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Risk Evaluation Triangle (RET) for Landslide Risk Management (LRM): A Case Study from Kota Kinabalu, Sabah, Malaysia

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Landslide Risk Evaluation (LREv) is a decision-making process for Landslide Risk Analysis (LRAn) results. This process determines whether the inherent risks are acceptable, tolerant, unacceptable or a detailed studies is required. LREv also involves consideration of risk perceptions, risk communication and risk comparisons aimed at developing appropriate steps or level of response. Part of the LREv procedure is to assess the risk acceptance criteria. To achieve this goal, the F-N curve is used. The F-N curve relates to an annual probability that may cause n or more fatalities (F) to the total fatalities (N). The F-N curve is a complementary cumulative distribution function and provides statistical observations for all levels in offsetting a risk. However, the results of the LREv study on the previous F-N curves indicate that there is a constraint in the context of continuity of the proposed method or extension for the appropriate Landslide Risk Management (LRM) approach. Therefore, to overcome this shortcoming, a diagram known as the "Risk Evaluation Triangle (RET)" was introduced. RET basically aims to assess the level of Risk Tolerance Index (RTI) quantitatively. The parameters involved are Landslide Hazard Analysis (LHAn) and fatalities estimation. RTI levels are classified from very low (<0.20) to very high (> 0.81) and follow-up detailed description are given. Hence, these RET outcomes are expected to serve as a continuation of the advanced method or approach in uniform LREv which has a co-ordination principle that can be developed for LRM purposes.

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

I. INTRODUCTION

Risk evaluation is defined as the stage at which values and judgments 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 (ISSMGE, 2007).

Risk evaluation is the processes of determining the significance of a risk to the individual, organisation or community. Only

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after significance of risk is assessed can an appropriate response be determined. Essentially the risk needs to be judged as *acceptable, tolerable,* or *intolerable* (Fell, 1994; Finlay & Fell, 1997). These judgments are however, hugely influenced by psychological, social and cultural values (Fischhoff *et al.,* 1981). Therefore it is important that risk is understood, evaluated and response options determined by those that live with the risk.

Perception of risk involves an intuitive evaluation by an individual or group and perceptions can vary widely between individuals even within the same community. Perception is influenced by a multitude of factors including: educational, acquired knowledge, experience of previous hazards, gender, age etc. and has been the subject of extensive psychological and sociological research (Garrick & Willard, 1991). From a management perspective, it is important that the variability of perception is reduced and that, through education and communication, the margin between reality and perception is narrowed.

A part of landslide risk evaluation is to select risk acceptance criteria. To differentiate, one can use the so-called *'F-N curves'.* The F-N curves relate the annual probability of causing N or more fatalities (F) to the number of fatalities (N). This is the complementary cumulative distribution function. The term "N" can be replaced by any other quantitative measure of consequences, such as monetary measures. Such curves may be used to express societal risk and to describe the safety levels of particular facilities. Figure 1 presents a family of F-N-curves. Man-made risks tend to have a steeper curve than natural hazards in the F-N diagram (Proske, 2004).

It is important to be clear that F-N curves give statistical observations and not the acceptable or tolerable thresholds. It is also important to clarify who defines the levels of acceptance and tolerance for risk: the potentially affected population, a government agency, the design engineer or geoscientist (Lacasse & Nadim, 2006). Societal risk to life criteria reflect the reality that society is less tolerance of events in which a large number of lives are lost in a single event, than if the same number of lives is lost in a large number of separate events. Examples are public concern to the loss of large numbers of lives in airline crashes, compared to the much larger number of lives lost in road traffic or small aircraft accidents (e.g. Alexander, 2000, 2002; in: Lacasse & Nadim, 2006).

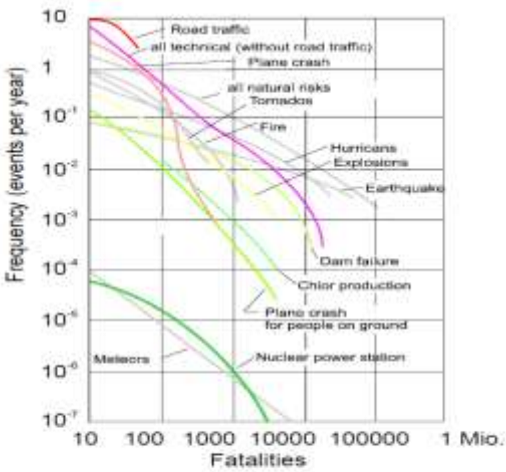

Figure 1: Family of F-N curves by Proske (2006); In: (Lacasse & Nadim, 2006)

Figure 2 presents an example risk criteria for natural hillside, used as an interim recommendation Hong Kong to assist landslide risk management (GEO, 1998). Acceptable risk refers to the level of risk which requires no further reduction. Tolerable risk, on the other hand, presents the risk level which one compromises to in order to gain certain benefits.

A construction within the acceptable risk level requires no action/expenditure for reduction (Lacasse & Nadim, 2006). A construction between the acceptable and tolerable risk level requires proper control and risk reduction if possible. Risks which are above certain threshold (A) are considered to be unacceptable, while below another threshold (B) are regarded as very small and hence acceptable (Lee & Jones, 2004). If the computed risk lies between A and B it should be reduced to an *"as low as reasonably practicable"* (ALARP) level.

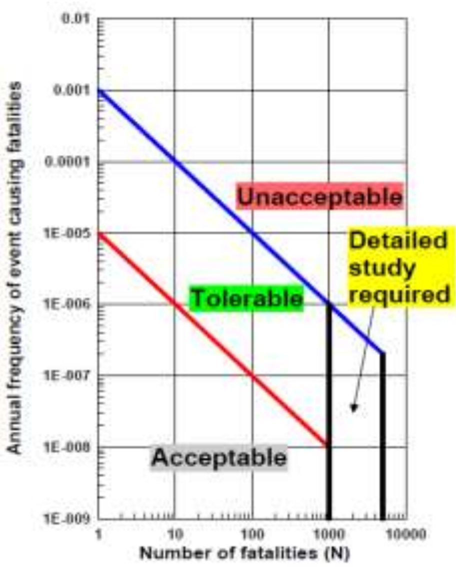

Figure 2: Risk criteria for natural hillsides by GEO (1998)

Table 1 gives risk as qualified for different situations. Risk acceptability depends on several factors such as (Osei *et al.*, 1997): voluntary vs. involuntary situation, controllability vs. uncontrollability, familiarity vs. unfamiliarity, short/long-term effects, existence of alternatives, type and nature of consequences, gained benefits, media coverage, availability of information, personal involvement, memory, and level of trust in regulatory bodies. Voluntary risk levels tend to be higher than involuntary risk levels. Once the risk is under personal control (e.g. driving a car), it is more acceptable than the risk controlled by other parties.

For landslides, natural and engineered slopes can be considered as voluntary and involuntary risk. Societies experiencing frequent landslides may have different risk acceptance level than those experiencing rare landslide situations. Informed societies can have better preparedness for natural hazards (Lacasse & Nadim, 2006).

Table 1: Definitions of "acceptance criteria" for landslides (Lacasse & Nadim, 2006)

No	Risk Qualifier	Definition
1	Acceptable	Level society desires to achieve
2	Tolerable	Level society accepts to live with to secure certain benefits
3	Individual	Imposed on an individual
4	Societal	Imposed to society as a whole
5	Voluntary	Risk voluntarily faced to

		gain benefits
6	Involuntary	Risk imposed by a body
7	Specific	Risk for a specific element
8	Total	Sum of specific risks

II. MATERIALS AND METHODS

A. F-N Curve

Figure 3 shows the F-N curve used in this study. This figure has been modified from GEO (1999) according to local relevance. Based on Figure 3.9, "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.

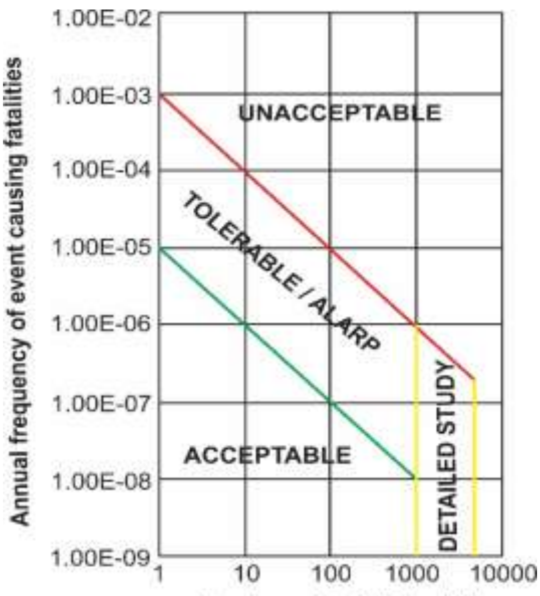

Figure 3: Proposed community risk criteria for landslides in the study area

B. Risk Evaluation Triangle (RET)

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.

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 4). 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.

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.

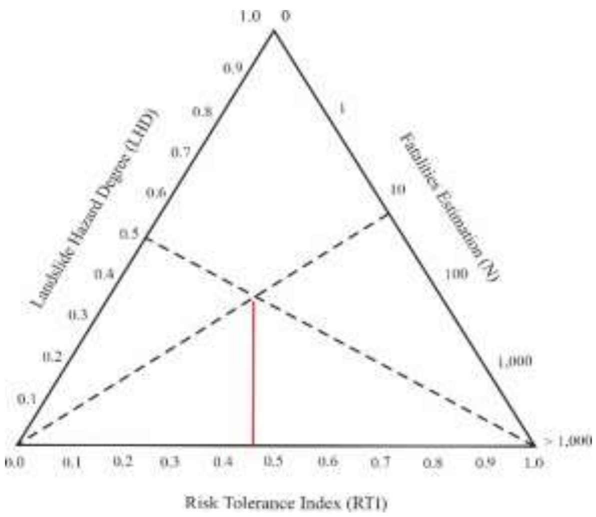

Figure 4: Risk Evaluation Triangle (RET) to assess the level of Risk Tolerance Index (RTI) based on fatalities estimation information.

III. RESULTS AND DISCUSSION

A. F-N Curve Results

Before Landslide Risk Evaluation (LREv) , Sebelum penilaian risiko gelinciran tanah dibuat, the Frequency Analysis (FA) should be conducted first according to Eq. (1) below:

$$\text{Frequency Analysis (FA)} = \frac{\text{Number of incidents } (N_I)}{\text{Number of landslide } (N_L) \times \text{Year } (N_Y)} \quad (1)$$

Number of incidents (N_I) = **61**
Number of landslide (N_L) = **2, 119**
Year (N_Y) = **88**
Number of fatalities (N) = **9**

$$FA = \frac{N_I}{N_L \times N_Y}$$

$$= \frac{61}{2119 \times 88}$$

$$= \mathbf{3.271 \times 10^{-4} \text{ / yearly}}$$

Based on the LREv results on the F-N curve (Figure 5), the risk tolerance level for the Kota Kinabalu area of Sabah is generally categorized as *"ALARP-As Low As Reasonably Practicable"*. The ALARP principle helps us to choose the risk mitigation measures to take. This requires appropriate assessment to determine whether the structural or non-structural approaches chosen can address this problem or not.

People who facing a landslide events frequently have different levels of risk acceptance compared with those who rarely experience landslides. From the point of community risk, the study area is categorized as a society that is willing to live with risks and at the same time acquiring certain benefits.

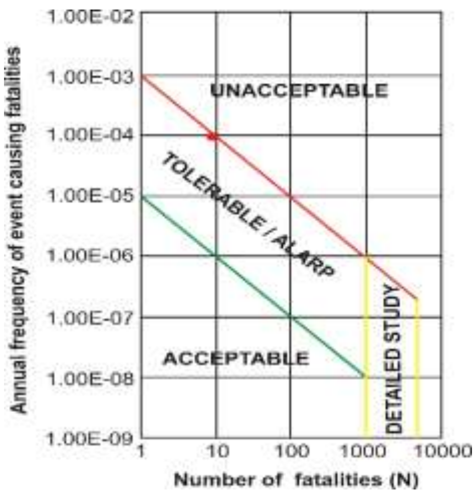

Figure 5: Community risk criteria for landslides in the area of Kota Kinabalu (Regional Studies)

B. Risk Evaluation Triangle (RET) results

The result of LREv will determine the degree of risk tolerance. Based on Figure 4 and 5 it is clear that there are four (4) results states ie: acceptable, unacceptable, ALARP and detailed study. The "acceptable" and "unacceptable" concepts are objective. Meanwhile the concept of "ALARP" and "detailed study" is subjective. ALARP is a condition when the risk level is lower than the tolerance limit. ALARP is acceptable if a risk reduction is practical or its cost is in equilibrium (depending on the level of risk) to achieve the level of remedies.

As a result of the LREv study on the previous F-N curve (Figure 5) shows that there is a constraint in the context of continuity of the proposed method or extension approach for the appropriate Landslide Risk Treatment (LRT) approach. Therefore, to overcome this shortcoming, a diagram known as the "Risk Evaluation Triangle (RET)" was introduced.

RET basically aims to assess the level of Risk Tolerance Index (RTI) quantitatively. Before evaluating the level of RTI, documentation or database development is required. Table 2 below shows the data obtained for the Kota Kinabalu, Sabah area:

Table 2. Databases on Landslide Hazard Assessment (LHAs) and Death Records (N) for Kota Kinabalu, Sabah

No	Description	Very Low Hazard	Low Hazard	Modeartely Hazard	High Hazard	Very High Hazard
1	LHAs value	0.126	0.161	0.231	0.301	0.336
	Death Records (N)	0	0	0	3	6
	Result	**0.05**	**0.08**	**0.12**	**0.22**	**0.29**
Risk Tolerance Index Classification		**Very Low**	**Very Low**	**Very Low**	**Low**	**Low**

Based on the results of the RET model shown in Figure 6 and Table 3, the RTI area of Kota Kinabalu, Sabah is classified as "Very Low" to "Low". The "Very Low" class RTI means its environmental vulnerability is less affected, no physical injury, death or homelessness involved. No cost involved. Based on the level of risk tolerance, the "Very Low" class area is categorized as Tolerance and "ALARP".

The "Low" class RTI means the Environmental vulnerability is slightly affected over a short period of time (several hours to <1 day). Estimates of the population involved in physical injury, death or homelessness are 0 to 5 persons. Estimated cost of loss involved is estimated to be RM 100,000 - RM1, 000,000. Based on the level of risk tolerance, the "Low" class area is categorized as "ALARP".

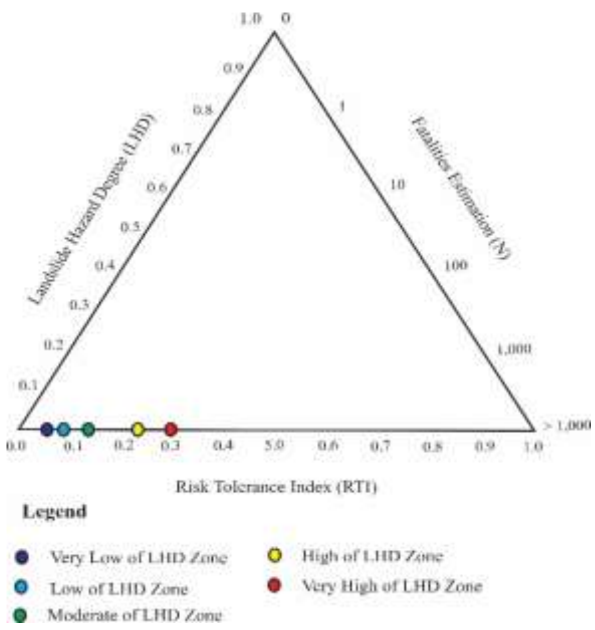

Figure 6. Figure Risk Assessment (RET) diagram to assess the level of Risk Tolerance Index (RTI) based on Landslide Hazard Degree (LHD) and Fatalities Estimation (N)

Table 3. Description of Risk Tolerance Index (RTI) in RET Risk Assessment Triangle

Level	Value	Risk Tolerance Index (RTI)	Description	Level of Risk Tolerance
I	< 0.20	Very Low	Environmental vulnerability is less affected, no physical injury, death or homelessness involved. No cost involved.	Tolerance and ALARP
II	0.21 – 0.40	Low	Environmental vulnerability is slightly affected over a short period of time (several hours to <1 day). Estimates of the population involved in physical injury, death or homelessness are 0 to 5 persons. Estimated cost of loss involved is estimated to be RM 100,000 - RM1, 000,000.	ALARP
III	0.41 – 0.60	Moderate	Environmental vulnerability is slightly affected at a moderate term (> 1 day to <2 weeks). Estimates of the population involved in physical injury, death or homelessness are 5 to 10 persons. The estimated estimated loss cost is estimated to be RM 1,000,000 - RM 10,000,000.	ALARP
IV	0.61 – 0.80	High	Environmental vulnerability is adversely affected over a long period of time (> 2 weeks to month). Estimates of the population involved in physical injury, death or homelessness are 11 to 100 people. Estimated estimated loss losses amounted to RM 10,000,000 to RM 100,000,000.	Unacceptable
V	0.81 – 1.00	Very High	Environmental vulnerability is adversely affected. Estimates of the population involved in physical injury, death or homelessness are above 100 persons and the cost of losses involved is estimated to exceed RM 100,000,000.	Unacceptable and Detailed Study

C. *Development of Landslide Mitigation Method*

The matrix selection for landslide mitigation categories is determined based on Figure 7. Once determined, the selection of landslide mitigation method is conducted by referring to the Table 4. However, Selection and implementation of appropriate options for dealing with risk. Examples of options for mitigation of risks for a slope or group of slopes would include:

1) Reduce the frequency of landsliding – by stabilization measures such as groundwater drainage, slope modification, anchors; or by scaling loose rocks;

2) Reduce the probability of the landslide reaching the element at risk – e.g. for rockfalls, construct rock catch fences; for debris flows construct catch dams.

Dgree of Hazard	Degree of Risk	Very Low	Low	Moderate	High	Very High	Categories
	Very Low	I	I	II	III	III	
	Low	I	II	II	III	III	
	Moderate	II	II	III	III	IV	
	High	III	III	III	IV	IV	
	Very High	III	III	IV	IV	V	

Figure 7. Matrix selection for Landslide mitigation categories

Table 4. Landslide mitigation method

Catego-ries	Mitigation Method	Structural Cost	Non-Structural Cost
I	Accept and modify the risk	High	Moderate
II	Modify and reduce the risk	Very High	High
III	Reduce the risk, risk monitor and postpone the results	Very High	Very High
IV	Risk monitor, postpone the results and ignore the risk	High	Moderate
V	Postpone the results, ignore the risk and risk transfer	Moderate	Moderate

IV. CONCLUSION

In light of available information, the following conclusions may be drawn from this study:

a. Landslide Risk Evaluation (LREv) is a decision-making process on Landslide Risk Analysis (LRAn) results. This process determines whether the inherent risks are acceptable, tolerant, unacceptable or require detailed study. LREv also involves consideration of risk perceptions, risk communication and risk comparisons aimed at developing appropriate steps or forms of response.

b. Landslide Risk Evaluation (LREv) involves consideration of risk perceptions, risk communication and risk comparisons aimed at developing appropriate steps or forms of response. It is direct and indirect to offset risks with benefits associated with risk exposure. The finding of the LREv study using the "F-N" curve and the RET Assessment Segment (RET) diagram in this study found that the Risk Tolerance Index (RTI) of the study area was classified as "Very Low" to "Low".

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