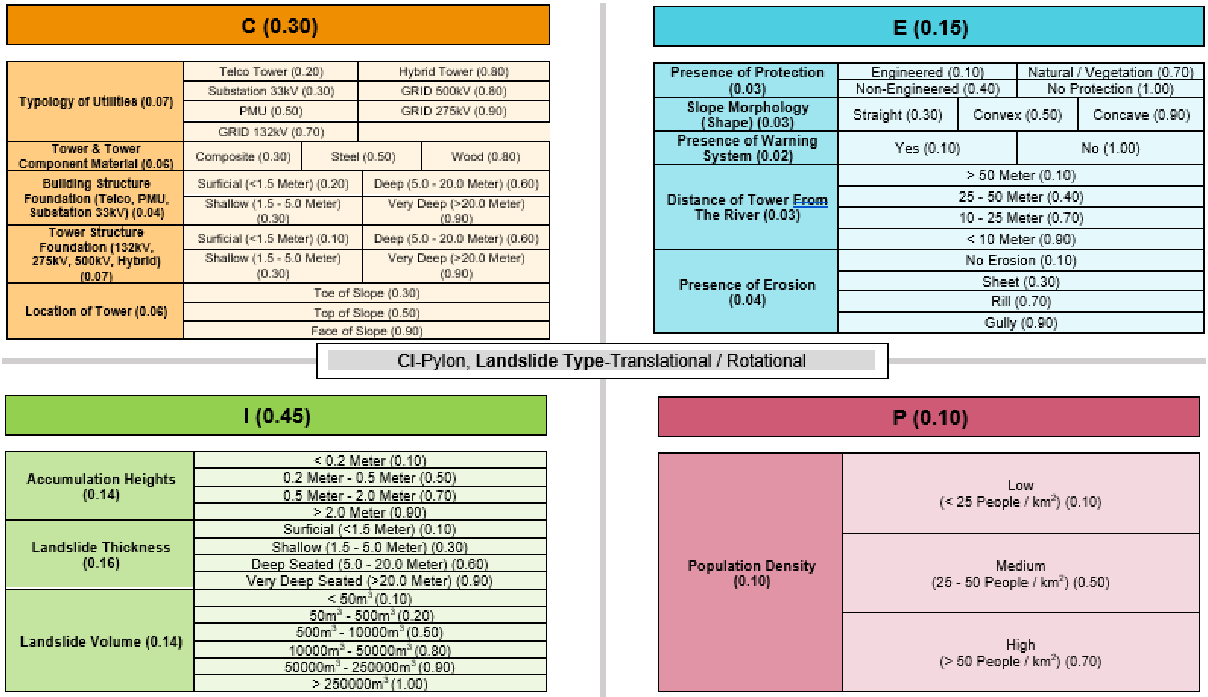


Fig. 9: Clusters, indicators and sub-indicators (C, E, I and P) and its weighting values for critical infrastructure (TNB powerline) with translational/rotational as the type of landslide.

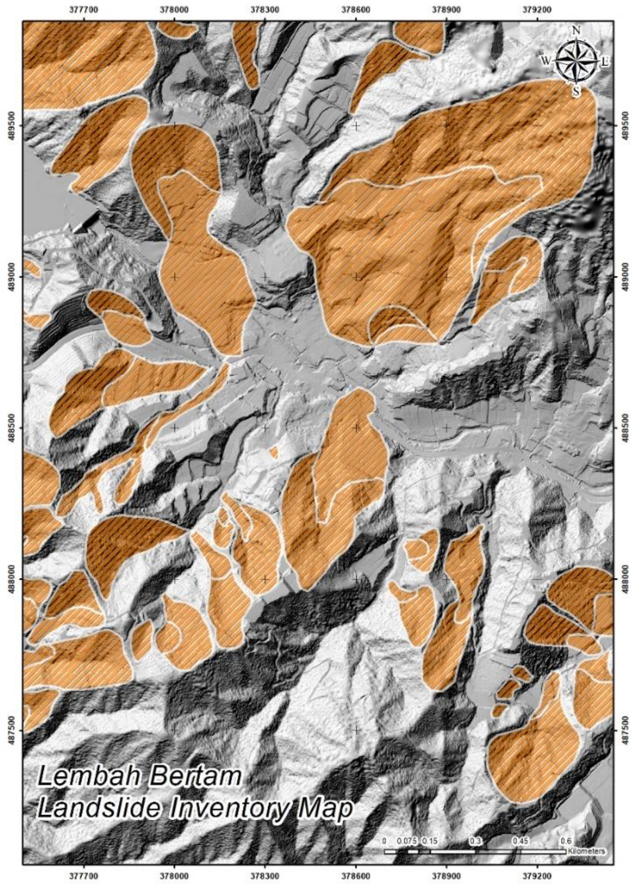


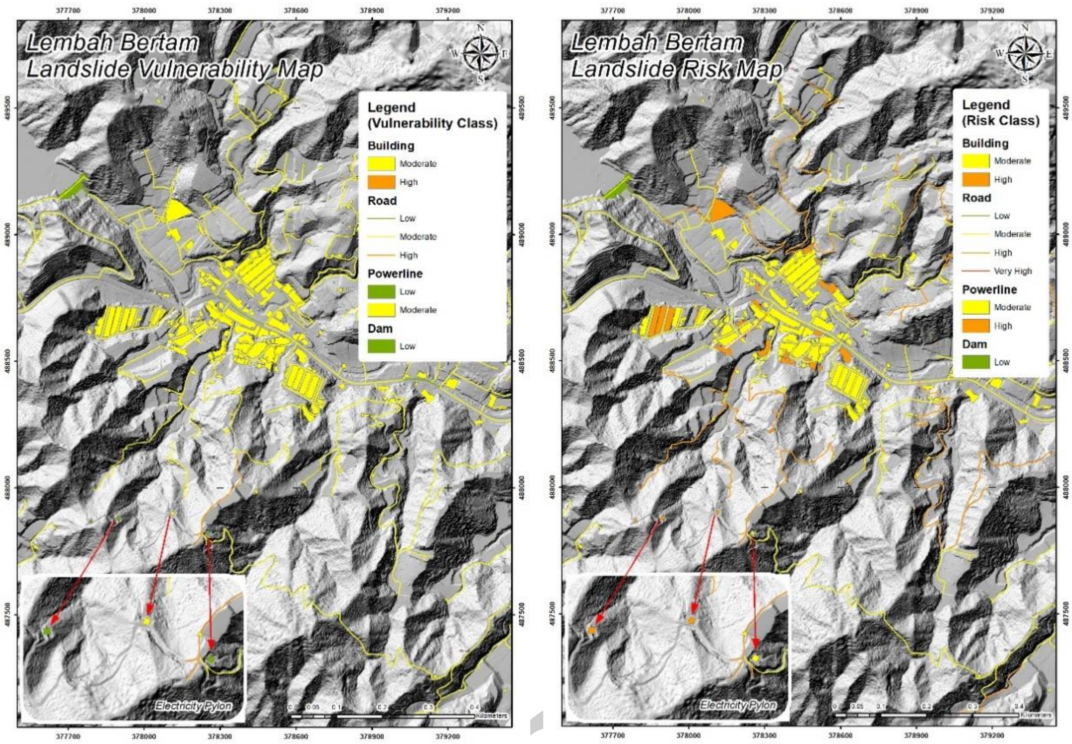
Fig. 10: Landslide inventory map of Lembah Bertam area in Cameron Highlands

-bination of landslide hazard and landslide vulnerability maps. Fig. 11(b) shows the land-slide risk map of the same area for the respective CI. Similarly, as the vulnerability map, the landslide risk map has only five classifications from very low until very high.

This study validated the vulnerability model by estimating the landslide vulnerability index and class at Taman Bukit Mewah, Bukit Antarabangsa by using a landslide vulnerability assessment tool (Fig.12). The indicators and sub--indicators were extracted from the Slope Engineering Branch (CKC), (Public Works Department, 2008) official report and resulted an estimated of vulnerability index 0.75 (high vulnerability index) (Table 1). The class of vulnerability for this particular assessment is described as structural breaks, partly destructed, reconstruction of destructed parts, death is highly likely (severe injury) and evacuation necessary. Based on the vulnerability class descriptions, the vulnerability model success-fully meets the expectation as described in the official report.

4. Conclusion

The establishment of clusters, indicators and sub-indicators with weighting values for CI were initially based on published literature since Malaysia has yet to compile national records of damage caused by the landslide events requiring this study to carry out semi-quantitative approach. The proposed landslide vulnerability assessment requires determination of 4 groups of indicators 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). Initially, each group of indicators are treated equally with 25% weighting value, in which all the group of



(a) (b)

Fig. 11: (a) Landslide vulnerability and (b) landslide risk maps for Lembah Bertam, Cameron Highlands.

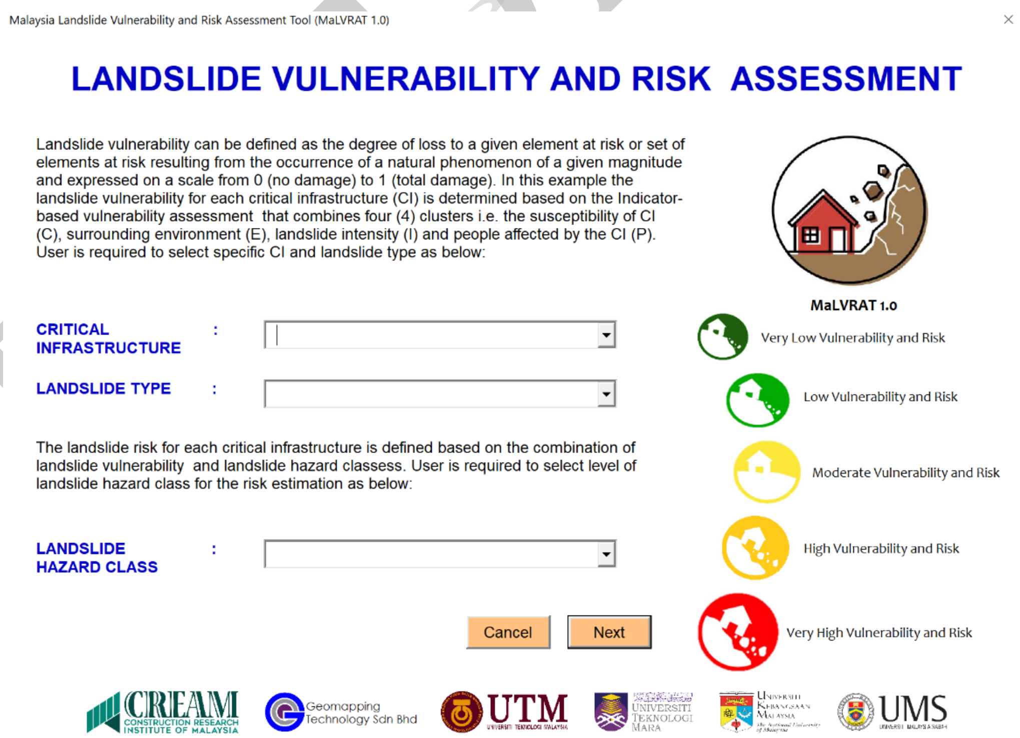


Fig. 12: Landslide vulnerability assessment tool.

Table 1: Landslide validation at Taman Bukit Mewah, Bukit Antarabangsa.

Scenario: Taman Bukit Mewah, Bukit Antarabangsa, Hulu Kelang, Selangor (6th December 2008)
Landslide type: Translational/Rotational
CI: Building
Susceptibility of CI (C) (0.36): • *Building typology (0.14)*: Reinforced concrete structure (0.40) • *Building Foundation Depth (Landslide Type Vs Deep Foundation Building (0.12)*: Accumulation height/landslide depth > 5 meter, shallow foundation (pad footing) (1.00) • *Number of floor (0.10)*: Medium rise (2 - 5 storey) (0.50) **Surrounding Environment (E) (0.18)**: • *Presence of protection (0.07)*: No protection (1.00) • *Distance between building (0.05)*: 3-5 meter (0.50) • *Building location (0.07)*: Building is located at the toe of slope (0.60) **Landslide intensity (I) (0.33)**: • *Accumulation height (0.15)*: > 2.0 meter (1.00) • *Landslide volume (0.18)*: 50,000 - 250,000 meter3 (0.90) **People inside the building (P) (0.13)**: • *Population density (0.04)*: High (0.90) • *Evacuation of alarm system (0.03)*: No (1.00) • *Age of people (0.03)*: Adults (0.20) • *Health condition (0.03)*: Health (Good) (0.10) ***Estimated vulnerability value***: 0.75
Class of vulnerability: High vulnerability
Class of vulnerability: Structural breaks, partly destructed, reconstruction of destructed parts, death is highly likely (severe injury) and evacuation necessary.

indicators have the same degree of influence on the final vulnerability value. Based on the FGD discussions, a total of 23 survey forms were completed with determined weighting values for each indicator and sub-indicator depending on the critical infrastructure given.

The results of the FGD shows that the expert panels tend to give similar scores to all indicators and sub-indicators. However, providing clear instructions to the panels during the FGD will minimize the generalization of giving the weighting values. The weighting values assigned for each indicator and sub-indicator should have good distribution between 0.1 and 1.0. The landslide vulnerability assessment based on different scenarios were conducted by using the data from FGD and internal experts' inputs show that further improvements should be made on the indicators, sub-indicators and more importantly on the weighting values.

In conclusion, the study has successfully achieved the objectives 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 Lembah Bertam, Cameron Highland and evaluated for the Bukit Antarabangsa 2008 landslide event where detailed records from the disaster showed convincing results supported from various remotely sensed data, field data and other ancillary geospatial data.

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