INCEPTION REPORT

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

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CONSTRUCTION RESEARCH INSTITUTE OF MALAYSIA (CREAM)

Subsidiary of the CIDB Malaysia

Prepared by

GEOMAPPING TECHNOLOGY SDN.BHD.

(593061-U)

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1.0 INTRODUCTION

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).

In this project, we propose an appropriate methodology and strategy for assessing 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 is capable of providing crucial input for development of method assess and estimate vulnerability index for the critical infrastructure. In addition the risk index can be defined by the product of landslide hazard, vulnerability and value for a specific infrastructure. The project promotes pre-disaster action rather than post-disaster reaction and aims at integrating efforts for assessing landslide vulnerability and possible risk assessment in a quantitative manner at site-specific, municipality and regional scales in Malaysia.

1.1 Objective Study

I. To identify issues related to vulnerability assessments and risk index for critical infrastructures.
II. To review the best practices of vulnerability assessments in other countries (Japan, Hong Kong, Taiwan, etc.) and provide benchmarking/ comparative analysis to Malaysia.
III. To assess and develop the parameters/indicators of landslide vulnerability assessment and risk index of critical infrastructures and assigning level for each parameter.
IV. To produce manual and guidelines for landslide vulnerability assessment and development of risk index.

1.2 Scope of Contract

I. Review issues regarding landslide vulnerability assessments and risk index on critical infrastructures for urban, urban highlands, sub-urban and rural areas including active tectonic zone in Malaysia.

II. Data collection focusing on the landslide vulnerability assessment method and development of landslide risk index for critical infrastructures in Malaysia (urban, urban highlands, sub-urban, rural and active tectonic zone).

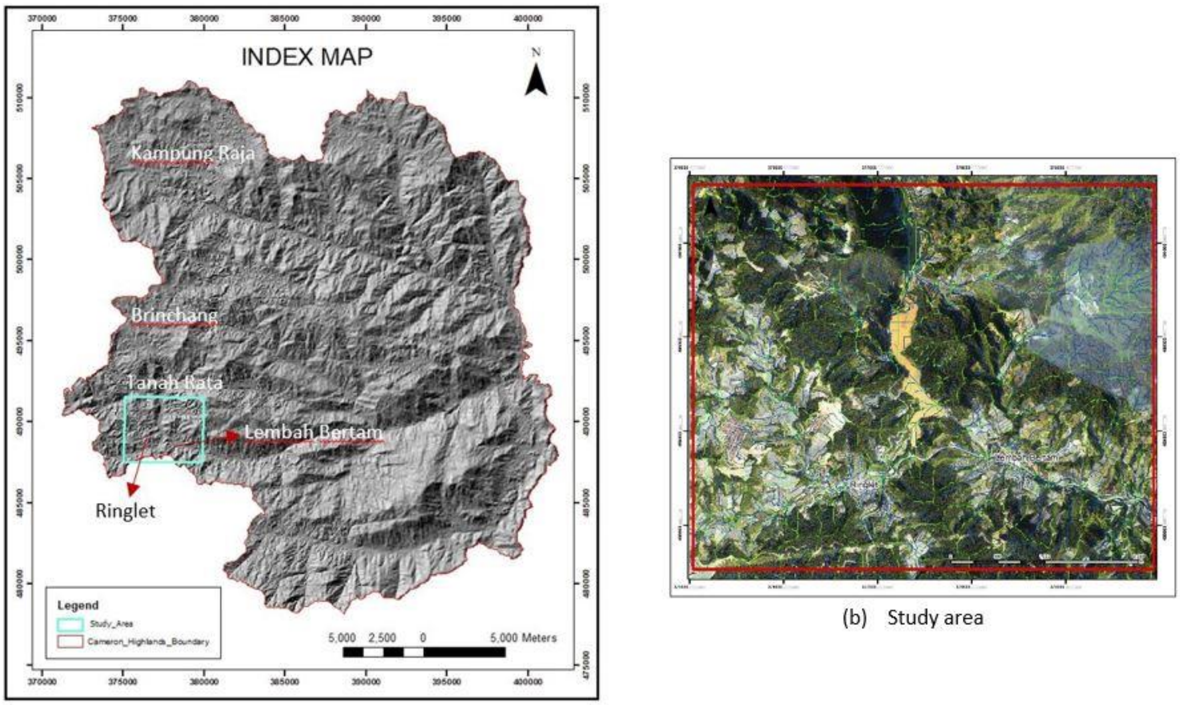
III. The output to this data collection will be used as indicators/ parameters for landslide vulnerability assessment and development of landslide risk index for critical infrastructures.

IV. Document analysis for vulnerability assessment and development of landslide risk index for critical infrastructures.

V. Final draft guidelines for Landslide Vulnerability Assessment and Development of Risk Index for Critical Infrastructure in Malaysia

2.0 STUDY AREAS

We propose a new methodological framework for landslide vulnerability mapping will be developed in Cameron Highland, Pahang. These areas will cover various types of critical infrastructure or element-at-risks (i.e. building, transportation network, lifelines, essential facilities, agriculture, economic activities and ecology) and vulnerability of the people (fatalities or injuries). The proposed study area consists of different types of landslides at different scales. These conditions allow development of more generic approach for landslide vulnerability mapping and assessment.



(a) Position of study area at Index Map of Cameron Highland

(b) Study area

Figure 1: Position of Study Area

3.0 METHODOLOGICAL FRAMEWORK

The overall methodology (Figure 2) can be divided into eleven (11) stages as follows:

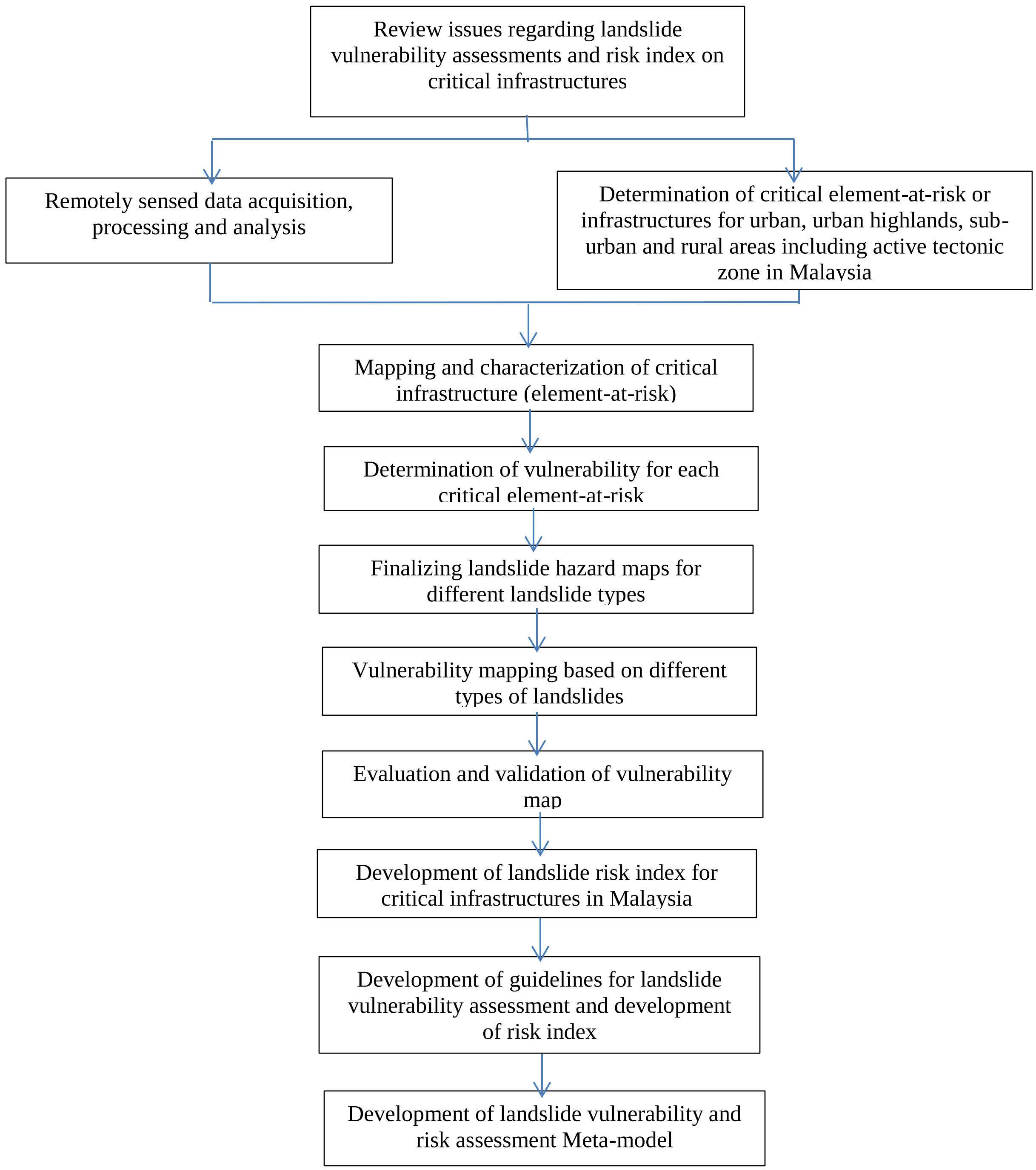


Figure 2: Conceptual methodology of the project

3.1 Review issues regarding landslide vulnerability assessments and risk index on critical infrastructures

Thorough review will be made on issues regarding landslide vulnerability assessment and model used to define risk index on critical infrastructures for urban, urban highlands, sub-urban and rural areas including active tectonic zone in Malaysia. Detailed review will emphasize on different aspects including:

1. Scale and transferability of vulnerability and risk assessment approach and results
2. Field data collection to improve the existing landslide vulnerability model
3. Landslide intensity determination for vulnerability model
4. Input data for vulnerability and risk assessment
5. Uncertainty in landslide hazard and risk assessment
6. Methods for landslide vulnerability and risk assessment

3.1.1 Issues on Scale and Transferability of Vulnerability and Risk Assessment Approach and Results

One of the important issues in vulnerability and risk assessment is on the scales of such analysis (Uzielli et al. 2008). The scales account for time or temporal and space scale of the assessments. The scale of analysis will determine type of approach for vulnerability and risk assessment as well as the amount of data required. For example the most detailed vulnerability assessment at local level i.e. of individuals or household usually required huge amount of not readily available data. Normally for decision making purposes, vulnerability and risk assessment at regional or national level assessment is adequate. Another related issue is on the down-scaling and up-scaling assessment results into different scales that might involve different levels of generalization and assumption and significantly affect the results. The quality and quantity of data will significantly affect the outcome of the vulnerability and risk assessments.

Furthermore vulnerability and risk assessments are site-specific that accounts characteristics of the hazard and element-at-risk (Fuchs et al. 2012; Lo et al. 2012). Different area might require different parameters and approach for susceptibility and hazard mapping depending on the natural and anthropogenic causal factors of a specific hazard. Furthermore, it is acknowledged that various types of the same process (e.g. debris flow vs. rock falls for landslide processes, fluvial floods vs. pluvial floods for flood processes) can result in different damage patterns.

3.1.2 Issues on the Field Data Collection To Improve the Existing Vulnerability Model

Papathoma-Köhle et al. (2015) reported difficulty of recording information regarding the intensity of the process on each building during field data collection to update existing vulnerability model. In their study the intensity of debris flow was not only determined by the deposition height and other factors for example velocity, the viscosity and the direction of the flow that approaches the building. The recording process of these factors is very challenging for the affected buildings (Jakob et al. 2011).

3.1.3 Issues on Landslide Intensity Determination For Vulnerability Model

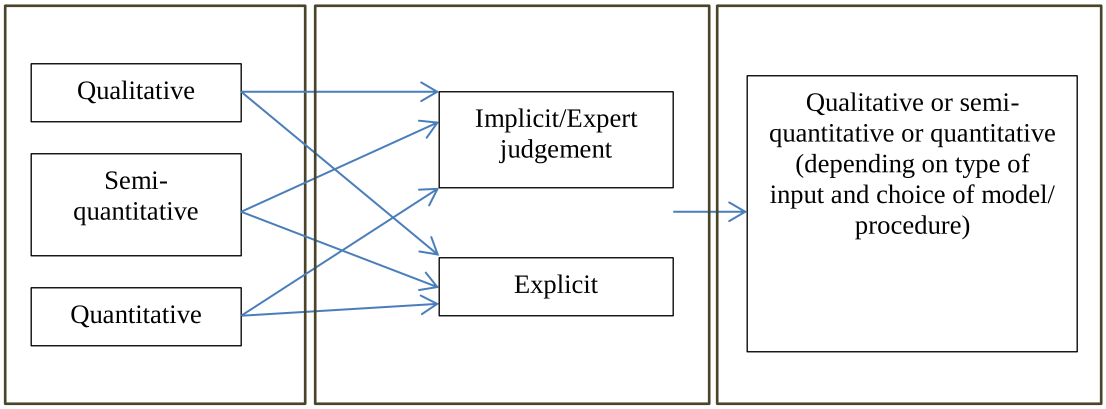
Mazzorana and Fuchs (2010) highlighted issues on the challenge in assessing the intensity of the landslide process on individual buildings. There is also gaps in understanding the interaction between the landslide process and the affected element-at-risk which complicates the selection of the suitable intensity parameter in vulnerability model (Papathoma-Köhle et al. 2015).

3.1.4 Issues on Input Data For Vulnerability and Risk Assessment

Detailed vulnerability assessment inevitably requires huge amount of data compiled during previous occurrences of landslides. Remondo et al. (2008) has setup an inventory of direct losses due to landslide disaster during nearly 50 years. The inventory was developed based on field surveys and consultations with both local inhabitants and public and private. The inventory was used to develop vulnerability curve, in which the vulnerability was defined as the ratio between loss of the element due to a landslide of a given type and magnitude and value of the element. Careful data collection of present and future landslide damages are also required to update the vulnerability model developed from the previous data (Papathoma-Köhle et al. 2017; Papathoma-Köhle et al. 2015). Advances in remote sensing technologies allow remotely sensed data to be obtained at fine resolution. This has permitted elaboration of more precise hazard models up-to-dated information on infrastructure and socio-economic activity (Bendimerad 2001; Remondo et al. 2008).

3.1.5 Issues of Uncertainty in Landslide Hazard and Risk Assessment

There are also issues on the landslide vulnerability and risk assessment uncertainties. The quantification of such uncertainties provides important information to stakeholder to support cost-benefit analyses of mitigation measures (Eidsvig et al. 2014). For example, a scenario with low potential losses should not be overlooked if the uncertainties associated with the estimations are large. The risk assessment consists of three fundamental aspects i.e. hazard, elements at risk and their vulnerability. In order to perform a probabilistic risk assessment, the uncertainty in all these three components needs to be assessed (Eidsvig et al. 2014). Uncertainty in vulnerability can be stem from input data, model or procedure and output depending on the stage of vulnerability assessment. Input to a vulnerability model could be qualitative (described with words), semi-quantitative (ranked on a relative scale, also denoted categorical) or quantitative (described as a dimensionless number between 0 and 1).



- Uncertainty associated with data

- Model uncertainty
- Propagation of uncertainty from input data through model
- Expert bias

- Uncertainty associated with two previous process stages
- Uncertainty associated with interpretation of the results

Figure 3: Propagation of uncertainties from input data to the results of landslide vulnerability modelling

3.2 Remotely Sensed Data Acquisition, 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)

The LiDAR data in the form of high density three-dimensional (3D) point clouds should involves the following processing:

1. Indexing and pre-evaluation
2. Filtering and classification
3. Digital Terrain Model (DTM), Digital Surface Model (DSM) and Canopy Height Model (CHM) generation

4. Feature extraction
5. Quality Assurance (QA) and Quality Control (QC)

3.3 Determination of Critical Element at-Risk

Determination of critical infrastructure or element-at-risk requires field investigation and definition of their important characteristics. The critical infrastructure can be grouped into:

1. Residential Areas;
2. Dam;
3. Building;
4. Road;
5. Power line;

Relevant element-at-risk characteristics for example types, materials, dimensions and locations are essential for detailed classification of each element-at-risk. Each element-at-risk will be classified into their sub-classification scheme based on their main characteristics. This information will be combined with landslide hazard as a primary input for expert-based vulnerability assessment.

3.4 Mapping and Characterization of Element at Risk

Geospatial approach for element-at-risk 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 will be 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 will be obtained from LiDAR data. These features will be combined in the object-oriented image classification. The resulting maps will be evaluated based on field observation and final map will be generated based on the evaluation report. The extracted land use/cover information will be transformed into the classes of critical element-at-risk. The GIS-based element-at-risk data will be characterized i.e. based on their types, materials, dimensions, age, state of maintenance, locations and etc. The characteristics of each element-at-risk should be defined based on the requirements set by the vulnerability assessment. Finally each element-at-risk will be sub-divided into their sub-class classification scheme.

3.5 Determination of Vulnerability for Each Critical Element At-Risk

One of the most critical steps towards risk analysis is the determination of landslides vulnerability (Uzielli et al. 2008). 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). Ideally vulnerability assessment accounts various factors including physical, economic, environmental, institutional and human factors. However, from the technical science perspective, vulnerability focuses primarily on the physical aspect which emphasizes on the hazard and its impact (Uzielli et al. 2008).

In the technical perspective, a number of methods have been made available for quantitative landslide risk estimation. Previous studies have shown that there is no general or universal approach in vulnerability assessment (Fuchs et al. 2011). However 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). The development of this indicator can easily be described in Figure 4. In another hand, physical vulnerability is generally defined as a scale ranging from 0 (no loss/damage) to 1 (total loss/damage), representing the degree of loss/potential damage of the element at risk. Figure 5 presents various sub-definitions of physical vulnerability pertaining to the general definition described above.

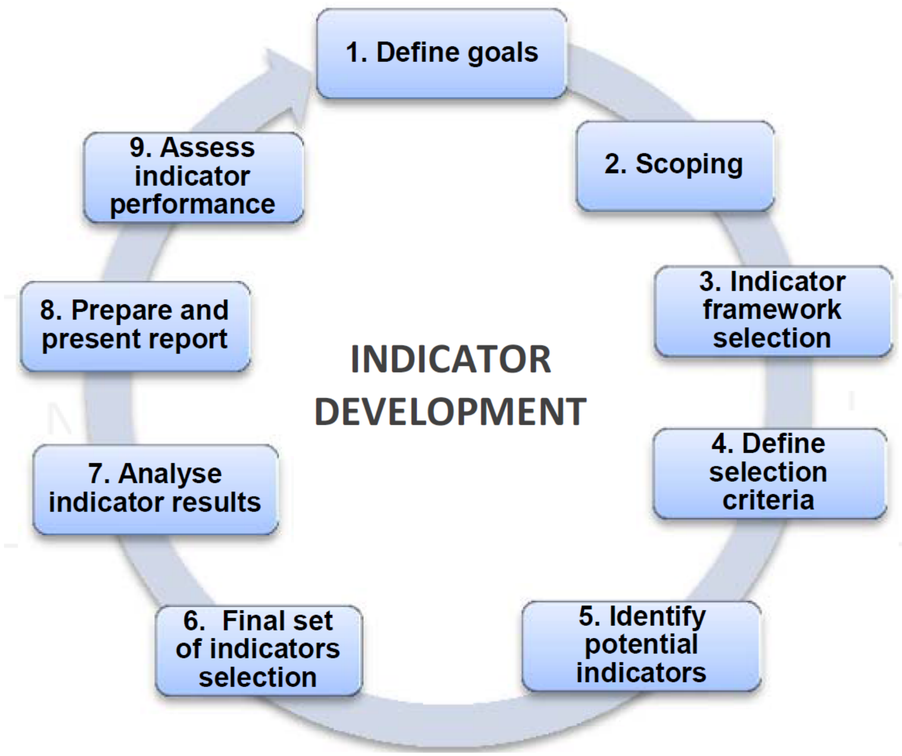


Figure 4: Development Process of Vulnerability Indicators

Working definitions(s): Vulnerability is…
The degree of loss to a given element at risk or a 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)
The conditions determined by physical, social, economic, and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards
The characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from impacts of a hazard
The intrinsic and dynamic feature of an element at risk that determines the expected damage/harm resulting from a given hazardous event and is often even affected by the harmful event itself. Vulnerability changes continuously over time and is driven by physical, social, economic and environmental factors
The degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change

Figure 5: General definitions of vulnerability used in risk assessment due to natural hazards and climate change

Uzielli et al.(2008) stated that landslide vulnerability assessment is more difficult compared to other types of hazard i.e. flooding and earthquake due to several reasons:

1. The complexity and the wide range of landslide process (landslides are determined by different predisposing and triggering factors which results in various mechanisms of failure and mobility, size, shape, etc.)
2. The lack systematic approaches to express landslide intensity. There is no general indicator of landslide intensity (e.g. for rock falls, impact pressure or volume can be used whereas for debris flow deposit height is common; other indicators such as flow velocity are rarely considered) and in practice data scarcity reduces their number significantly
3. The quantitative heterogeneity of vulnerability of different elements at risk for qualitatively similar landslide mechanisms due to their intrinsic characteristics (here, human life constitutes a special case)
4. The variability in spatial and temporal vulnerability
5. The lack of historical damage databases – usually only events which cause extensive damage are recorded and data about the type and extent of damage is often missing
6. Non-physical factors influence the vulnerability of people (e.g. early warning, hazard and risk perception, etc.)

In qualitative method of vulnerability assessment suitable vulnerability values are given to a specific element-at-risk based on the landslide type (Cardinali et al. 2002; Kappes et al. 2012). The values were assigned by experts based on their experience and historical records of damages based on a specific landslide type. These methods are flexible, for example indicator-based method is easy to use and understand by decision makers. However, this method relies on the expert judgments and there is no direct (quantified) relation between hazard intensities and degree of damage (Uzielli et al. 2008).

The semi-quantitative approach reduces level of generalization in the qualitative method (Dai et al. 2002). The methods are flexible reduce subjectivity, compared with the qualitative method. Based on this method, damage matrices, for example, are composed by classified intensities and stepwise damage levels. Previous study by Frédéric et al. (1996) damage matrices were suggested 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). However, this certainly required detailed information on the impact of a specific landslide hazard towards specific element-at-risk.

Due to complexity and highly detailed information required by the quantitative most of time this method was applied at local scale or individual infrastructures (Fuchs et al. 2007; Kaynia et al. 2008; Li et al. 2010; Uzielli et al. 2008). The method usually employed by engineers that involved in the technical decision making where 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. The procedures for physical vulnerability assessment can be made based on the expert judgement (heuristics), damage records (empirical), or statistical analysis (probabilistic).

3.5.1 Vulnerability Matrices

Vulnerability matrices are qualitative method which either being developed alone or most of the time based on the real events and more detailed vulnerability assessment approaches. The input for vulnerability matrices is often either based on empirical data or expert judgment. Intact structural element-at-risk will be assigned with 0 and 1 for totally damage building. All other conditions will be given between these values (Papathoma-Köhle et al. 2017).

Guillard-Gonçalves et al.(2016) used a qualitative assessment of the physical vulnerability of buildings to landslides. The physical vulnerability assessment was based on an inquiry of a pool of European landslide experts and a sub-pool of landslide experts who know the study area. The variability of the answers was assessed using standard deviation of each vulnerability value. In their study structural building types was divided into 4 groups namely, 1) wood or metal (SBT1), 2) adobe/rammed earth/loose stone walls (SBT2), 3) brick/stone masonry walls (SBT3), and 4) masonry walls confined with reinforced concrete (SBT4). These building structural types were crossed with the landslide intensity (i.e. depth or slip surface and height of accumulated materials) as shown in Figure 6.

Zêzere et al.(2008) defined the physical vulnerability of buildings and road not only on structural properties of exposed elements, but also on the type of process, and its magnitude (see Figure 7). The vulnerability values were defined based on the past records of landslides occurrences in the study area. Landslides affect the physical element-at-risk at various impact mechanisms for example burial, collision impact, earth pressures, differential shearing in tension, compression or torque, plastic deformation (flow), by object displacement and by removal or deformation of valued ground, such as productive soil and foundation substrate. The degree to which these mechanisms are manifest is generally reflected by the type of landslide (Glade 2004). However many landslides exhibit complex behaviour and a variety of different impact mechanisms may be represented in the one landslide type. Despite this problem, a classification scheme has been suggested by (Flageolett 1999) as shown in Figure 8.

		Landslide body: depth of slip surface									
		1 m		3 m		5 m		10 m		20 m	
		Avg. vuln.	SD	Avg. vuln.	SD	Avg. vuln.	SD	Avg. vuln.	SD	Avg. vuln.	SD
Pool of European experts (52)	SBT1	0.60	0.24	0.73	0.21	0.84	0.18	0.90	0.19	0.90	0.20
	SBT2	0.57	0.23	0.72	0.20	0.85	0.17	0.92	0.14	0.91	0.17
	SBT3	0.46	0.22	0.60	0.22	0.76	0.18	0.88	0.18	0.91	0.18
	SBT4	0.35	0.20	0.48	0.18	0.66	0.19	0.80	0.18	0.86	0.19
Sub-pool of study area experts (14)	SBT1	0.64	0.19	0.84	0.14	0.96	0.09	1.00	0.00	1.00	0.00
	SBT2	0.59	0.15	0.77	0.15	0.96	0.09	1.00	0.00	1.00	0.00
	SBT3	0.43	0.15	0.66	0.15	0.86	0.12	0.99	0.05	1.00	0.00
	SBT4	0.30	0.10	0.50	0.13	0.71	0.15	0.91	0.13	0.99	0.05

		Landslide foot: height of accumulated material							
		0.5 m		1 m		3 m		5 m	
		Avg. vuln.	SD	Avg. vuln.	SD	Avg. vuln.	SD	Avg. vuln.	SD
Pool of European experts (52)	SBT1	0.45	0.22	0.61	0.20	0.85	0.17	0.94	0.12
	SBT2	0.38	0.23	0.53	0.21	0.78	0.18	0.93	0.12
	SBT3	0.30	0.18	0.40	0.22	0.66	0.17	0.83	0.17

Figure 6: Vulnerability matrices for building structural types crossed with the landslide intensity (i.e. depth or slip surface and height of accumulated materials) (Guillard-Goncalves et al., 2016)

Elements at risk value and vulnerability considering exposure to different landslide types within the Fanhões-Trancão test site

Vulnerable elements		Value €		Vulnerability		
		m^2	Pixel	Shallow translational slides	Translational slides	Rotational slides
Buildings	Poor traditional masonry buildings	600	15,000	0.5	1	1
	Poor adobe stone or taipa buildings	600	15,000	0.5	1	1
	Poor other resistant elements (wood, metallic) buildings	600	15,000	0.4	1	1
	Usual traditional masonry buildings	1197	29,925	0.5	1	1
	Usual reinforced concrete buildings	1197	29,925	0.3	1	1
	Luxurious reinforced concrete buildings	2186	54,650	0.3	1	1
	Heritage traditional masonry	2217	55,425	0.5	1	1
Roads	Motorway, bridges, viaducts	933	23,325	0.6	1	1
	National road	933	23,325	0.6	1	1
	County road	8	200	0.6	1	1
	Rural road	2.5	62.5	0.6	1	1

Figure 7: Vulnerability matrices for building and road types crossed with the landslide types namely, shallow translational slides and rotational slides (Zerere et al., 2008)

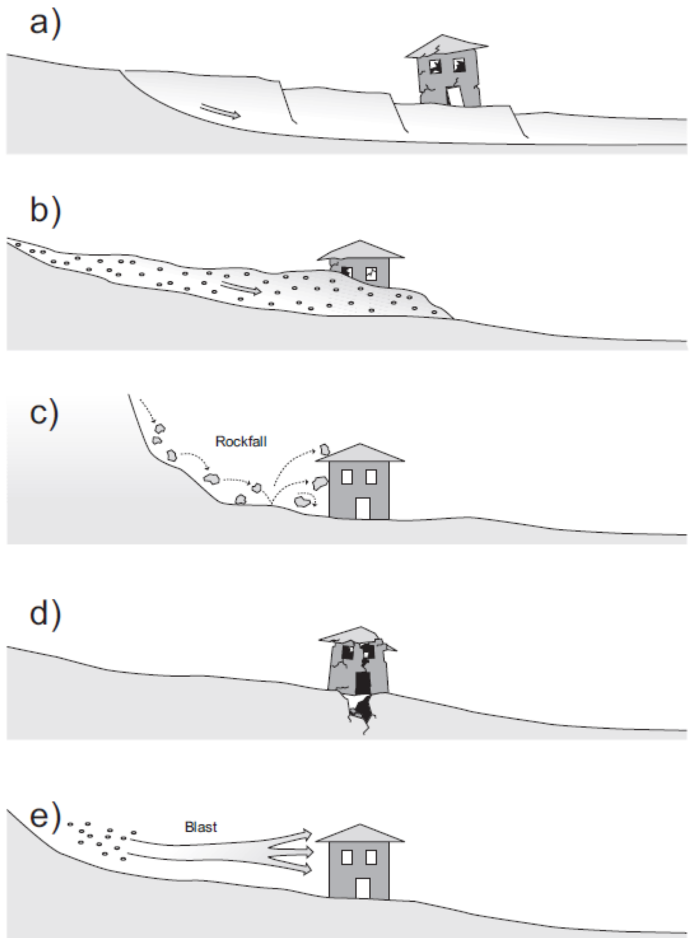


Figure 8: Schematic representation of structural damage to buildings for different landslide types (according to Flageolett 1999). Damage is assigned to slide and flow processes (a), to flows (b), to falls and topples (c), to subsidence (d), and to rock avalanches or large rock failures.

Frédéric et al. (1996) proposed a vulnerability matric that relates different types of element-a-risk with different intensities of landslides. Figure 9 shows a sample of the structural damage matric for different categories of buildings, which damages were explained in Figure 10.

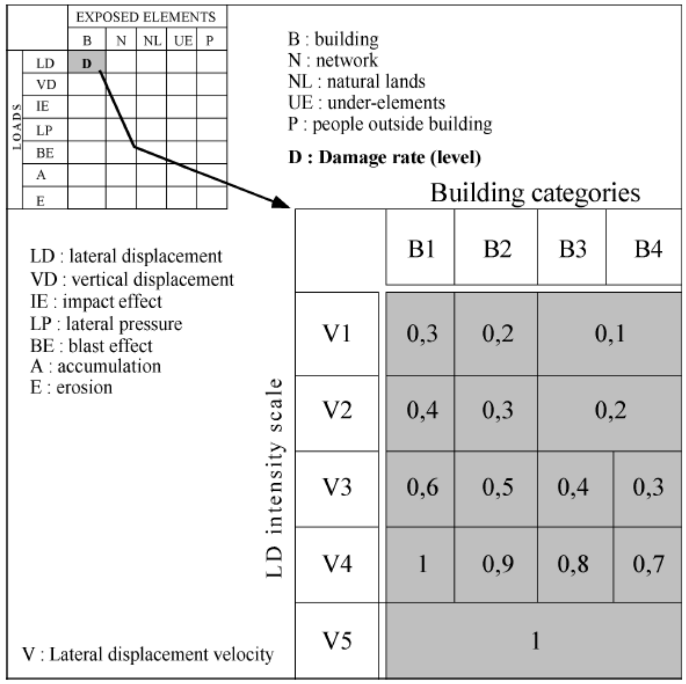


Figure 9: Sample of vulnerability matric for different building categories (Frédéric et al. 1996).

I	Light damage (on furniture only). Stability not affected.	0,01-0,1
II	Cracks on walls, but stability not affected. Repairs not urgent.	0,2-0,3
III	Important deformations, cracks widely open. Cracks on structures. Stability affected. Doors and windows unusable. Necessity of evacuation.	0,4-0,6
IV	Breaks on structures. Separation of parts. Partial collapse of floor and breaks on walls. Necessity of evacuation. Rehabilitation compromised.	0,7-0,8
V	Total collapse. Area must be evacuated. No possibility of rehabilitation.	0,9-1

Figure 10: Sample of the typology of the types and levels of damage of the main elements exposed (Frédéric et al. 1996).

3.5.2 Vulnerability Curves

Vulnerability function or also known as vulnerability curves are commonly used to express physical vulnerability in a quantitative way (Papathoma-Köhle et al. 2017). Vulnerability curves can be defined as "a continuous curve associating the intensity of the hazard (X-axis) to the damage response of a building (Yaxis)" (Tarbotton et al. 2015). The function defines the degree of loss generally between 0 and 1 and it requires significant amount of empirical data to be reliable. In this case, the information on magnitude of loss and intensity of landslide hazard is required for different categories of element-at-risk. The intensity of the hazard required detailed information of hazard characteristics that could potentially cause damages to the element-at-risk for example for debris flow, intensity can be represented by debris height, velocity or viscosity. The damage records for element-at-risk can be obtained directly either from the actual damage cost or compensation cost or indirectly from photographic documentation or earth observation data that may be translated later into monetary costs (Papathoma-Köhle et al. 2012).

Papathoma-Köhle et al.(2015) developed a toolbox to support landslide vulnerability assessment mainly in field damage assessment standard method, method for future hazard assessment and database to update vulnerability curve for different element-at-risk. Structural vulnerability per building was defined as the ratio between the values of the building (in terms of reconstruction costs) to the monetary damage caused by the event. The vulnerability curve for a specific type of building was developed based on empirical damage data of buildings and the height of deposits caused by debris flow.

Remondo et al.(2008) developed a landslide vulnerability from a detailed analysis of past damage over 50 years from mass movements. The inventory of landside damages was based on field surveys and consultations with both local inhabitants and public and private. The vulnerability values were determined from a detailed analysis of past damage from mass movements, which has been recorded over nearly 50 years. The inventory is based on field surveys and consultations with both local inhabitants and public and private. However the data is still not complete and extrapolations and theoretical assumptions were needed for the assessment. The vulnerability of infrastructure was defined as the ratio between Loss of the element due to a landslide of a given type and magnitude and value of the element. In general the vulnerability values could theoretically be greater than 1, since repair could cost more than construction of a new structure. However, the maximum value considered in this analysis is 1 (total loss). In this study, the values of past losses were corrected for inflation, an assumption which can also be used for predicted future losses. They have only considered shallow slide for the risk estimation. The risk was estimated using Equation 1.

$$R = H \times E \times V \qquad (1)$$

Where *R* is the risk, *E* is the value for each element-at-risk and *V* is the vulnerability. They have pointed that a complete view of the risk for a given element-at-risk should combine multiple scenarios of hazards and vulnerability values for the different types of mass movements and their magnitude.

3.5.3 Vulnerability Indicators

Based on the study of social vulnerability by Birkmann (2006) vulnerability indicators can be defined as "variables which are operational representations of a characteristic or quality of the system able to provide information regarding the susceptibility, coping capacity and resilience of a system to an impact of an albeit ill-defined event linked to a hazard of a natural origin". Vulnerability indicator for landslide hazard includes the selection of relevant indicators, the identification of variables, their weighting and, finally, their aggregation in a vulnerability index (Papathoma-Köhle et al. 2017).

Isaza-Restrepo et al.(2016) estimated physical vulnerability of building as in Equation 2.

$$VE = V_E \times A_E \times D_\$ \quad (2)$$

where *VE* is the structural vulnerability (given in likely total economic losses), V_E is the structural vulnerability index, A_E is the area of the structure or of the built area and $D_\$$ is the commercial cost of the structure per square meter. The structural vulnerability was defined based on the type of structure, state of maintenance and age (Equation 3).

$$V_E = BSF \times W_{BSF} \quad (3)$$

where *BSF* is the building susceptibility factor and W_{BSF} is the weight of each factor.

Uzielli et al.(2008) proposed a vulnerability assessment framework quantitative estimation of physical vulnerability of element-at-risk for a specific landslide hazard. In their study, vulnerability was defined as the product of landslide intensity and susceptibility of element-at-risk (Equation 4). Both intensity and susceptibility (Equation 5) are expressed in dimensionless terms with values between 0 and 1.

$$V = I \times S \quad (4)$$

$$S = 1 - \coprod_{i=1}^{n_s}(1 - \varepsilon_i) \quad (5)$$

Where ε_i is the i-th of n_s susceptibility factors (each defined in the range [0, 1]) contributing to the category susceptibility. The susceptibility of the element-at-risk refers to the lack of inherent capacity of the elements in the spatial extension under investigation to preserve their physical integrity and functionality in the course of the physical interaction with a generic sliding mass. They have stressed that susceptibility as defined in the study is independent of the characteristics of the acting agent, i.e. the landslide. The susceptibility value accounts its physical resilience to landslide occurrence, which mainly depends on the technological and its state of maintenance. The susceptibility classes for structural typology (ξ_{STY}) were divided into 6 classes as listed in Table 1.

Table 1: Proposed values of susceptibility factor for structural typology

Structural typology	Resistance	Susceptibility
Lightest, simple structures	None	1.00
Light structures	Very low	0.90
Rock masonry, concrete and timber	Low	0.70
Brick masonry, concrete structures	Medium	0.50
Reinforced concrete structures	High	0.30
Reinforced structures	Very high	0.10

The state of maintenance (ξ_{SMN}) expresses the reduced capacity of structures in comparison with the “very good” category in which maximum capacity is expected. Table 2 shows the proposed values for the state of maintenance.

Table 2: Proposed values of susceptibility factor for structural typology

State of maintenance	ξ_{SMN}
Very poor	0.50
Poor	0.40
Medium	0.25
Good	0.10
Very good	0.00

The landslide intensity parameter can be defined quantitatively using various approaches. Landslide intensity has been addressed and defined quantitatively using a variety of parameters i.e. maximum velocity, total displacement, differential displacement (relative to points adjacent to the point under consideration), depth of the moving mass, depth of deposits after the movement ceases, depth of erosion, unit discharge, kinetic energy per unit area, maximum thrust, impact pressure, maximum normal or shear strain at or below ground surface (Hungr 1997). Uzielli et al. (2008) in their study used a composite landslide intensity parameter that accounts kinetic and kinematic characteristics of the interaction between the sliding mass and the reference area (Equation 6).

$$I = k_S + I_K + r_M + I_M \qquad (6)$$

Where

$$k_S = {}^{A_i}/_{A_t} \qquad (7)$$

k_S is the spatial impact ratio, A_i is the area pertaining to the element-at-risk that is affected by the landslide, A_t is the total area pertaining to the element-at-risk, r_K is the kinetic relevance factor of the category, r_M is the kinematic relevance factor of the category, I_K is the kinetic intensity parameter of the element-at-risk and I_M is the kinematic intensity parameter of the element-at-risk.

Li et al.(2010) proposed a new quantitative model for vulnerability of structures and persons based on landslide intensity and resistance of exposed elements. In their study, vulnerability (*V*) was defined as a function of the hazard intensity (*I*), the exposed elements at risk and the resistance ability (*R*) of the elements to withstand the hazard.

$$V = f(I,R) = 2\frac{I^2}{R^2}\ for\ \frac{I}{R} \leq 0.5 \text{ (6)}$$

$$V = f(I,R) = 1.0 - 2\frac{(R-I^2)}{R^2}\ for\ \frac{I}{R} \leq 1.0 \text{ (7)}$$

$$V = f(I,R) = 1.0\ for\ \frac{I}{R} > 1.0 \text{ (8)}$$

In their study, the landslide intensity is defined as a function of dynamic and geometric intensity factors.

$$I = I_{dyn} + I_{dpt} \text{ for structure outside landslide area (9)}$$

$$I = I_{dyn} + I_{dfm} \text{ for structure inside landslide area (10)}$$

where I_{dyn} is the dynamic intensity factor that accounts stationary and non-stationary element-at-risk, I_{dpt} is the debris-depth factor, which was used to evaluate the element-at-risk outside rapid landslide area, and I_{dfm} is the deformation factor, which is mainly used to evaluate the structures within the sliding mass of a slow landslide. The resistance reflects the physical resilience of vulnerable element-at-risk to withstand specific landslide hazard intensity. The resistance of structure was defined as follows:

$$R_{str} = \left(\varepsilon_{sfd} \times \varepsilon_{sty} \times \varepsilon_{smn} \times \varepsilon_{sht}\right)^{1/4} \text{ (11)}$$

Papathoma-Köhle (2016) highlighted that it is important to account information on intensity of the process in the indicator-based method and indicators that reflect the physical resilience of the buildings (Figure 10). In this study, the relative vulnerability index (RVI) is calculated using Equation 8.

$$RVI = \sum_{1}^{m} w_m \times I_m \times S_n \qquad \text{(8)}$$

where *w* represents the m different weights, *I* the *m* indicators and *s* the *n* scores of the indicators.

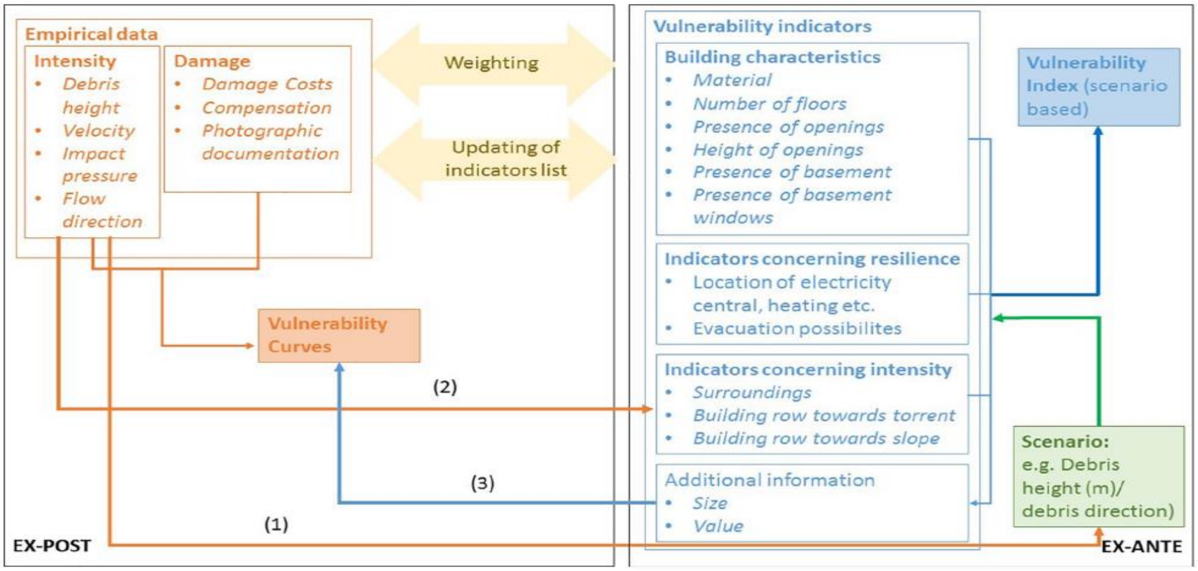


Figure 11: A framework indicating how different approaches of physical vulnerability assessment may interact with each other (Papathoma-Köhle 2016).

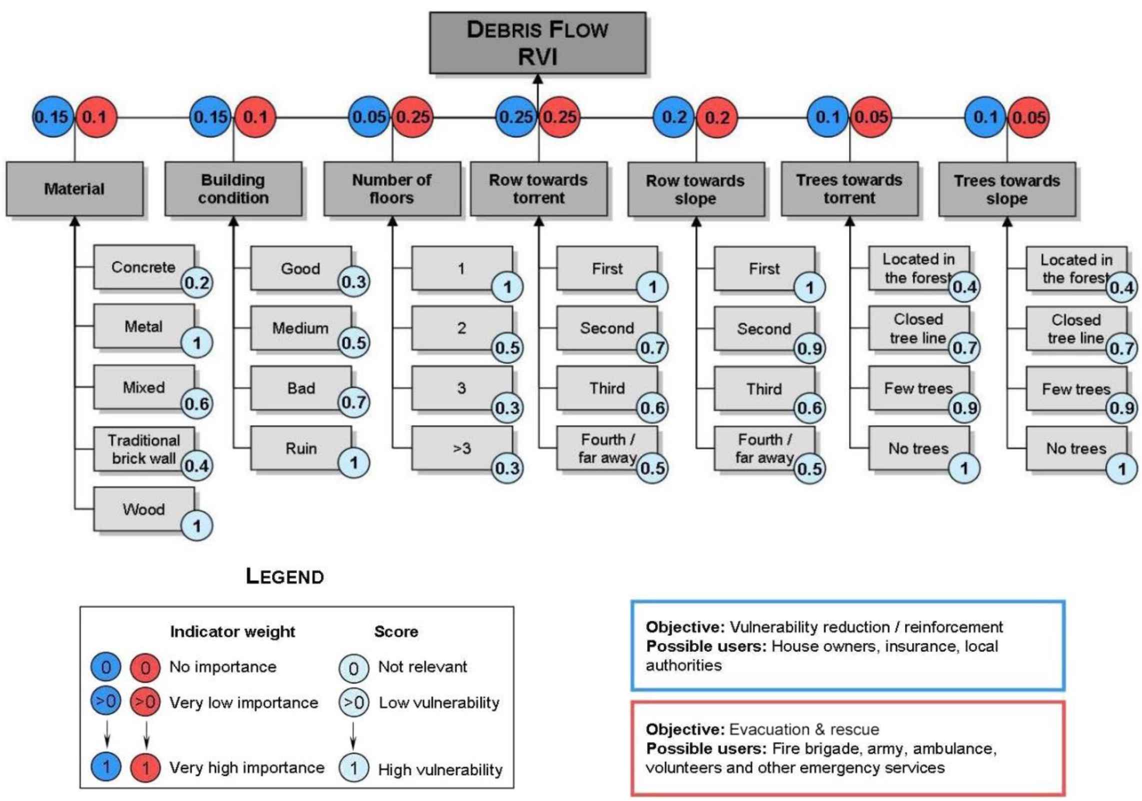


Figure 12: The vulnerability indicators are demonstrated together with the weight index, which varies according to the objective of the vulnerability assessment and the end users (Papathoma-Köhle 2016).

In this project the landslide vulnerability and risk assessment will be made based on thorough justification on the advantages and disadvantages of the existing methods and issues as highlighted in previous chapter. We propose to use the semi-quantitative indicator-based vulnerability assessment. Each landslide type will have different vulnerability indicators and vulnerability value for each critical infrastructure. This is followed by a semi-quantitative approach for landslide risk assessment. However the selection of landslide vulnerability and risk assessment methods are still subjected to availability of data. Series of workshops will be conducted together with the related agencies, which aims to determine the vulnerability indicators that include critical infrastructure characteristics, hazard intensity and vulnerability information for each critical infrastructure. In addition the workshop will be used to enhance the stakeholders' knowledge and awareness on landslide vulnerability and its importance on effective landslide hazard and risk mapping. During the workshop each expert will be explained on the aim of the assessment, related procedures and the expected outcomes. The expert will also be supplied with local information on the landslides occurrences and photos of element-at-risk in the study area.

The experts will be selected based on certain criteria namely:

a) Knowledge on landslides vulnerability mapping and analysis based expert judgment
b) Knowledge on landslides risk mapping based on geospatial approach
c) Local knowledge on landslides occurrences and their characteristics in the study area
d) Coping capacity for different element at risk to withstand landslide hazard in the study area
e) The impact of different landslide types in on different element-at-risk classes

The final vulnerability values for each element-at-risk will be determined based on the weighted approach assigned based on the reliability of the experts.

3.6 Finalizing Landslide Hazard and Inventory Maps for Different Landslide Types

Generation of landslide vulnerability maps require the landslide hazard maps to be generated for different landslide types. 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. The quality of the existing landslide hazard maps of the study area will be checked and necessary improvements will be done based on the input requirement for the vulnerability and risk mapping.

3.7 Vulnerability Mapping Based on Different Types of Landslides

The landslide vulnerability mapping will combine information obtained in the vulnerability matrices, maps of element-at-risk and landslide hazard maps. Based on this information, the vulnerability maps that account different types of landslide and element-at-risk can be generated.

3.8 Evaluation and Validation of Landslide Vulnerability Maps

The landslide vulnerability maps will be evaluated and validated based on the field observation and past records of casualties or damages occurred in the study area.

3.9 Development of Landslide Risk Index for Criticsl Infrastuctures In Malaysia

A final map of landslide risk shall technically present the subdivision of the terrain into zones that are characterised 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, either in the form of qualitative or quantitative manner. 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 (IUGS, 1997; TC32, 2004; UN-ISDR, 2004; Fell et al., 2008a). Suitable approach for landslide risk analysis will be determined based on requirement by the authorities for example scale of mapping and essential information that should be considered by the risk index. In addition the risk index will be proposed for each element-at-risk and detailed explanation on the losses will be explained clearly.

3.10 Development of Guidelines for Landslide Vulnerability Assessment and Development of Risk Index

The proposed landslide vulnerability mapping and assessment were based on the expert opinion. The proposed approached and its results should be consistently updated by detailed recording of element-at-risk damages for every reported landslide occurrences. Based on the best practices and standard approach used internationally, special standard of procedure (SOP), form and approach will be proposed for on-site vulnerability assessment of any landslide incidence. The records can be used to update and validate the existing vulnerability value for each element-at-risk based on the empirical approach. Development of risk index will be based on the input from landslide hazard, vulnerability value for each infrastructure and its value. The resulting specific risk values will be transformed to a specific risk index level with a clear definition about the characteristics of the element-at-risk and its vulnerability towards specific landslide hazard magnitude.

3.11 Development of Landslide Vulnerability and Risk Assessment Meta-Model

As a further abstraction of a model, Meta-model is used as a language to describe disaster management and create a decision support system to unify, facilitate and speed up the process of managing disaster (Visconti and Cook, 2002). Meta-model can support all stages of disaster management which includes vulnerability and risk. Vulnerability and risk will be shown in the form of a Meta-model system tool which can be translated into the form of software engineering and this allows disaster management to become a complete management (Othman and Beydoun, 2010). Furthermore, a Meta-model can be used for documenting GIS process.

The process of developing Meta-model can be constructed by using Unified Modelling Language (UML). Figure 12 shows the four-layers framework of developing Meta-model which includes the meta-metamodel layer, metamodel layer, model layer and data layer.

1. Metamodel layer describes the types and relationships of the elements of the information model in the model layer and it represents the universal concepts of manufacturing process information such as step, part and operation.
2. Model layer is the instantiation model of the metamodel which means that model layer is the inheritance and implementation of the classes in metamodel layer. The methods used in model layer are such as aggregation and inheritance.
3. Data layer consists of the input, production and output data of digital process planning system. It is an instance of the model, and directly interacts with users of the system.

A Meta-model integrates disaster management stages including vulnerability and risk in ensuring that all stages carried out uses the same standard operation procedure (SOP) which later on facilitate all parties' task integration. For each disaster management phase, Meta-model provide ease of use for stakeholders to make appropriate decisions based on stages of disaster management. Figure 13 shows a disaster management Meta-model that contains relationships among corresponding stages.

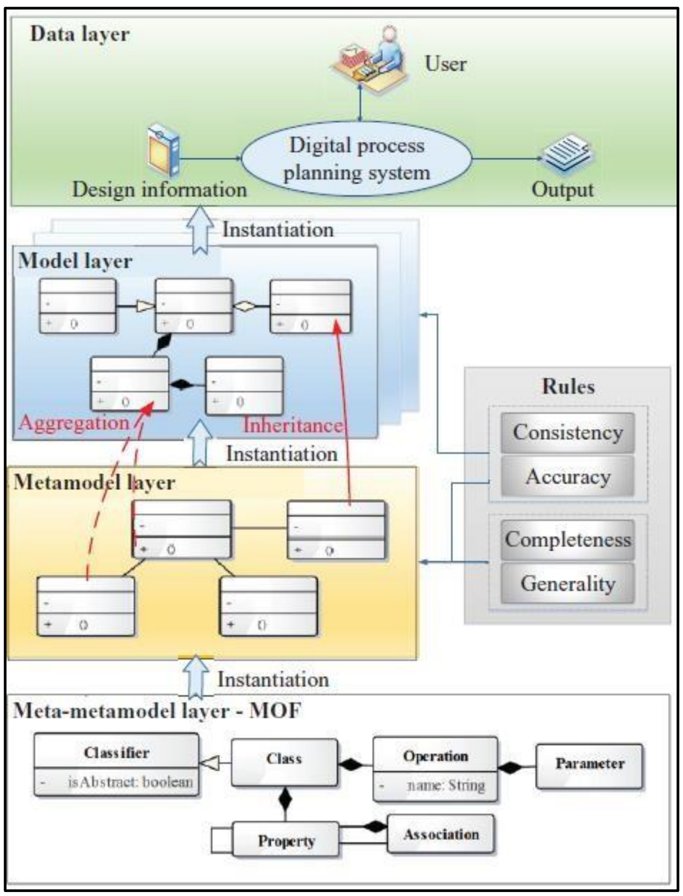


Figure 13: Framework of manufacturing process Meta-model (Bin Y. et al., 2016)

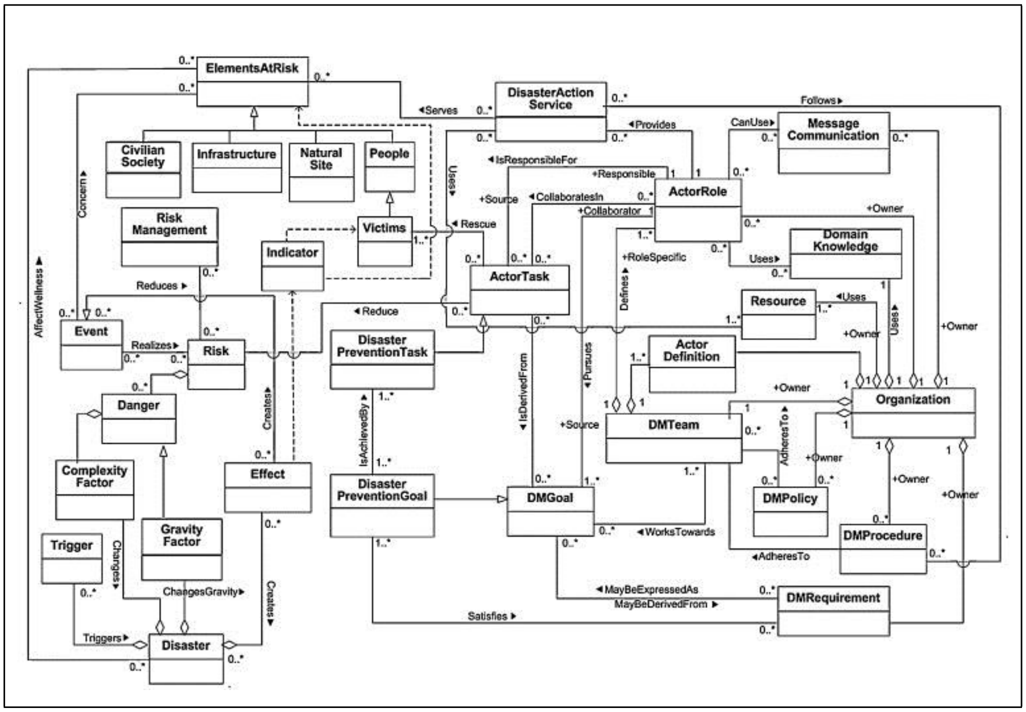


Figure 14: Disaster Management Meta-model (Othman and Beydoun, 2013)

4.0 WORK PLAN & PROJECT IMPLEMENTATION

All results for each level of work will be presented. Progress report will be sent periodically as stated on schedule of project implementation proposed by the consultant (Appendix 1).

The schedule of payments are stated in percentage (%) as below:

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

Task Name	Duration	Start	Finish	Progress (%)
Inception Report (Objective 1)	16 days	4/6/2018	27/6/2018	10%
Interim Report 1 (Objective 2)	42 days	27/6/2018	27/8/2018	20%
Interm Report 2 (Objective 3)	55 days	3/9/2018	23/11/2018	20%
First Draft Report (Objective 4)	34 days	15/10/2018	3/12/2018	10%
First Draft Final Report (Objective 4)	25 days	4/12/2018	10/1/2019	10%
Final Report (Objective 4)	20 days	11/1/2019	11/2/2019	30%

5.0 MATERIALS REQUIRED FOR THIS STUDY

All the materials or data required need to be supplied by client or relevant agencies such as topography map, survey data (LiDAR,ifSAR or DTM) and engineering geology map.

6.0 RESEARCH TEAM

PROJECT LEADER

Dato' Zakaria Bin Mohamad

SUBJECT MATTER EXPERT:

Dr Tajul Anuar Bin Jamaluddin (Landslide Impact Assessment)

Prof. Ir. Zainab (Geotechnical Risk Assessment)

ADMIN AND FINANCE SUPPORT TEAM

RESEARCHER

GEOSCIENCE TEAM

(Hazard Impact Assessment)

1. Abd Rasid bin Jaapar
2. Dr Rodeano Roslee
3. Dr Mustapha Atta
4. Afiq Farhan bin Abdul Rahim
5. Mohamad Faruq Syahmi bin Md Aripin

GEOSPATIAL ANALYST/MODELLING TEAM

(Vulnerability Risk Analysis)

1. Dr Zulkarnain Abd Rahman
2. Dr Mohd Faisal Abdul Khanan
3. Dr Rozaimi Che Hassan
4. Muhammad Afifi Harun
5. Muhammad Fadhil Bin Jasmee

GEOTECHNICAL TEAM

(Geotechnical Risk Assessment):

1. Dato' Ir. Razlan
2. Dharam Singh A/L Jagar Singh
3. Nurul A'dilah Sailey
4. Syed Muhammad Bahthiar bin Syed Osman

7.0 CONCLUSION

The quality of landslide risk assessment is very dependent on the input data especially the landslide vulnerability mapping and assessment. The output of this study must be consistently updated with a new record of structural damages due to landslides. Continuous recording the landslide damages based on the recommended approach permits accurate construction of vulnerability curves for every critical infrastructure. In addition any coping mechanism that has been applied to each element-at-risk should be integrated in the vulnerability curves. In this project advanced remote sensing technology will be used to recognize and characterize the critical infrastructure, which later will be used to map landslide vulnerability at larger scale. In addition, suitable method for field vulnerability assessment will be specially designed to record landslides occurrences and its related damages. The records can be directly merged into the database that permits more accurate vulnerability curve construction for each element-at-risk.

Based on the value, each critical infrastructure will be assigned with its specific risk level. In this project the risk level will be clearly defined by considering its loss towards specific landslide hazard and the characteristics of the infrastructure. Finally the guidelines for landslide vulnerability assessment and development of risk index will be stored systematically in the specially developed meta-model.

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