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Landslide Vulnerability Assessment (LVAs): A Case Study from Kota Kinabalu, Sabah, Malaysia

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Abstract - The topic on Landslide Vulnerability Assessment (LVAs) in Malaysia is relatively new and received little attention from geoscientists and engineers. This research paper tries to formulate the concept of LVAs by taking into account the science and socio-economic aspects. A new approach in vulnerability concept is also introduced herein. To achieve this goal, a framework was designed for assessing the LVAs. The framework was formulated semiquantitatively through the development of database for the risk elements (human and properties) based on information from secondary data (technical reports), extensive review of literature, and field observations. The vulnerability parameters included in assessing LVAs are 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, and diversity). Each considered parameter in the vulnerability assessment is allocated with a certain index value ranges from 0 (0 % damage/victims/period), 0.25 (1 - 25% damage/victims/period), 0.50 (26 - 50% damage/victims/period), 0.75 (51 - 75% damage/victims/period), and 1.00 (75 - 100% damage/victims/period). All of these parameters are compiled and analyzed with "Landslide Distribution Map" (LDM) to generate a "Landslide Vulnerability Degree map (LVD)". The LDM was produced based on field studies and satellite image interpretations in order to locate the landslide locations in the studied area. Finally, three types of physical, human, and environment vulnerabilities were then classified into five classes of vulnerabilities, namely: Class 1 (< 0.20): Very Low Vulnerability; Class 2 (0.21 - 0.40): Low Vulnerability; Class 3 (0.41 - 0.60): Medium Vulnerability; Class 4 (0.61 - 0.80): High Vulnerability); and Class 5 (> 0.81): Very High Vulnerability. Results from this study indicate that a further study is needed to the areas of high to very high vulnerability only. This LVAs approach is suitable as a guideline for preliminary development planning, controlling, and managing the landslide hazard /risk in the studied area and potentially to be extended with different background environments.

Keywords: vulnerability, risk elements, landslide risk management, Malaysia

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Introduction

Vulnerability is defined as the potential degree of loss (damage) to a given element or risk elements resulting from the occurrence of a natural phenomenon of a given magnitude. Vulnerability is expressed on a numerical scale from 0 (no damage) to 1 (total damage), and it depends on the intensity of the landslide that occurred (Anonymous, 2007; Anonymous, 2011a).

Vulnerability concept was developed in the context of natural disaster researches over the last thirty years. This means that the more days it is becoming increasingly diverse. The explanation for this wide diversity is also being doubled and takes the relationship between the human and natures which was triggered by dynamic, multidimensional, and multiscalar issues such as the globalization and climate change or global environment (Roslee and Jamaluddin, 2012). Due to the absence of border globalization, various disciplines which differ in their background have defined some senses of vulnerability (Cutter, 1996; Aleotti and Chowdhury, 1999), and as a result there are many mixed methodology and conceptualization of vulnerability. Since the early 1980s, Timmerman (1981; *in*: Fuchs *et al*., 2007) indicates that the term "vulnerability" does not only cover the areas of natural disasters, but it is also applied in other fields such as business, psychology or health society.

Landslide Vulnerability Assessment (LVAs) references can be found in very much quantities. LVAs concept 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 slippage); and (d) elements at risk (life) as humans (vulnerability to disasters, the situation and their position in the building/road) (Finlay, 1996; *in* Dai *et al*., 2002) (Figure 1).

How people perceived LVAs approach depends on many factors: social (Blaikie *et al*., 1994; Slovic *et al*., 2004; Jóhannesdóttir and Gisladottir, 2010), psychology (Pidgeon *et al*., 1992; Blaikie *et al*., 1994; Jóhannesdóttir and Gisladottir, 2010), economy (Jóhannesdóttir and Gisladottir, 2010), culture (Boholm, 1998; Sjöberg, 2000), and environment (Mileti, 1994; Haynes *et al*., 2008; Jóhannesdóttir and Gisladottir, 2010), or a combination from all of those factors (Alexander, 2005; Jóhannesdóttir and Gisladottir, 2010). Furthermore, residents or other risk elements also have a threat of damages and

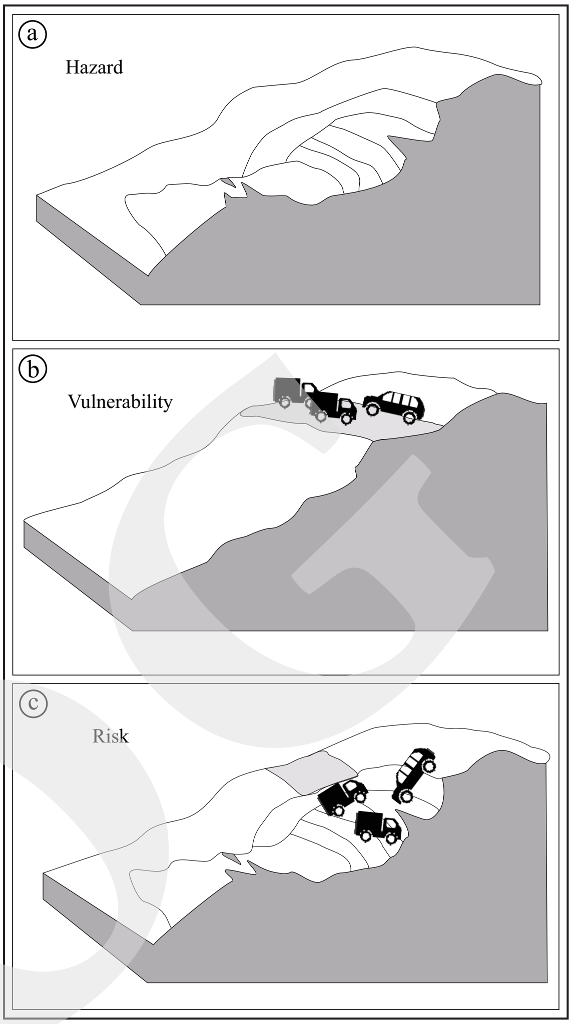

Figure 1. Vulnerability conceptual distinction with hazard and risk in the Landslide Risk Management Research (Source: Varnes and the AEG Commission on Landslide, 1984).

losses due to factors mentioned above. In this connection, LVAs can raise awareness in determining the loss of an area to arrive at a higher level than the disaster itself.

Studied Area

Kota Kinabalu, Sabah, Malaysia (Figure 2), has emerging and growing population. Kota Kinabalu area is proposed to be used as a pilot study for Landslide Vulnerability Assessment (LVAs). The impact of rapid development in the studied area had led to slope cutting activities and increasingly spread to the hilly terrain. Therefore, LVAs research should be developed and

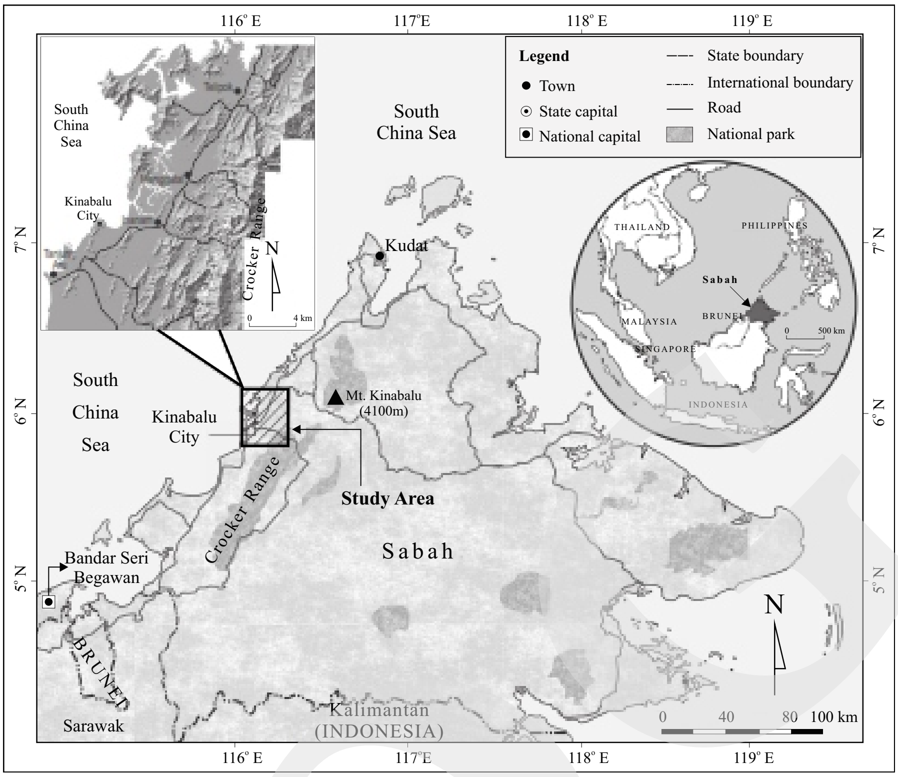

Figure 2. Locality map of the studied area.

implemented for the preliminary development planning, controlling, and managing the landslide hazard/risk in the studied area.

The increment in the population growth rate in Kota Kinabalu is estimated to increase around 25.6% to 36.6% per 10 years (Anonymous, 2008a; 2009). This information indicates that the element of risks (population, vehicles, infrastructure, and property) exposed to vulnerability of landslide also increases.

The rapid development in the studied area is expected to continue. The development of the area began to grow southwestward of Kota Kinabalu in 1978, and right up to the north in the era of 2010 (Figure 3). Most of the forest area has been exploited for the purpose of agricultural development activities. This phenomenon can be proved by the change of forest or farm land area which degraded each year from 81% in 1978, 71% in 1994, 65% in 2010, and 54% in 2012. Figure 4 shows the changing part of the studied area (Bukit Kepungit, Kepayan) from 1978 to 2010.

Sabah Public Work Department (Anonymous, 2008b) has identified a total of six hundred slopes are problematic in Sabah, Malaysia. To address this problem, the government needs funding nearly RM 920 million (Anonymous, 2011b). From 1973 to 2007, Malaysia is estimated to have incurred a loss of RM 2.55 billion due to landslide occurrences (Anonymous, 2011b). This condition indirectly gives a negative impact on society and socio-economic development (Figure 5) (Roslee *et al.*, 2011).

Material and Methods

Vulnerability concept is often associated with the magnitude of the landslide , and it depends on their propagation distance, volume and velocity of slides, and the risk elements (property and life) which are involved. Loss of property is evaluated based on the relative damage to the property value involved. Human vulnerability refers to the probability which is the number of victims, whether alive or dead.

Landslide Vulnerability Assessment (LVAs) involves observation information about the types

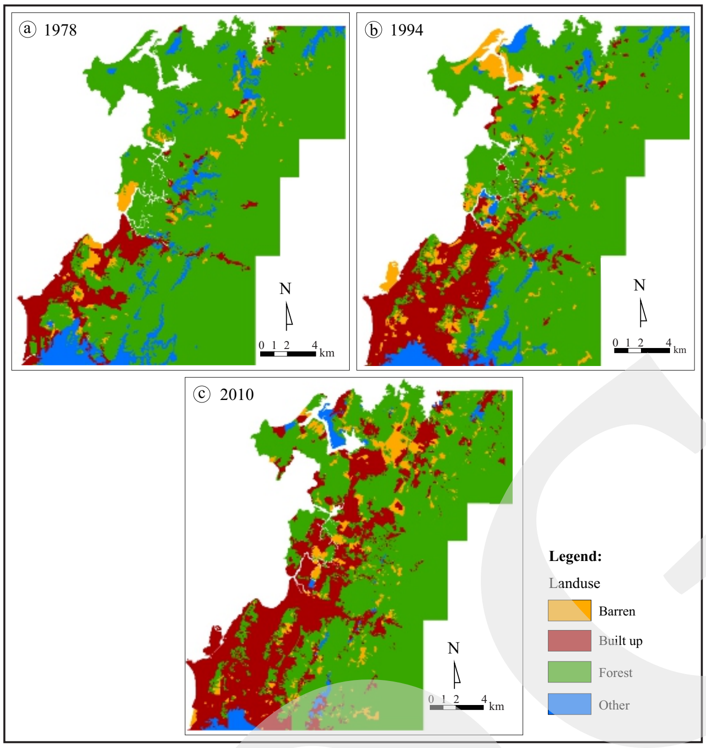

Figure 3. Different types of land use in three different years (1978, 1994, and 2010) in the studied area (Sources from Norbert, 2012).

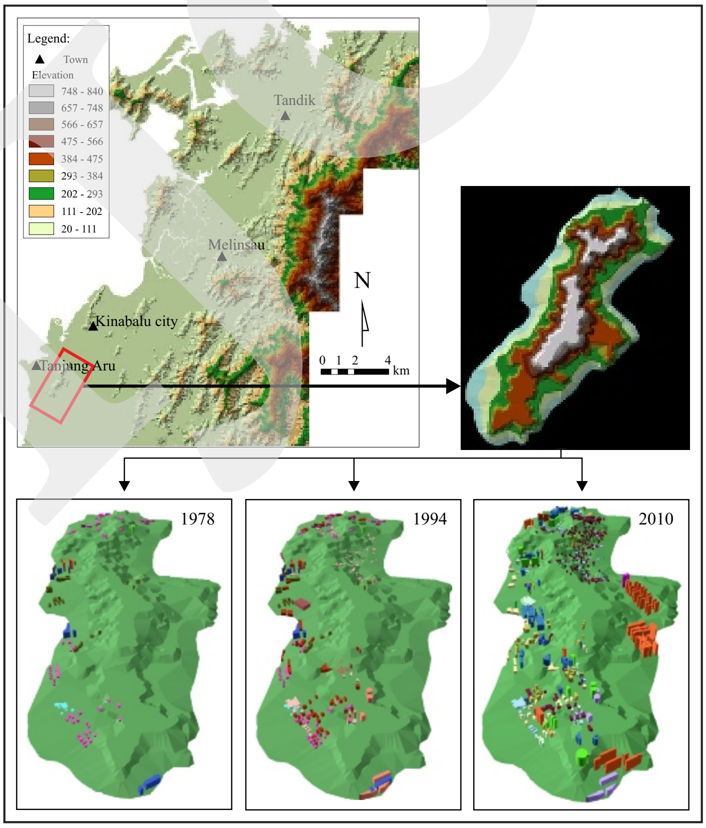

Figure 4. Changes in land use and development for three different years (1978, 1994, and 2010) in Bukit Kepungit, Kepayan, Kota Kinabalu (digitized from aerial photographs) (Sources from Norbert 2012).

Figure 5. Some cases of landslide in Kota Kinabalu, Sabah. (a) Kampong Lok Bunoq Sepangar; (b) Simpang Karambunai Resort Sepangar; (c) Jalan Shantung Luyang; (d) Jalan Bantayan Penampang; (e) Taman Fantasy Likas; (f) Jalan Bukit Bendera Likas; (g) Jalan Penampang Minitod; and (h) Taman Winley Kepayan.

of landslide and how its impact can cause damage at different levels. In most literature, LVAs is often associated with expert judgment. This is because most of the existing information is usually incomplete due to lack of data or constraints of data access.

Based on a literature review conducted, there has not been any consensus approach that can be used as appropriate standards and applied effectively for LVAs in Malaysia. Therefore, a reasonable and more practical workflow has been designed to suit the local conditions (Figure 6).

LVAs is taking into account several parameters such Physical Vulnerability (Vp), Social Vulnerability (Vs), and Environment Vulnerability (Ve). These data are collected through field observa-

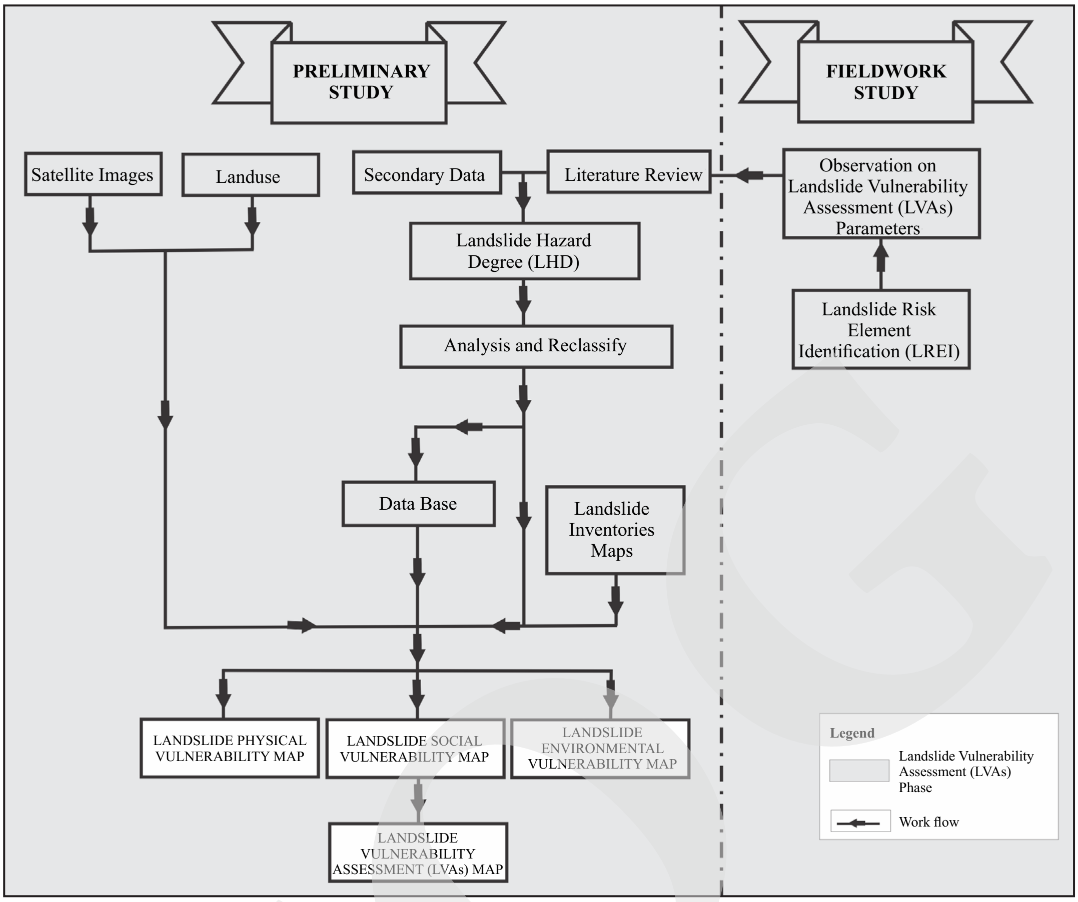

Figure 6. Landslide Vulnerability Assessment (LVAs) methods.

tions, compiling landslide occurrence records, and secondary data. Based on Figure 4, the first step begins with a literature review and gathering landslide hazard information based on the secondary data such as technical report from the local authority, government agencies and companies. The combination of literature information and the secondary data is to produce the Landslide Risk Element Identification (LREI).

The identification of causal factors of the landslide was done in areas identified as having high Landslide Hazard Degree (LHD). Based on a combination of LREI (property and life) with vulnerability parameters, a database was created and LVAs parameters were listed (Figure 6). The vulnerability parameters include:

(a). Physical implication (building structures, internal materials, property damage, infrastructural facilities, and stabilization actions);

(b). Social status (injury, fatalities, safety, loss of accommodation, and public awareness); and

(c). Interference on environment (affected period, daily operation, and diversity).

Each considered parameter in the vulnerability assessment is allocated with a certain index value ranges from 0 (0 % damage/victims/period), 0.25 (1 - 25% damage/victims/period), 0.50 (26 - 50% damage/victims/period), 0.75 (51 - 75% damage/victims/period), and 1.00 (75 - 100% damage/victims/period). This step intended to generate values for each parameter LVAs proportions.

The next step is to observe the data fields for each vulnerability parameter sets. These data are then reanalyzed based on Standardization Method introduced by Voogd (1983). This method aims to rescale the field data by the Linear Transform Numerical (LTN) approach which starts from the 0.00 to 1.00 by applying the following equation:

$$\text{Standardization Method} = \frac{\text{Raw data}}{\text{Raw data Maximum}} \quad ... (1)$$

Three types of physical, human, and environment vulnerabilities were then classified into five classes of vulnerabilities, namely:
(a). Class 1 (< 0.20): Very Low Vulnerability;
(b). Class 2 (0.21 - 0.40): Low Vulnerability;
(c). Class 3 (0.41 - 0.60): Medium Vulnerability;
(d). Class 4 (0.61 - 0.80): High Vulnerability; and
(e). Class 5 (>0.81): Very High Vulnerability.

All of these vulnerability parameters are compiled and analyzed with "Landslide Distribution Map" (LDM) in order to generate three types of Landslide Vulnerability Map (LVM), namely:
(a). Physical Vulnerability Map;
(b). Social Vulnerability Map; and
(c). Environment Vulnerability Map.

The generation of all the maps mentioned above is conducted by the Geostatistical-Kriging Interpolation Technique (GEOSTAINT-K) introduced by Roslee *et al*. (2012). GEOSTAINT-K is the characteristic points in the geostatistical calculations. The goal of this model is to determine the probability variables for each location which may not be identifiable or has no data. The approach is in GEOSTAINT-K uses the geostatistical interpolation.

Finally, Landslide Vulnerability Map (LVM) for Kota Kinabalu, Sabah, was generated by the combination of the Physical, Social, and Environment Vulnerabilities Maps.

Results and Discussion

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 depends on the nature of the risk element exposed, the mechanism of landslide and the level of danger, building structure, building materials used, the basic structure of the system, the size and the shape of elements of risk and long-life used. The similar damage assessment Vp can be estimated using vulnerability coefficient varying between 0 (no damage) to 1 (total destruction). The results of the Kota Kinabalu Vp indicate that 8.49% of the total area is classified as Very Low, 10.28% as Low, 50.18% as Moderate, 29.07% as High, and 1.98% as Very High (Figure 7).

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 Kota Kinabalu Vs indicate that 10.39% of the total area is classified as Very Low, 17.43% as Low, 25.47% as Moderate, 8.41% as High, and 38.29% as Very High (Figure 8).

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 can not be measured only in terms of the value of the lost timber, but it 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 Kota Kinabalu Ve indicate that 6.36% of the total area is classified as Very Low, 12.10% as Low, 57.60% as Moderate, 23.6% as High, and 2.86% as Very High (Figure 9).

Landslide Vulnerability Assessment (LVAs) for Kota Kinabalu, Sabah, was produced by combining or overlaid of all Vp, Vs, and Ve maps. Figure 10 proposes 17.78% of the total area is classified as Very Low, 6.25% as Low, 28.56% as Moderate, 11.08% as of High, and 17:53% as Very High.

Landslide Vulnerability at a "high" to "very high" degree can leave an impact on individuals and society. If the vulnerability level received only involves individuals, the level of the vulnerability is not a great hazard. On the other hand,

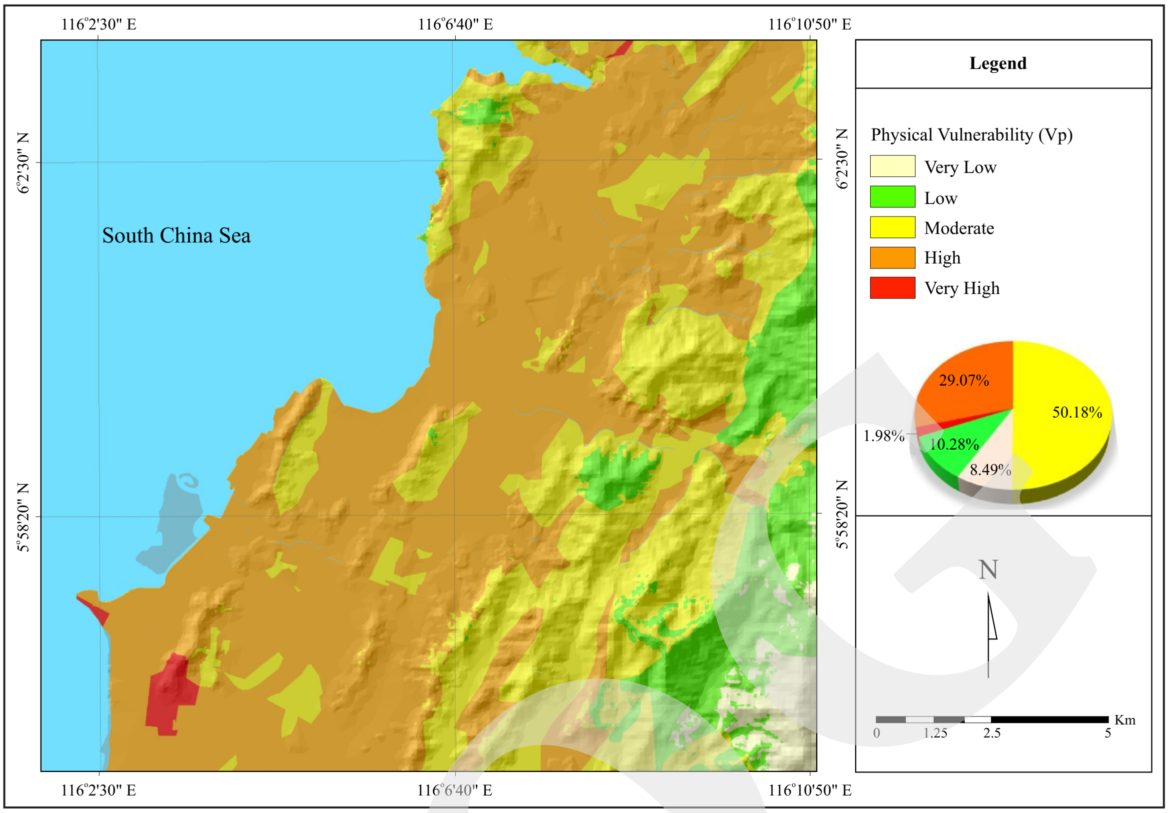

Figure 7. Physical Vulnerability (Vp) Map.

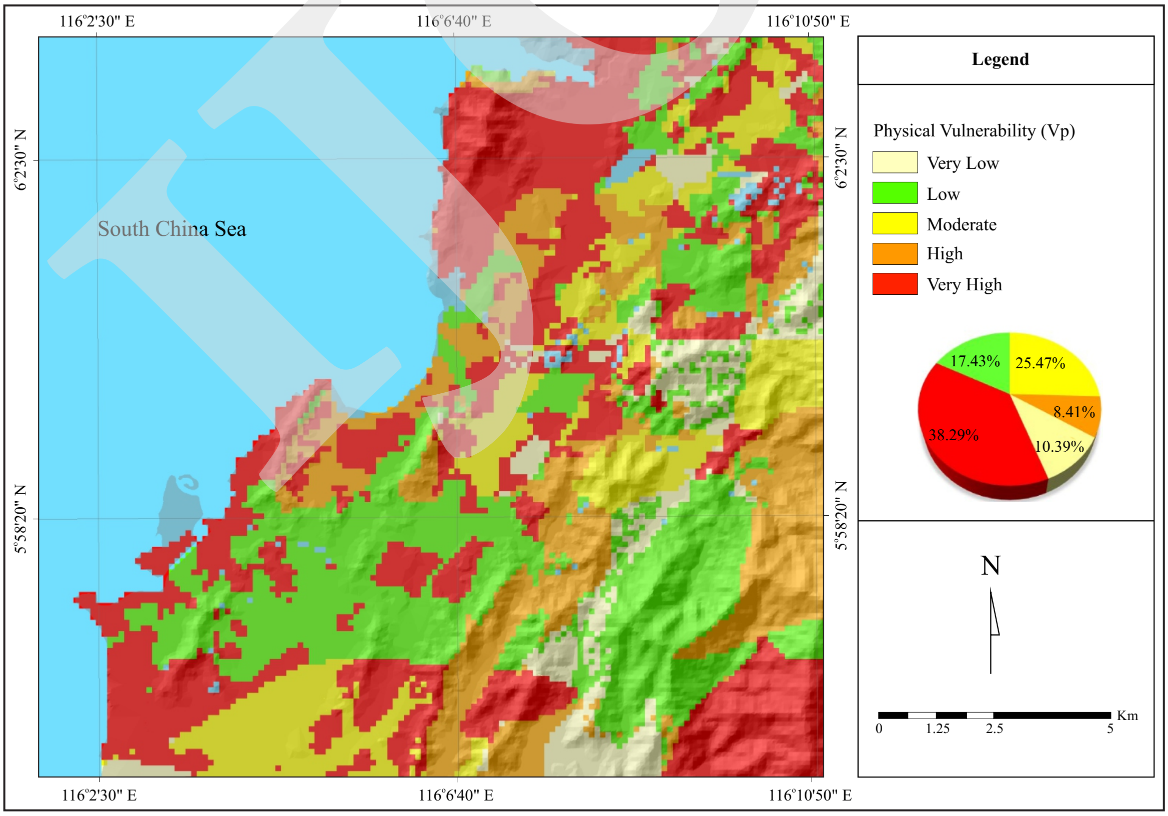

Figure 8. SocialVulnerability (Vs) Map.

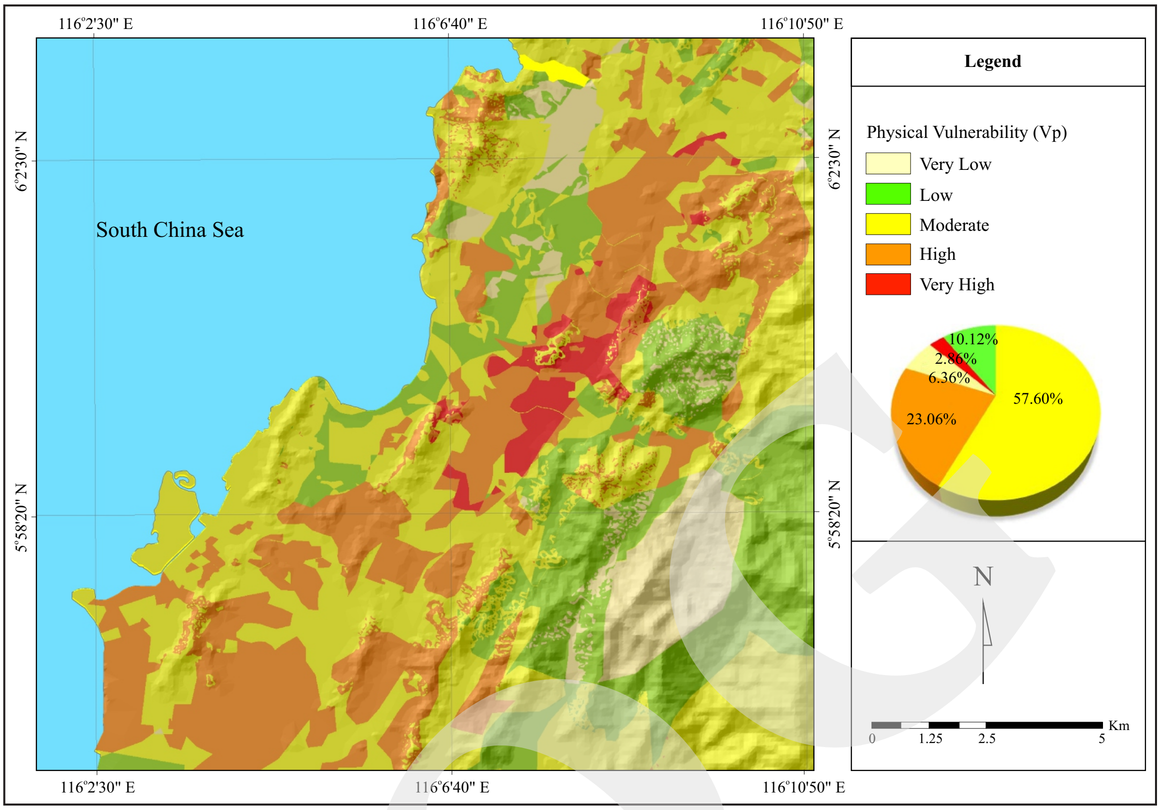

Figure 9. Environmental Vulnerability (Ve) Map.

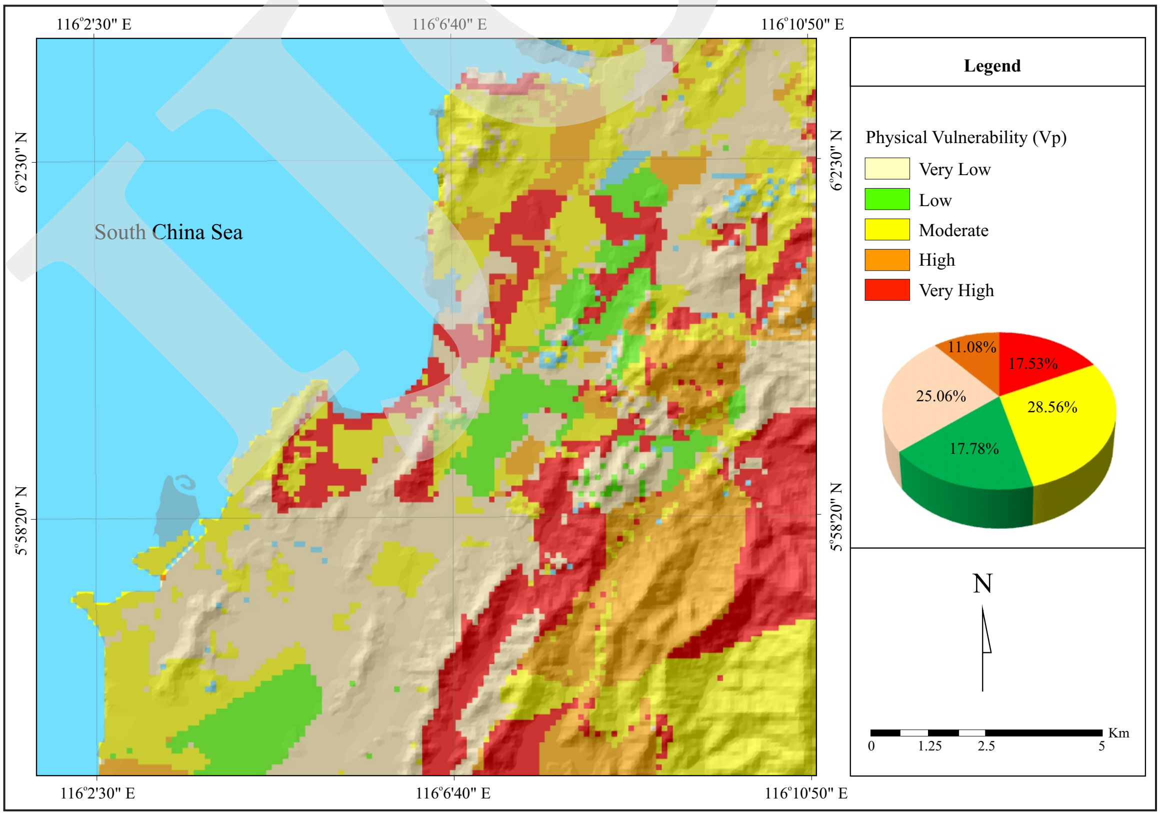

Figure 10. Landslide Vulnerability Assessment (LVAs) Map for Kota Kinabalu, Sabah.

if a society bears landslide vulnerability level on the big stage and the rate of occurrence happens too often and may be at the expense of life and property, the level of vulnerability will be seen as a threat of a major disaster.

Measurement taken to reduce the level of landslide vulnerability in the studied area is to be more complex and difficult for many parties involved who have to deal with it. Although the effects of hazards in the studied area can be overcome, the impact of large vulnerability may exist when exposure parameter vulnerability risks continue to rise and adaptation capacity continues to decline.

Conclusion

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

1. Landslide Vulnerability Assessment (LVAs) for Kota Kinabalu, Sabah, indicates that 17.78% of the total area is classified as Very Low, 6.25% as Low, 28.56% as Moderate, 11.08% as of High, and 17:53% as Very High.
2. Landslide Vulnerability at a "high" to "very high" degree can affect the economy and the daily activities of the population.
3. Residential, commercial, public, and industrial infrastructures have higher vulnerability rather than the agricultural and forestry areas. It is because most of the population concentrated in the three regions.
4. This Landslide Vulnerability Assessment (LVAs) approach is suitable as a guideline for preliminary development planning, controlling, and managing the landslide hazard/risk in the studied area and potentially to be extended with different background environments.

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