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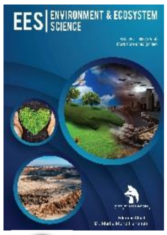

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RESEARCH ARTICLE

LANDSLIDE VULNERABILITY ASSESMENT (LVAs) IN LUYANG AREA, KOTA KINABALU, SABAH, MALAYSIA

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ABSTRACT

Landslide issues in Malaysia is successfully attract the interest and attention of stakeholders and the community of scientists to reduce the risk. Landslides are influenced by many factors that range from the intensity, duration and extent of a triggering factor (e.g. earthquake and rainfall) to the local physical conditions such as landform, morphological, geological materials and structures, hydrological and land uses. In this paper, we present the results of the Landslide Vulnerability Assessment (LVAs). Vulnerability is defined as the degree of losses of a given element at risk of being exposed to the occurrence of a landslides of a given magnitude or intensity, and often expressed on a scale of 0 (no loss) to 1 (total loss). The selection of the best LVAs depends on the exposed elements, landslide types and the scale of analysis. The concept of LVAs also refers to the feasibility of elements at risks on engineering structures, infrastructure facilities, communication systems, commercial (including insurance disclosures) and social. The vulnerability parameters include in assessing LVAs in this study are 1) physical implication (building structures, internal materials, property damage, infrastructural facilities and stabilization actions), social status (injury, fatalities, safety, loss of accommodation and public awareness) and interference on environment (affected period, daily operation & diversity). LVAs for study area produced by combining or overlaid of all Physical Vulnerability (Vp), Social Vulnerability (Vs) and Environmental Vulnerability (Ve) maps. The results for the Total of LVAs indicates that 30% (0.90 sq.m) of the study area classified as Very Low, 8% (0.24 sq.m) as Low, 8% (0.24 sq.m) as Moderate, 28% (0.84 sq.m) as High, 8% (0.24 sq.m) as Very High and 18% (0.54 sq.m) as Extremely High. Landslide Vulnerability level at a "high" to "very high" degree can leave an impact on individuals and society. This study found that residential, commercial, public and industrial infrastructure has higher vulnerability rather than the agricultural and forestry areas. This LVAs approach is suitable as a guideline for preliminary development planning, control and manage the landslide hazard / risk in the study area and potentially to be extended with different background environments.

KEYWORDS

Landslide Vulnerability Assessment (LVAs), Elements at Risk & Kota Kinabalu

1. 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 attract 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.

Vulnerability concept was developed in the context of natural disasters research over the last 30 years; this means that the more days it is becoming increasingly diverse. The explanation for this wide diversity also being doubled and takes the relationship between the human and natures which was triggered by issues of dynamic, multi-dimensional and multi-scalar such as globalization and climate change or the global environment (Rodeano and Tajul, 2012; Rodeano et al., 2017). Due to the absence of border globalization, the various disciplines which differ in their background have defined some sense of vulnerability and as a result there are many mixed methodology and conceptualization of vulnerability (Aleotti and Chowdhur, 1999). Since the early 1980s, have indicates that the term "vulnerability" which not only covers the areas of natural disasters, but also applied in other fields such as business, psychology or health society (Timmerman, 1981; Fuchs et al., 2007).

Landslide Vulnerability Assessment (LVAs) references can be found in very much quantities. LVAs studies is depends on (a) a runoff; (b) the volume and velocity of slides; (c) risk elements (properties) such as buildings and other infrastructure facilities (nature and proximity against

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slippage); and (d) elements at risk (life) as humans (vulnerability to disasters, the situation and their position in the building/road) (Figure 1) (Finlay, 1996; Dai et al., 2002).

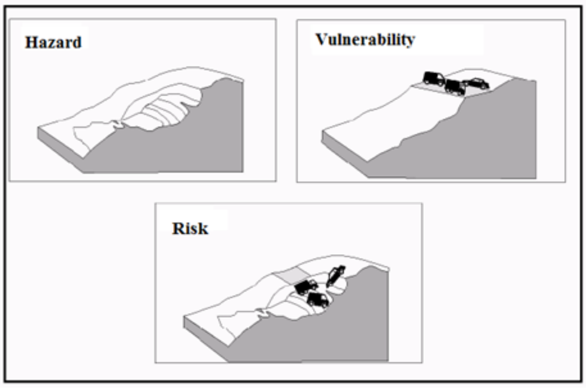

Figure 1: Vulnerability conceptual distinction with hazard and risk in the Landslide Risk Management Research (Source: Varnes and the AEG Commission on Landslide, 1984)

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 and 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 and Hartford 1997; Glade 2003).

The ultimate goal of LVAs 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 and Glade, 2005). 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 LVAs 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 vulnerability which depend on locations and on scales in which the assessment is carried out. Taking into account the importance and characteristics for Disaster Risk Reduction (DRR), the investigations on LVAs has increased enormously in the last decade.

2. Background of The Study Area

Rapid economic development in Luyang area, Kota Kinabalu, Sabah, Malaysia resulted in further pressure to utilize the slope land for various purposes such as recreation, infrastructure and human settlements (Figure 2).

2.1 Topography and Hydrology

The elevation in the study area can be divided into two main areas: lowland (<10 m) and highland areas (> 11m) (Figure 3). Almost 52% (1.56 sq.km) of the study area consists of lowland areas which concentrated in the eastern and western parts of the study area with little hills. The eastern part of the ridge is relatively steeper slope than on the western side. This region includes the alluvial plains and areas which have undergone a process of cut and fill slopes activities for urbanization, housing, manufacturing and others infrastructure construction. Highland areas covered about 48% (1.44 sq.km) of the entire study area. This area is part of the Crocker Formation that forms a ridge nearly parallel to the strike of the bedding planes at the northeast-southwest of the study area. Highland areas most widespread has changed from its original height due to the activities of urbanization. There are several residential areas (villages) built in this area. Infrastructure and utilities are very limited and not as good as lowland areas.

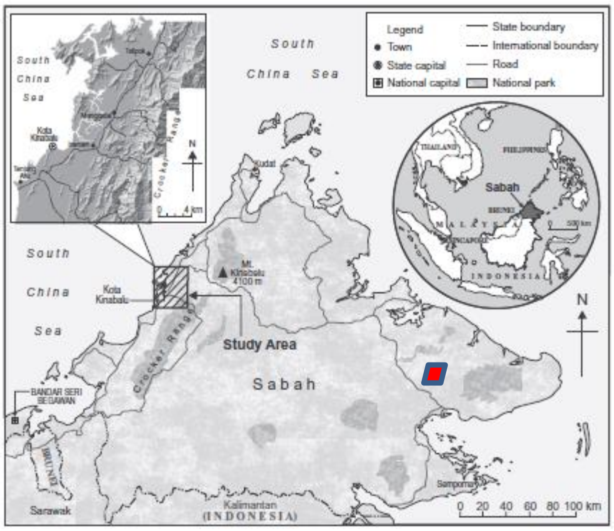

Figure 2: Location of the study area

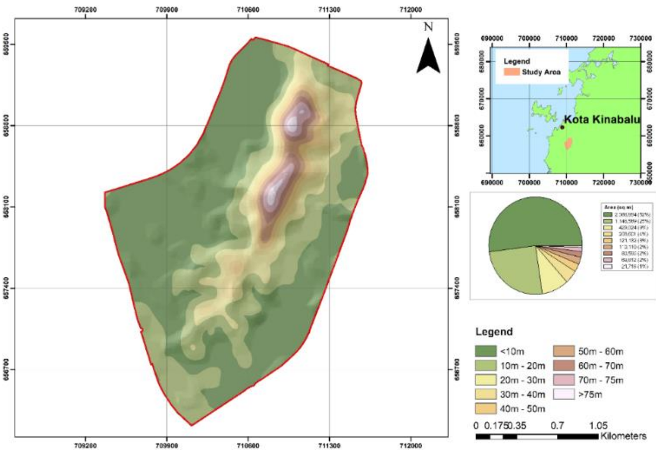

Figure 3: The terrain elevation and topography of the study area

Elevation influences to landslide are often displayed as indirect relationships or by means of other factors. In the study area, the weathering factor that plays an important role in landsliding, is closely related with elevation. At higher elevation, more erosion occurs leading to lesser weathering depth. Because the region has a tropical monsoon climate, where erosion and weathering processes are intense, they strongly affect the influence of elevation on landslides.

There is no permanent stream within the study area. However there are a few seasonal streamlets on both side of the ridge. Potential runoffs from higher elevation on the eastern and western parts of the ridge would be flowing into the lowland area at the perimeter of the existing residential and shoplots area about 1-2 km away.

2.2 Landuse

Landuse activities plays a very important role in landslide mechanisms. In this study, seven types of landuse are considered: Public (2%) (0.06 sq.km), Industrial (11%) (0.33 sq.km), Infrastructure (1%) (0.03 sq.km), Residential (41%) (1.23 sq.km), Commercial (8%) (0.24 sq.km), Forest/Barren (36%) (1.08 sq.km) and Utilities (1%) (0.03 sq.km) areas (Figure 4). The study area has been explored more than 60% for development activities. Construction activities of commercial and residential buildings as well as the extension of agricultural areas are increasingly spreading to high-tech areas. In areas with bare hills or shrubs, the soil stability strongly reduces due to lack of root cohesion, and increase possibly of a soil moisture, etc. Therefore, erosion processes are enhanced, increasing local landslide hazards. Hence, the areas with shrubs and bare hills in the study region are very favorable for landsliding. The uncontrolled development also involves direct slope cutting activity in the study area. This situation can increase the level of landslide vulnerability and hazard in the study area.

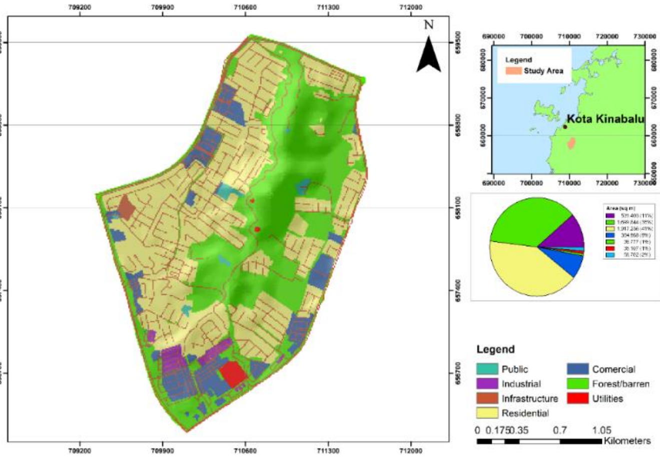

Figure 4: The landuses within and adjacent to the study area

2.3 Geology

The study area comprises of two main lithological units which are the Crocker Formation and the Quaternary deposits (Figure 5). The Crocker Formation consists of grey sandstones and various coloured shales aged from Oligocene to Miocene. The thickness of this formation is estimated to be not less than 6,000 m. From the regional study, the layered nature of the sandstone and shale of the Crocker Formation in the study area are oriented between N340E to N035E and show steep dips (55-85 degrees) eastward (Rodeano et al., 2006, 2011, 2017; Rodeano 2019). The Crocker Formation. The Crocker Formation are dissected by numerous lineaments with complex structural styles developed during series of regional Tertiary tectonic activities. The tectonic complexities reduced the physical and engineering properties of the rock masses and produced intensive displacements and discontinuities among the strata, resulting in high degree of weathering process and instability. The weathered materials are unstable and may cause subsidence, sliding and falling induced by high pore pressure subjected by both shallow and deep hydrodynamic processes (Rodeano and Felix, 2018a; 2018b & 2018c).

Meanwhile, at the low plain area is underlain by Quaternary deposits is a terrace deposit which composed of coarse gravel in most outcrops. The alluvium was deposited along the riverside and flood-plain areas. Quaternary deposits is typically made up of a variety of materials, including fine particles of silt and clay and larger particles of sand and gravel. When this loose alluvial material is deposited or cemented into a lithological unit, or lithified, it would be called an alluvial deposit (Rodeano and Felix, 2018a; 2018b & 2018c). Due to the tropical climate, weathering generally extends to great depth in these rocks and the top portions are usually weathered into residual soil. The residual soil is composed of silt, clay and sometimes sand, depending on the degree of weathering and type of sedimentary rock (Rodeano and Tajul, 2012; Rodeano et al., 2017).

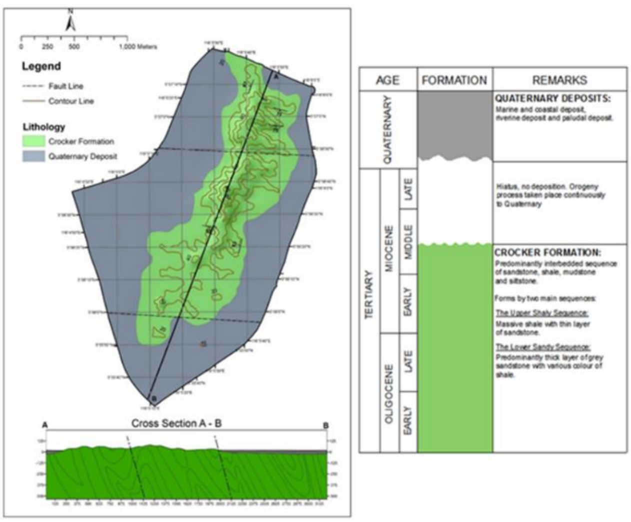

Figure 5: The geology map and stratigraphic setting of the study area

3. Material and Methods

Vulnerability concept is often associated with the magnitude of the landslide depends on their propagation distance, volume and velocity of slides, and the risk elements (property and life) are involved. Loss of property is evaluated based on the relative damage to the property value involved. Human vulnerability refers to the probability that the number of victims whether alive or dead. Based on Figure 6, the first step begins with a literature review and gathering landslide hazard information based on the secondary data. The combination of literature information and the secondary data is to produce the Landslide Risk Element Identification (LREI). Identification of causal factors of landslide was done in areas were identified as having high of Landslide Hazard Degree (LHD). Based on a combination of LREI (property and life) with vulnerability parameters, a database created and LVAs parameters were listed. The vulnerability parameters includes:

1. Physical implication (building structures, internal materials, property damage, infrastructural facilities and stabilization actions);
2. Social status (injury, fatalities, safety, loss of accommodation and public awareness); and
3. Interference on environment (affected period, daily operation & diversity).

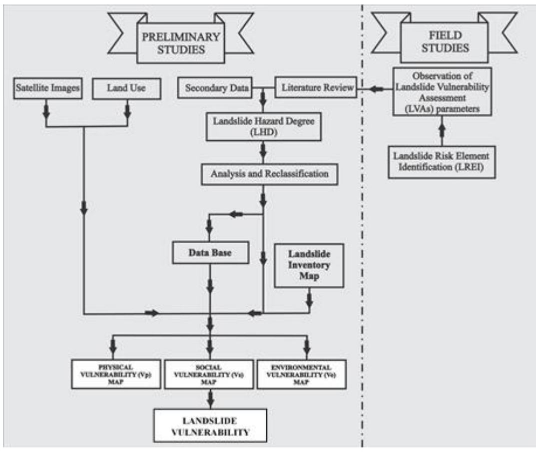

Figure 6: Landslide Vulnerability Assessment (LVAs) methods (Rodeano, 2015)

4. Results and Discussion

4.1 Landslide Vulnerability Analysis (Physical) (Vp)

Physical Vulnerability (Vp) in this study involves the assessment of damage or destruction of the building structure, internal equipment, damage to property, infrastructure and stabilization measures. The proportion of Vp depending on the nature of the risk element is exposed, the mechanism of landslide and the level of danger, building structure, building materials used, the basic structure of the system, the size and shape of the elements of risk and long-life used. Similar damage assessment Vp can be estimated using vulnerability coefficient varying between 0 (no damage) to 1 (total destruction). The results of the study area for Vp indicates that 20% (0.60 sq.m) of the total area classified as Very Low, 10% (0.30 sq.m) as Low, 10% (0.30 sq.m) as Moderate, 8% (0.24 sq.m) as High, 26% (0.78 sq.m) as Very High and 25% (0.75 sq.m) as Extremely High (Figure 7). The details of Vp are described in Table 1.

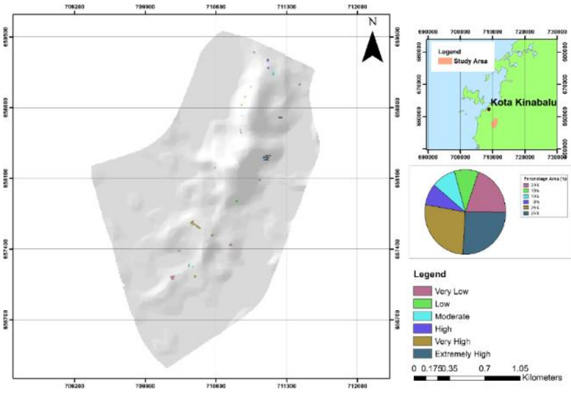

Figure 7: Physical Vulnerability (Vp) Map

Table 1: Characteristics of Physical Vulnerability (Vp) (Rodeano, 2015)

Index Value	Class	Classification	Description
< 0.21	I	Very Low Vulnerability	No damage to building structure, interior equipment, property or infrastructure facilities. Stabilization action is very satisfying.
0.21 – 0.40	II	Low Vulnerability	Small damage to building structures, interior equipment, property or infrastructure facilities that do not require immediate repair work. Stabilization action is satisfactory.
0.41 – 0.60	III	Moderate Vulnerability	Moderate damage to building structures, internal equipment, property or infrastructure facilities can still be improved. Stabilization action is simple.
0.61 – 0.80	IV	High Vulnerability	Serious damage to building structures, internal equipment, property or infrastructure facilities that are difficult to repair. Stabilization action is not satisfactory.
> 0.80	V	Very High Vulnerability	Full damage to the structure of buildings, interior equipment, property or infrastructure that can't be inhabited. Stabilization action is very unsatisfactory.

4.2 Landslide Vulnerability Analysis (Social) (Vs)

Social Vulnerability (Vs) in this study involves the assessment of the level of injury, death, salvation, homeless and public awareness vulnerability population exposed to landslide. The proportion Vs involves consideration of the potential or actual victims as a unit. The results of the study area for Vs indicates that 20% (0.6 sq.m) of the total area classified as Very Low, 65% (1.95 sq.m) as Low, 25% (0.75 sq.m) as Moderate and 2% (0.06 sq.m) as High (Figure 8). The details of Vs are described in Table 2.

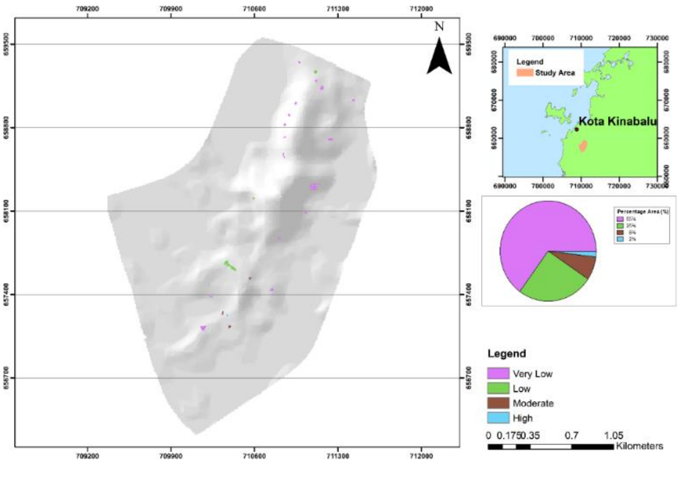

Figure 8: Social Vulnerability (Vs) Map

4.3 Landslide Vulnerability Analysis (Environment) (Ve)

Environment Vulnerability (Ve) in this study involves the assessment of the duration of the repair, diversity and daily operations. Environment Vulnerability (Ve) is basically very difficult to implement. For example, the destruction of part or the whole of the agricultural and forestry sectors cannot be measured only in terms of the value of the lost timber, but should be evaluated and analyzed in the context of the increasing potential damage generated. The destruction of the natural environment caused by landslide also involves impairment of plant or animal species habitat. Long-term damage in the agricultural and forestry sector due to fire could also be contributing to the decline in the productivity. The results of the study area for Ve indicates that 16% (0.48 sq.m) of the total area classified as Very Low, 28% (0.84 sq.m) as Low, 28% (0.84 sq.m) as Moderate, 4% (0.12 sq.m) as High, 20% (0.60 sq.m) as Very High and 2% (0.06 sq.m) as Extremely High (Figure 9). The details of Ve are described in Table 3.

Table 2: Characteristics of Social Vulnerability (Vs) (Rodeano, 2015)

Index Value	Class	Classification	Description
< 0.21	I	Very Low Vulnerability	No resident involved.
0.21 – 0.40	II	Low Vulnerability	No physical injury, death or homelessness. The safety and public awareness of the population is at a high level.
0.41 – 0.60	III	Moderate Vulnerability	The population can still live in and perform daily activities even though there are few cases of physical injury or homelessness (<5%). The public safety and awareness are at a moderate level.
0.61 – 0.80	IV	High Vulnerability	Involves a moderate number of injuries, deaths or homelessness (<20%). The public safety and awareness of the population is at a low level.
> 0.80	V	Very High Vulnerability	Involves large numbers of injuries, deaths or homelessness (> 20%). The security and public awareness of the population is at a very low level.

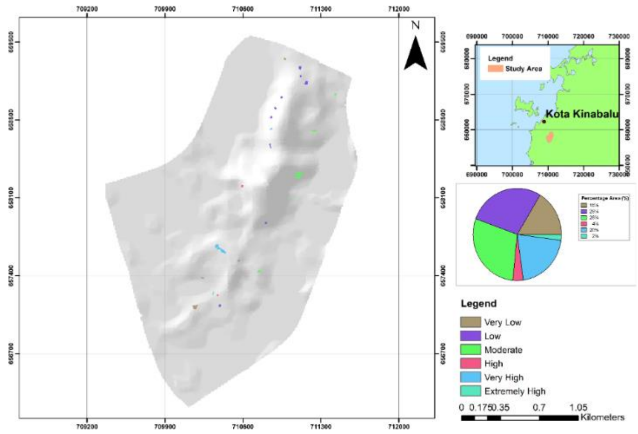

Figure 9: Environmental Vulnerability (Ve) Map

Table 3: Characteristics of Environmental Vulnerability (Ve) (Rodeano, 2015)

Index Value	Class	Classification	Description
< 0.21	I	Very Low Vulnerability	Unaffected.
0.21 – 0.40	II	Low Vulnerability	It is affected by a short period of time (several hours to <1 day) and involves <10% of the diversity affected.
0.41 – 0.60	III	Moderate Vulnerability	It is affected at a moderate (> 1 day to <2 weeks) and involves 11% - 20% of the diversity affected.
0.61 – 0.80	IV	High Vulnerability	Affected for a long time (> 2 weeks to months) at the level of physical susceptibility and involves 21% - 30% of the diversity affected.
> 0.80	V	Very High Vulnerability	Infected permanently and involve> 30% of the diversity affected.

4.4 Total Landslide Vulnerability Analysis

Total Landslide Vulnerability Assessment (LVAs) for study area produced by combining or overlaid of all Vp, Vs and Ve maps. The results of the study area for total LVAs indicates that 30% (0.90 sq.m) of the total area classified as Very Low, 8% (0.24 sq.m) as Low, 8% (0.24 sq.m) as Moderate, 28% (0.84 sq.m) as High, 8% (0.24 sq.m) as Very High and 18% (0.54 sq.m) as Extremely High (Figure 10). Total LVAs at a "high" to "very high" degree can leave an impact on individuals and society. Based on follow-up observation and confirmation of results that have been conducted in the field, residential, commercial, public and industrial infrastructure has higher vulnerability rather than the agricultural and forestry areas. It is because most of the population are concentrated in the three regions. Measurement were taken to reduce the level of landslide vulnerability in the study area is to be more complex and difficult for many parties involved have to deal with it. Although the effects of hazards in the study area can be overcome, but the impact of large vulnerability may exist when exposure parameters vulnerability risk continues to rise and adaptation capacity continues to decline.

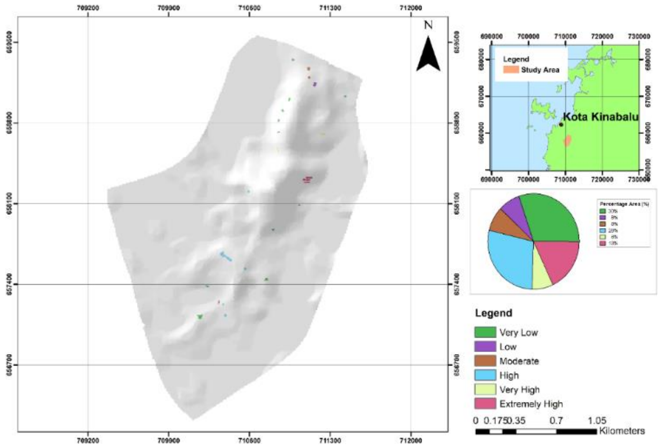

Figure 10: Total Landslide Vulnerability Assessment (LVAs) map of the study area

5. Conclusion

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

1. The results of the study area for Total LVAs indicates that 30% (0.90 sq.m) of the total area classified as Very Low, 8% (0.24 sq.m) as Low, 8% (0.24 sq.m) as Moderate, 28% (0.84 sq.m) as High, 8% (0.24 sq.m) as Very High and 18% (0.54 sq.m) as Extremely High. Landslide Vulnerability at a "high" to "very high" degree can affect the economy and the daily activities of the population.
2. Residential, commercial, public and industrial infrastructure has higher vulnerability rather than the agricultural and forestry areas. It is because most of the population concentrated in this three regions.
3. This Landslide Vulnerability Assessment (LVAs) approach is suitable as a guideline for preliminary development planning, control and manage the landslide hazard / risk in the study area and potentially to be extended with different background environments.

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