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Landslide Risk Management (LRM): Towards a Better Disaster Risk Reduction (DRR) Programme in Malaysia

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Landslide Risk Management (LRM) is relatively new and received little attention from geoscientists and stakeholders in addressing landslide geodisaster especially in Malaysia. The main objective of this paper was to develop a practical and comprehensive model of LRM for Malaysia. To achieve this goal, firstly; a database was developed through literature review, landslide inventory, fieldwork and laboratory studies. Secondly, is Landslide Hazard Assessment (LHAs) determination. Thirdly, Landslide Risk Elements Identification (LREI) (population and properties value) and Landslide Vulnerability Assessment (LVAs) (Physical, Social and Environmental). Fourthly, Landslide Risk Estimation (LREt). Fifthly, Landslide Risk Evaluation (LREv) is conducted based on the F-N curve and Risk Evaluation Triangular (RET) figures, which was designed to determine the Risk Tolerance Index (RTI). Finally, to determine the appropriate Landslide Risk Treatment (LRT) either structural or non-structural approaches. The study concludes/suggests that the LRM model involves defining the LHAs, LREI, LVAs, LREt, LREv and LRT. This LRM model is suitable for development planning, the selection of land use suitability, control and manage the landslide hazard/risk in Malaysia and potentially to be extended with different background environments.

Keywords: Landslide Risk Evaluation (LREv); F-N curve; Risk Tolerance Index (RTI); Landslide Risk Management (LRM)

I. INTRODUCTION

The occurrence of landslide shows a growing trend in the future although much effort has been made to reduce the risk. Global climate change, human ignorance, population growth, ecosystem damage and environmental quality deterioration have contributed to the increased degree of hazard and risk of landslides.

In Malaysia, the issue of landslide successfully attracted the interest and attention of stakeholders and the community of scientists to reduce the risk. Authorities as well as individuals or organizations have spent millions of ringgit to treat the risk of landslides. Landslide are an important issue in urban areas and hills that are vulnerable to tropical storm threats and prolonged rainy seasons. This disaster is usually associated with other geological disasters such as floods and earthquake. Although there are several records of damage due to landslide disaster in Malaysia, the information is not comprehensive.

Historical of landslide records are also incomplete due to the absence of good and systematic database of landslide inventory and systems. Therefore, the scopes of landslide studies in Malaysia was limited and focused mainly on mapping of landslide location, slope stability analysis and slope design. This scopes of this study is considered to be inadequate in the context of Landslide Risk Management

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(LRM). The LRM system introduced in this paper is comprehensive and interdependent as it is able to analyze, estimate, evaluate and manage the risk of landslides effectively especially in areas with varying degrees of hazards, adverse impacts and risks. The LRM system is also useful in making the selection of land use suitability and development planning.

The ultimate goal of LRM studies is to protect the population, the economy and the environment against potential damage caused by landslides. This requires an accurate assessment of the level of threat from a landslide: an objective reproducible, justifiable and meaningful measure of risk (Crozier & Glade, 2005). Risk, in this context, is seen as a disaster that could happen in the future. Considering this relationship, it is evident that an accurate assessment model is of the utmost importance as it may under- or over-estimate the occurrence of future events. However, there is not yet a common agreement on LRM at least for landslide disasters and still many issues on methods and data remain partially under research (Castellanos, 2008). It is also relevant the spatial dimension of risk which depend on locations and on scales in which the assessment is carried out. Taking into account the importance and characteristics for disaster reduction, the investigations on risk assessment has increased enormously in the last decade.

II. TERMINOLOGY

One of the motivations for generating standard concepts about landslide came up with the idea of producing a World Landslide Inventory (WLI). In order to support the implementation of the WLI, some publications were produced by the IAEG Commission on Landslides, the UNESCO working party on world landslide inventory and later by the IUGS Working Group on Landslides. These publications have led to support a certain level of standardization in fields related to landslides, including: nomenclature for landslides (IAEG-Commission on Landslides, 1990; UNESCO-WP/WLI, 1993a), activity of landslides (UNESCOWP/WLI, 1993b), causes of landslides (UNESCO-WP/WLI, 1994), rate of movement of a landslide (IUGS-Working group on landslide, 1995) and remedial measures for landslides (IUGS-Working group on landslide, 2001).

Recently, the three geotechnical societies ISSMGE, ISRM and IAEG have created the a so called Joint Technical Committee on Landslides and Engineered Slopes (JTC-1), which continues to work in the standardization and promotion of research on landslides among the different disciplines (Castellanos, 2008). Therefore, Landslide Risk Management (LRM) requires communication, not only among engineers and geoscientists, but also among specialists from other fields of expertise. To ensure effective communications, the profession needs to agree on and use consistent terminology. For this reason, the most important terms are first defined in this paper.

The terminology used in this paper is consistent with the "Glossary of Terms for Risk Assessment" developed by Technical Committee on Risk Assessment and Management (TC32) of the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE) (www.engmath.dal.ca/tc32). Some other related terminology are also referred to as Crozier & Glade (2005), AGS (2007a; 2007b, 2007c; 2007d; 2007e) and UPC (2011).

Acceptable risk: A risk which everyone impacted is prepared to accept. Action to further reduce such risk is usually not required unless reasonably practicable measures are avail- able at low cost in terms of money, time and effort.

ALARP (As Low As Reasonably Practicable) principle: The principle which states that risks, lower than the limit of tolerability, are tolerable only if risk reduction is impracticable or if its cost is grossly in disproportion (depending on the level of risk) to the improvement gained.

Consequence: In relation to risk analysis, the outcome or result of a hazard being realized.

Danger (Threat): The natural phenomenon that could lead to damage, described in terms of its geometry, magnitude, mechanical and other characteristics. The danger can be an existing one (such as a creeping slope) or a potential one (such as a tsunami). The characterization of a danger or threat does not include any spatial-temporal probability or forecasting.

Deterministic: Describing a process with an outcome that is always the same for a given set of inputs, i.e. the outcome is "determined" by the input. Deterministic contrasts with random, which describes a process with an outcome that can vary even though the inputs are the same. Deterministic analysis contrasts with probabilistic analysis.

Disaster: Serious function disorders that exceed the ability of the community or society to wreak havoc on human, material, economic or environmental damage. Disasters are a result of harmful combinations, adverse effects and inadequate capacity or measures to reduce risky negative impacts.

Elements at risk: Population, buildings and engineering works, infrastructure, environ- mental features and economic activities in the area affected by a hazard. Also, a set of conditions and processes resulting from physical, social, economic, and environmental factors, which increase the susceptibility of a community to the impact of hazards.

F-N curves: Curves relating the probability per year of causing N or more fatalities (F) to N. This is the complementary cumulative distribution function. Such curves may be used to express societal risk criteria and to describe the safety levels of particular facilities.

Frequency: A possible action expressed as the number of occurrences of an event within a specified time or the number of numbers given in the experiment.

Hazard: Probability that a particular danger (threat) occurs within a given period of time.

Individual risk: The risk of fatality or injury to any identifiable (named) individual who live in the zone impacted by the landslide; or follows a particular pattern of life that might subject him or her to the consequences of the landslide.

Landslide inventory: Inventory on location, classification, amount, activity and date of landslide.

Likelihood: Used as a qualitative explanation of the probability or frequency.

Loss: Any negative consequence, financial or otherwise.

Probabilistic: A description of procedures, which are based on the application of the laws of probability. Contrasts with deterministic.

Probability: A measure of the degree of certainty. This measure has a value between zero (impossibility) and 1.0 (certainty). It is an estimate of the likelihood of the magnitude of the uncertain quantity, or the likelihood of the occurrence of the uncertain future event.

Preparedness: Activities and steps taken first to ensure effective response to disaster and its consequences.

Prevention: Activities to avoid any disastrous consequences and outcomes.

Reliabilty: A measurement of the system or part of the system to prevent the occurrence of a disaster.

Resilience: A measure of recovery or rebounding of a natural system to return to its original state after a disaster event.

Residual risk: The level of risk at any time before, during and after the program of risk mitigation measures has been taken.

Risk: Measure of the probability and severity of an adverse effect to life, health, property, and/or the environment. Quantitatively, Risk = f (Hazard, Potential Worth of Loss). This is commonly expressed as "Probability of an adverse event times the consequences of that event".

Risk analysis: The use of available information to estimate the risk to individuals or populations, property, or the environment, from hazards. Risk analysis generally contains the following steps: scope definition, hazard identification, and risk estimation.

Risk assessment: The process of making a decision recommendation on whether existing risks are tolerable and present risk control measures are adequate, and if not, whether alternative risk control measures are justified or will be implemented. Risk assessment incorporates the risk analysis and risk evaluation phases.

Risk estimation: the process used to produce a measure of the level of health, property, or environmental risks being analysed. Risk estimation contains the followings steps: frequency analysis, consequence analysis and their integration.

Risk evaluation: The stage at which values and judgment enter the decision process, explicitly or implicitly, by including consideration of the importance of the estimated risks and the associated social, environmental, and economic consequences, in order to identify a range of alternatives for managing the risks.

Risk management: The systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, mitigating and monitoring risk.

Risk control or risk treatment: the process of decision making for managing risks, and the implementation, or enforcement of risk mitigation measures and the re-evaluation of its effectiveness from time to time, using the results of risk assessment as one input.

Sensitivity analysis: Analysis to determine the different range results in terms of unit changes or input parameters.

Societal risk: The risk of widespread or large scale detriment from the realisation of a defined risk, the implication being that the consequence would be on such a scale as to provoke a socio/political response.

Susceptibility: Assessment quantitatively or qualitatively for the classification, volume (or area) and spatial distribution of soil present or potential occurrence in an area.

Tolerable risk: A risk within a range that society can live with so as to secure certain net benefits. It is a range of risks regarded as non-negligible and needing to be kept under review and reduced further if possible.

Total risk: The consequences (loss) expected to come from a level of danger somewhere over a certain period of time. The amount of risk depends not only on the disaster process but also on the risky elements and the effects of their adverse effects.

Uncertainty: Evidence of any situation without certainty not described by the probability distribution. Uncertainty due to natural change and / or incomplete knowledge (lack of understanding or insufficient data).

Voluntary risk: The risk that a person faces voluntarily for some benefits.

Vulnerability: The degree of loss to a given element or set of elements within the area affected by a hazard. It is expressed on a scale of 0 (no loss) to 1 (total loss).

III. LANDSLIDE RISK MANAGEMENT (LRM) FRAMEWORK

Several frameworks have been proposed, e.g. AGS (2000); Aleotti and Chowdhury (1999); Dai *et al.* (2002); Einstein (1988); Fell (1994); Fell and Hartford (1997); Fell *et al.* (2005); GEO (1999); Ho *et al.* (2000); IUGS (1997); Lee and Jones (2004); Morgenstern (1997); Nadim and Lacasse (2003); NRC (1996); Roberds (2001); Varnes (1984); Whitman (1984); Wu *et al.* (1996). The proposed frameworks have the common objective of answering the following questions (after Ho *et al.*, 2000; Lee & Jones, 2004; and Lacasse & Nadim, 2006):

1. What are the probable dangers? [Danger Identification];
2. What would be the magnitude of dangers? [Hazard Assessment];
3. What are the elements at risk? [Elements at Risk Identification];
4. What might be the degree of damage to the elements at risk? [Vulnerability Assessment];
5. What is the probability of damage? [Risk Estimation];
6. What is the significance of the estimated risk? [Risk Evaluation]; and
7. What should be done? [Risk Management].

An integrated risk assessment framework procedure for LRM has four phases: Hazard Assessment (Phase 1), Risk Analysis (Phase 2), Risk Assessment (Phase 3) and Risk Management (Phase 4) (Fig. 1).

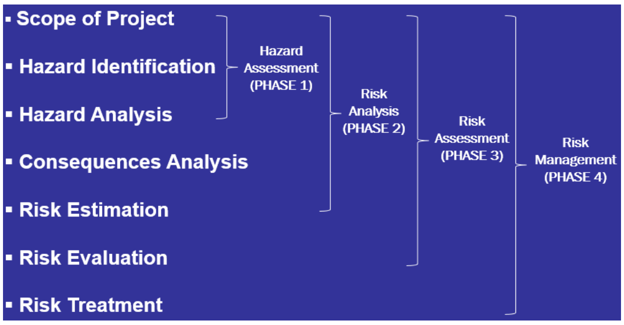

Figure 1. Landslide Risk Management (LRM) framework.

A. Hazard Assessment (Phase 1)

Landslide Hazard Assessment (LHAs) is carried out in 3 stages: a) Determination of project scope; b) Landslide Hazard Identification (LHI); and c) Landslide Hazard Analysis (LHAn).

The scope of project is consists as follows:

a. Site location and geographic limits;
b. Potential danger of landslide (threats);
c. Vulnerability of risk elements assessment;
d. Hazard and risk analysis approaches to be chosen;
e. Basis for risk evaluation; and
f. Selection of appropriate risk treatment methods.

The key elements in LHI involve: a) Observation and preparation of database; and b) Provision of data and map preparation. Observation and preparation of database takes into account several parameters as follows:

a. Geological and geomorphological characteristics (rock litology, soil type, lineament distance, discontinuity, weathering and erosion);
b. Geodynamic features (activity stage, activity distribution, activity pattern, movement velocity, magnitude of failure and distance of propagation);
c. Geomorphometric factors (slope type, slope angle, slope height, slope position, slope cross-section, slope plan, drainage system, engineering structure and vegetation cover);
d. Hydrological and hydrogeological conditions (daily

rainfall, permeability rates and groundwater levels);

e. Landuse types (primary and secondary forest, agricultural area, public infrastructure area, road area, village area, housing area, school / universities area, industrial area and municipal area);
f. Determination of rock and soil mechanics (point load index (PI), rock compression strength (σ), rock quality marker (RQD), standard penetration test (SPT), soil friction angle (ϕ), soil cohesion (C) and soil shear strength (τ));
g. Landslide types (creep, flow, fall, toppling, spread, slide and complex); and
h. Mitigation (structural or non-structural approach).

Provision of data and map preparation are based on two main features: a) relevance; and b) availability of data. Relevance refers to the major causes of landslide occurrences in the study area. Data availability refers to existing data that will be used to produce thematic maps.

Landslide Hazard Analysis (LHAn) is defined as the probability of a particular hazard (threat) occurring over a period of time (Crozier & Glade 2005; AGS 2007a; ISSMGE 2007; UPC 2011). Important concepts in the definition of LHAn are "what", "where", "when", "how strong" and "how often" (Crozier & Glade 2005). Guzzeti (2002) summarizes some of the elements of danger to three simple concepts: the location (where landslide will occur), time (when it will happen) and magnitude (how strongly it is and how often it will happen).

The term "strong" here refers to how the impact of the volume content and the velocity of the ground fluctuation (Crozier 2010). The most important thing in the LHAn element is "time" and "location" as well as the probability of landslide occurring in an area (Corominas *et al.*, 2003; AGS 2007a; JTC-1 2008).

In the literature, there are four different approaches to the analysis of LHAn, namely: landslide inventory-based probabilistic, heuristic (which can be direct geomorphological mapping, or indirect qualitative map combination), statistical (bivariate or multivariate statistics) and geotechnical approach. Detail description has been discussed in Rodeano *et al.* (2018).

B. Risk Analysis (Phase 2)

Landslide risk analysis (LRAn) is involves the dissociation or decomposition of risk systems and resources into its basic parts. LRAn involves the following processes:

a. Landslide Hazard Assessment (LHAs) (Determination of project scope, Landslide Hazard Identification (LHI) and Landslide Hazard Analysis (LHAn));
b. Landslide Risk Elements Identification (LREI);
c. Landslide Vulnerability Assessment (LVAs); and
d. Landslide Risk Estimation (LREt).

Landslide Risk Elements Identification (LREI) consists of population, property, economic activity, public amenities, environmental characteristics and infrastructure. E can be described as Et = ∑ (Ep + + Ee, ..., + Ea) where Et is the sum of the combined elements of all involved elements, while Ep, Ee and Ea etc are individual elements (Fell 1995). LREI are also defined as conditions or processes resulting from physical, social, economic and environmental factors that can enhance the advancement of a community (Crozier & Glade 2005; Hufschmidt *et al.* 2005; ISSMGE 2007). The level of detail of various risk factors depends on the scale of the research. For example,

a. Residential or resident area is one of the elements of regional scale assessment;
b. A home or a member of his family is one of the elements for a local scale assessment;
c. Room or individual space in a house is one of the elements for a specific scale assessment / case study.

Spatial, temporal and thematic features for risky elements need to be included in the database for risk analysis. Although the mapping method for hazardous elements is almost identical to the hazardous inventory mapping method, its emphasis is on the advantages of land sliding (van Westen *et al.*, 2006). Identification of objects such as buildings, roads and utilities is very important as a guide to risky elements. If digital data on a local scale does not exist, remote sensing methods can be used to extract data or information of elements at risks.

The concept of the Landslide Vulnerability Assessment (LVAs) concept can be understood in the context of LRM research based on the potential damage or death in the past, present or future as a result of different landslide events. Fell (1994) suggests that the quantity of Sustainability (V) can be determined based on several components ie V = VS × VT × VL, where VS is a spatial effect, VT is a temporal effect while VL is the loss of life for a particular individual as a risk elements.

LVAs depends on (a) distance of propulsion, (b) volumetric velocity, (c) risk factor (property) and (d) risky (animate) element. How people view and evaluate LVAs based on various factors such as social, economy and environment.

The concept of LVAs refers to the feasibility of elements at risks on engineering structures, infrastructure facilities, communication systems, commercial (including insurance disclosures) and social (Wisner 2004; Fuchs *et al.*, 2007). The significance of sanitation may vary depending on the understanding of the different perspectives (Alexander 2000; Jóhannesdóttir & Gísladóttir 2010). The perspectives in LVAs are divided into two branches; (1) socio-economic perspective and (2) science perspective.

The socio-economic perspective is not only different from the point of view of the land-grabbing method, however, in contrast to individual perceptions or social influences on the risk of landslide disaster (Fuchs *et al.* 2007). The level of advancement can vary according to the situation continuously, either as an individual or group. The constant change in the human system that interacts with the physical system has triggered a dynamical disaster and expeditious degradation (Weichselgartner 2001, Kunreuther *et al.*, 2001; Alexander 2005; Galli & Guzzetti 2007).

In the science perspective, the feasibility of referring to the "technical" or "physical" spatial concept is defined as the degree of loss for risk-bearing elements from the disaster (Varnes & IAEG Commission on Landslide 1984; Fell 1994). LVAs in science perspective involve cases of assessment of several different parameters such as building materials, maintenance stages, presence of protection structures, presence of warning systems, financial values or probabilities of life and so forth (Fell 1994; Fell & Hartford 1997; Glade 2003).

Landslide Risk Estimation (LREt) is still considered in development stage as only a few new methods are implemented. At present, the LREt proposed by AGS (2000) has been adopted extensively but improvements are still possible. The classification of LREt can be divided into three main approaches: qualitative, semi-quantitative and quantitative (AGS 2000; Powell 2000; Walker 2000; Chowdhury & Flentje 2003; Crozier & Glade 2005).

The qualitative LREt approach is based on specialist experience and expertise. The number of classes in the qualitative approach is very varied but typically consists of three or five classes (eg in very high risk areas: "Physical and non-physical mitigation measures are indispensable and no other infrastructure development is allowed in this class"). Fell (1994) proposes some terms for qualitative LREt considering classes for each magnitude, probability, danger, sanitation and risk.

The main difference between qualitative and semi-quantitative of LREt approaches is the setting of weighted values under certain criteria which provides the value (number) as a result rather than qualitative classification. The semi-quantitative LREt approach is useful in the following situations (AGS 2000):

a. As the initial screening process to identify hazards and risks;
b. When the level of risk (pre-assumption) does not involve time and effort; and
c. If the possibility of obtaining numerical data is limited.

The semi-quantitative LRAs approach makes clear consideration of several factors that affect stability (Chowdhury & Flentje 2003). The uniformity of scores and determination of determinations in each factor can be used to evaluate the extent to which factors favor or inadvertent to the occurrence of a hazard and the occurrence of loss or damage (impact effect).

The hazardous matrix and impact effects are used to derive the risk level rating by combining a set of hazard categories with a set of impact effect categories. The risk value can be listed with qualitative implications. Risk estimation can be done separately for loss of life and economic losses.

Quantitative LREt approach has been used for specific slopes or very small areas by using the probability method (Whitman 1984; Chowdhury 1988; Nadim & Lacasse 2003; Lacasse & Nadim 2006). A comprehensive description of the quantitative LREt approaches was also found in literature studies such as Aleotti & Chowdhury (1999), Dai *et al.* (2002), Bell & Glade (2004), etc. The equality of the risk in the quantitative approach of LREt uses the same combination of hazards and impacts, but differs in practice.

C. Risk Assessment (Phase 3)

Landslide Risk Assessment (LRAs) require information from a variety of disciplines that need to be collected, analyzed and eventually presented in different forms, from planning to regulatory activities for emergency management (Fedra 1998). Modern information technology provides several tools to support LRAs research, leading to the development of risk information systems. Risk information systems can be used to analyze risks and assess the impact of damage to mitigate or mitigate risk in the short term (emergency planning) and long-term (development plans). LRAs involves the following processes:

a. Landslide Hazard Assessment (LHAs) (Determination of project scope, Landslide Hazard Identification (LHI) and Landslide Hazard Analysis (LHAn));
b. Landslide Risk Elements Identification (LREI);
c. Landslide Vulnerability Assessment (LVAs);
d. Landslide Risk Estimation (LREt); and
e. Landslide Risk Evaluation (LREv).

Landslide Risk Evaluation (LREv) involves the process of decision-making in LRAs that refers to physical and social factors (Fell 1994; Finlay & Fell 1997; AGS 2000; Crozier & Glade 2005; ISSMGE 2007; UPC 2011). This process determines whether risks are acceptable or not. LREv involves consideration of risk perceptions, risk communication and risk comparisons aimed at developing appropriate phases or forms of response influenced by psychological, social and cultural values (Fischhoff *et al.*, 1981).

After LREt is carried out, the LRAs process must end with LREv. LREv also defines as decision-making process for consumers (local authorities, disaster managers, city planners, etc.) about the level of risk assessment to consider. The term used to describe the risks is difficult to understand by non-experts.

The level of risk acceptance is also associated with the risk value of the community ready to receive it (ICG, 2003). In theory, areas under very high levels of risk do not require further mitigation of landslide risks such as reduction, monitoring and physical rehabilitation measures. However in the real situation, low risk areas should be carefully considered. Recovery measures need to be taken to reduce the risk. Similar considerations need to be addressed for low-risk areas, but are highly vulnerable. Bell *et al.* (2004; 2005) discussed in depth the problems in determining acceptable levels of risk taking into account case studies from countries such as Iceland, Hong Kong and Switzerland.

The risk of tolerance is a risk in a community that can live safely. Tolerable risk is a range of risks that are considered non-negligible and require escalation and review to reduce it in the future if necessary (AGS 2000; Crozier & Glade 2005; ISSMGE 2007).

Figure 2 shows the F-N curve used in this study. This figure has been modified from GEO (1999) according to local relevance. Based on Figure 2, "acceptable risk" or "tolerable" refers to a level of risk that does not require any risk mitigation measures. "Risk that cannot be" accepted requires proper decision-making of the risk treatment. If the risk is calculated in the category of "unacceptable risk", then the risk should be reduced to the "As Low As Reasonably Practicable" principle (Rodeano, 2018).

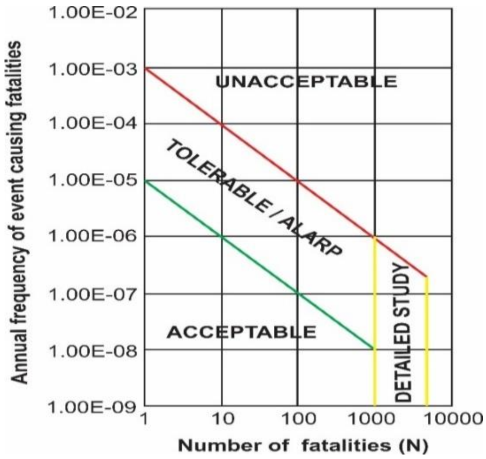

Figure 2. Proposed community risk criteria for landslides in Malaysia (Rodeano, 2018).

The result of the Landslide Risk Evaluation (LREv) will determine whether the risk is tolerable or tolerant and does not require any mitigation options, or the risks are not polarized and require some mitigation alternatives. Appropriate follow-up reaction should be determined if the level of risk can be assessed based on its tolerance level.

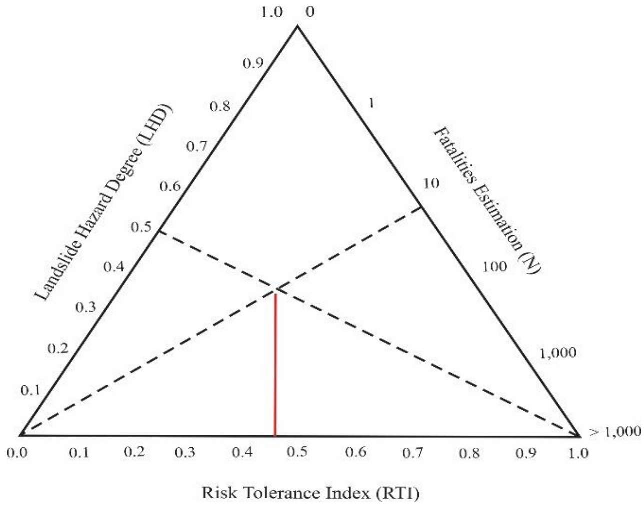

Figure 3. Risk Evaluation Triangle (RET) to assess the level of Risk Tolerance Index (RTI) based on fatalities estimation information (Rodeano, 2018).

A diagram known as "Risk Evaluation Triangle (RET)" is specially designed in this study to quantify the level of Risk

Tolerance Index (RTI) quantitatively (Figure 3). The parameters involved in the assessment are "Landslide Hazard Degree (LHD)" and "Fatalities Estimation (N)". The intersection of these two parameters will determine the level of RTI. A detail description and application for RET has been discussed by Rodeano (2018).

RTI levels will be classified from very low (0.00 - 0.20) to very high (0.81 - 1.00). The results of the RTI level classes will determine the degree of tolerance and recommendations of the Landslide Risk Treatment (LRT) action to be implemented.

D. Risk Management (Phase 4)

Landslide Risk Management (LRM) involves the following processes:

a. Landslide Hazard Assessment (LHAs) (Determination of project scope, Landslide Hazard Identification (LHI) and Landslide Hazard Analysis (LHAn));
b. Landslide Risk Elements Identification (LREI);
c. Landslide Vulnerability Assessment (LVAs);
d. Landslide Risk Estimation (LREt);
e. Landslide Risk Evaluation (LREv); and
f. Landslide Risk Treatment (LRT).

Landslide Risk Treatment (LRT) is a decision-making process for managing risk, implementation or enforcement of risk mitigation measures and revaluation of their effectiveness from time to time using risk assessment decisions (ISSMGE 2007; UPC 2011). After the LREv results are known, the follow-up action is LRT.

LRT involves management principles to reduce the likelihood of occurrence or adverse effects on humans, daily activities, property and the environment, and provide emergency feedback. LRT can be grouped into:

a. Accept risk;
b. Avoid risk;
c. Modifying risk;
d. Reducing the impact of risk;
e. Early monitoring and warning systems;
f. Move risks; and
g. Suspend decision.

The LRT and its design plans are intended to minimize the risks present in an unavoidable situation. LRT also involves engineering work aimed at protecting / isolating / eliminating risky elements from the effects of landslide hazards and reducing the probability of landslide.

A variety of landslide risk reduction options are summarized as follows:

a. Hazard modifications: Engineering solutions aim to alter the features of impact and reduce frequency.
b. Modification of behavior: reducing impact by avoiding, reducing the level of vulnerability, warning system, development planning, education, legislation and financial incentives.
c. Loss sharing: includes insurance systems, disaster relief, development assistance and compensation.

However, responsibilities for the implementation of landslide mitigation (including audits and reports) require ongoing maintenance. Nevertheless, it should be recognized that there may be situations where development is not permitted and requires detailed investigation.

The LRT technique involves two major approaches, reducing the driving moment and increasing the momentum of the retainer. Reduced driving moment approach involves: shear stress reduction acting along the plane plane failure. Example. avoiding incidents; and b. The shear stress transfer from the basic or anchored elements to stable slope formation. For example, construction of retaining structures, structural strengthening, closing plants and bio-engineering applications.The approach to enhancing the moment of arrest involves:

a. An increase in the number and effective normal stress acting along the plane of the failure surface such as structural strengthening;
b. Reduction of pore pressure measurement such as surface and drainage protection as well as sub-surface drainage; and
c. Increased strength of slab material such as consolidation or soil treatment techniques.

IV. CONCLUSION

The study concludes/suggests that the Landslide Risk Management (LRM) model involves defining the Landslide Hazard Assessment (LHAs), Landslide Risk Elements Identification (LREI), Landslide Vulnerability Assessment (LVAs), Landslide Risk Estimation (LREt), Landslide Risk Evaluation (LREv) and Landslide Risk Treatment (LRT) (Figure 4).

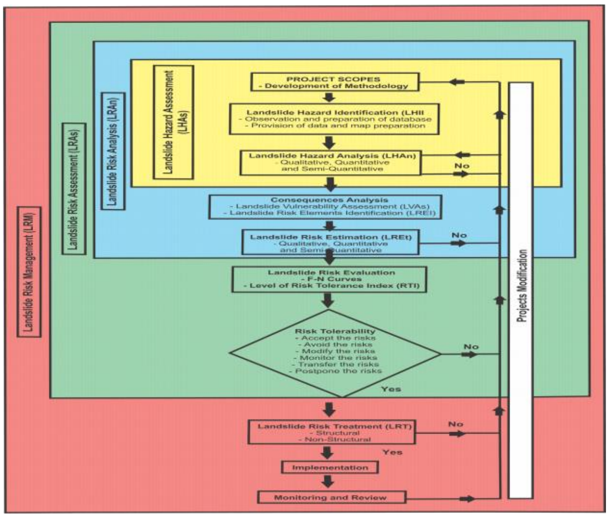

Figure 4. Recommendation of Landslide Risk Management (LRM) model for Malaysia (Rodeano, 2015).

Situations where Landslide Risk Management (LRM) must be summed:

a. Where the element at risk is exposed to a number of types of landslide;
b. Where the landslide may be triggered by more than one phenomena e.g. rainfall,
c. earthquake, human activity;
d. Where the element at risk is exposed to a number of different sizes of landslide of the same classification;
e. Where the element at risk is exposed to a number of slopes on which landslide can occur; and
f. Sum taking account of dependence.

The LRM model presented has been successfully used for engineered and natural slopes. The model may be adapted to suit a variety of problems, with due regard to the nature of the issues involved. However recent practice involves the use of risk-based qualitative, quantitative and semi-quantitative methods in many applications. Acceptability/tolerability also requires risk perception research in different countries and societies. Therefore, this LRM model is suitable development planning, the selection of land use suitability, control and manage the landslide hazard/risk in the study area and potentially to be extended with different background environments for Disaster Risk Reduction (DRR) Programme.

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