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Landslide Susceptibility Modelling for Agricultural Activities in Hilly Areas

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Abstract: The slope failure risk assessment of a particular area can be prepared by considering the data available. Many attempts have been made to classify the risk where evaluations are made in rating or in grading the slopes based on their characteristics and erosion problems. The assessments were done for geo-hazard such as erosion and landslide recognized in planning and guidance. Most of the hazard risk analyses require detailed knowledge of the geo- environmental predisposition factors and initial events that led to failure. The results of these analyses consist of identification and mapping of all erosion induced landslide phenomenon and are often translated in the form of maps, which is the fundamental step of the hazard assessment. The ranking of susceptibility areas and the delineation of probable failure areas are among essential features relevant to the production of these maps. In this study, Landslide Susceptibility Modelling was developed by taking into consideration all the landslide susceptibility factors in Cameron Highlands.

The landslide susceptibility map was produced based on the historical records of a landslide in that area for 20 years and the frequency ratio model was developed using map-overlaying techniques. The susceptibility map offers substantial benefits as a regional-scale tool over earlier susceptibility maps and Cameron Highland landslide- susceptible terrain zoning. The susceptibility map has the advantage of assisting with the implementation of suitable efforts to prevent landslides.

Keywords: Agriculture, Landslide and Slope failure risk

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I. INTRODUCTION

Malaysia is a tropical country where heavily forested and contains numerous mountain ranges. Deforestation is unpreventable in order to develop these areas for urbanization, agriculture or any activities that required a massive development. Activities like construction buildings, roads, highways where related to deforestation can be lead to severe soil erosion especially in steep areas [1-3]. Heavy rainfall is identified as a one of the cause for soil erosion which rainfall can lead and produce soil mass movements and landslides [4-7]. Therefore, government authorities need to enforce acts and regulations regarding the deforestation activities, so that it can be controlled. Rapid replacement of plants after deforestation activity could reduce soil erosion and landslides [8].

Malaysia receives heavy rainfall throughout the year and Malaysia's climate can be classified as hot and humid nature. Recently, massive development can be observed due to population and attractive places primarily in hilly areas. Obviously, it can be seen for Cameron Highlands where receives heavy pressure from agricultural and urban development [9]. Cameron Highland become a major producer of vegetables in Malaysia due to topography condition and required suitable temperature for vegetable cultivation. In Cameron Highlands, agricultural activities are popular as well as tourism activities. The agricultural practices including open farm, shelter rain, fertilizer and pesticides applications. These activities cause several problems in this hilly area. The problems that can be seen in this hilly area are erosion, sediment and landslide. Cameron Highland environment degradation is mainly caused by uncontrolled development and illegally farming. The total sediment yield in Cameron highland was increasing at an alarming rate annually [10]. In 1997 and 2006, the annual sediment recorded was 282,465.5 m^3/year and 334,853.49 m^3/year respectively [11].

This 18.55% increase in sediment yield within just nine years would certainly pose a great danger in agricultural lands and hydropower generation reservoirs in near future unless active measures are taken in order to control the effect in the area. Moreover, soil transformation had a significant influence on susceptibility to erosion in the sense that the forest area has less effect compared to developed areas. Land use development from forests to market gardens and residential areas, through tea estates and orchards, have successively had more significant impacts on the soil surface and causing in increased soil erosion rates. The eroded sediments caused by soil erosion
events were continuously deposited along river channels in the Ringlet Reservoir [12].
Thus, the objective of this study is to develop landslide susceptibility modeling for agricultural activities in hilly areas.

II. STUDY AREA

Pahang is located in the central of Peninsular Malaysia, about 250 km from the Malaysia capital, Kuala Lumpur. The state has covered about 35,964 square kilometers of land area and estimated the size and density of population were about 1,543,000 [13]. Cameron Highland is one of the smallest district in Pahang where locate at North West of Pahang as shown in Figure 1. There are 3 district in Cameron Highland namely, Ringlet, Tanah Rata and Ulu Telom. Cameron Highland covered as 712.18 square kilometers for the area, where has experienced a population growth over the years due to tourist attraction. The urbanization growth at the time has shown 2% per years as compared about 2.3% of the average national growth rate.

Fig. 1 Location of Cameron Highlands District and its Mukim

III. METHODOLOGY

Landslide Inventory Map

The inventory of landslides data has been prepared from different sources, including remote sensing, field survey measurement, and historical records. High-resolution aerial photography and SPOT panchromatic images were used in the previous study for visual inspections of landslides [14]. Landslides occur in vegetation area can be measured through satellite images, field measurements and historical records have collected these landslides [14]. Multiple field measurements were carried out using Global Navigation Satellite System (GNSS) device where Malaysia Survey Department gives the real-time corrections. In this field survey, 625 samples were identified to prepare the analysis with their associated attributes as shown in Figure 2. The landslide types included shallow landslides and rock fall. Then, the data was divided into two subsets (training (70%) and testing (30%)) ensuring both sets have all the types of landslides by a stratified sampling [15]. The training data were used for training the models, and the remaining data were used for model optimization (10%) and accuracy testing (20%) [16].

Fig. 2 Landslide Inventory Map for Cameron Highlands

The Landslide Susceptibility Map

In this study, a new landslide susceptibility map is being created and combined together with susceptibility map developed by Jabatan Mineral dan Geosains Malaysia (JMG) in project Penghasilan Peta Bahaya & Risiko Cerun Di Kawasan, Ipoh, Perak & Cameron Highlands, Pahang. The newly developed landslide susceptibility map was adopted the landslide susceptibility methodology from USGS [17] using IFSAR data as the primary data for terrain and slope analysis, Geological information from a geological map of Peninsular Malaysia for geology information and Average Annual Rainfall for precipitation information. The flow chart of the methodology adopted for the new Landslide Susceptibility Modelling is shown in Figure 3. The first phase for conducted Landslide Susceptibility Modelling comprised of geology, slope and annual average rainfall. The most crucial phase is the second phase which involves the field verification.

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Meanwhile, Landslide Inventory method was performed after the three variables were completed. In order to verify the Landslide Susceptibility, Bivariate Statistical, Weighted Factor Maps, Land Susceptibility Index Map, Assign Zones to the Maps, are needed to complete the Landslide

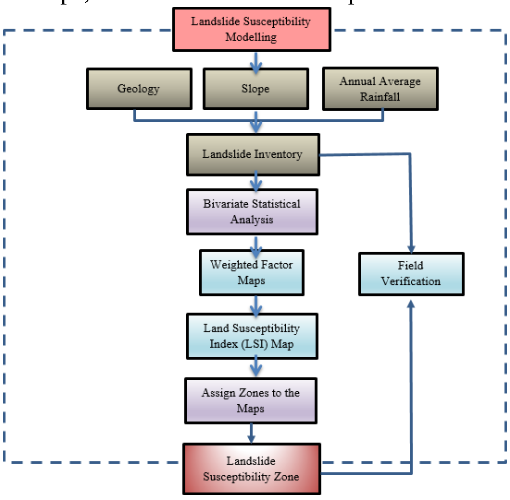


Fig. 3 Flowchart of the methodology adopted for the Landslide Susceptibility Modelling [12]

Landslide Susceptibility Modelling with GIS

Landslide inventory data were used for the definition of factors, which are highly linked with slopes liable to landslides. The factors are then used in completing and calibrating computer models. Due to the relative complexity of relief, landslides occur in the whole range of surfaces except flat plains. Aspect is not the most relevant factor other than there is a higher frequency of landslides on the northern, northwestern and southwestern slopes.

The angle of the slope is one of the most critical elements. More than 95% of all landslides occur on slopes with angles 15–45°. The lithology of the sloping bedrock is also an import factor. The most vulnerable to land sliding is phyllite rocks, followed by shales, schists, poorly cemented sandstones, gneiss, granites and quartzite [18]. Even though weathered gneiss experienced with to rill and gully erosion, this order is also appropriate for slope failures within weathered materials [18]. In Cameron Highland, Phyllite, shales, schists, limestone and acid intrusive was found. Even this type of lithology only covers 5.5% of the area, but almost half of landslides events (221 out of 404 events) recorded in landslide inventory fell in this area. Rock type has a significant impact on land sliding, but it is difficult to assess the role of rock type compared to the outcome of human action. The original of the slopes, together with the type and depth of the material on the slopes, often influences human activity. Since these are affected by the rock type, the contributing factors are difficult to differentiate [18]. Therefore, assuming that landslides in Cameron Highland can be explained and predicted by the rock type nature would be dangerous. The angle of the slope is one of the critical factors in the instability of the slope. The IFSAR DEM produced a slope map with a 5-m grid cell size. The map shows the spatial distribution of the slope values in the study area. These have been classified into four classes with an interval of 10° according to the slope classification [19-20]. According to the study area, the maximum area was

Susceptibility Zone. Lastly, the Landslide Inventory and Landslide Susceptibility Zone were verified the work in the field for accomplishing the aim and the objective for this study.

occupied by the slope classes of 15° to 25° and 25° to 35°, while steep slopes in the area are much less common in the area. [21]

While these preparatory factors may result in failure, a final trigger may be recognized in most instances as setting off the landslide. Storm rainfall is the most common trigger for landslides. When rainfall faster than it can drain into the ground, eventually water builds up in the slope. As per pore spaces in the slope become filled with water, a progressive pore water pressure develops which produces a hydraulic elevating force, which reduces the stabilizing effect from the overlying material weight.

Numerical Rating Scheme

Identifying potential landslide areas requires the factors to the existence of landslides. This can be achieved through the development of a rating scheme where numerical values are assigned to the factors and their classes. A rating scheme was developed based on the associated contributing factors

Data Layers	W3	W4	W5
Geology Lithology	WQI Class		
Slope	0.94 III	1.3 III	0.1 I
Precipitation	3.8 IIB	6.8 III	3.8 IIB
Precipitation	Slightly Polluted	Slightly Polluted	Slightly Polluted

for the field site and the previous work [22]. In this scheme, in order of significance, the factors were assigned a numerical ranking on a 1 to 4 scale. Weight was also assigned on 1 to 4 ordinal scales to the classes of factors where higher weights indicate more influence on the occurrence of landslides. The scheme has been modified appropriately by multiple iterations using different weight combinations. The rating scheme is shown in Table 1.

Table. 1 Ranks and weights for factors and their classes

Data Integration and Landslide Susceptibility Mapping

Data integration is done in data layers where weight values of the factor classes are used to generate the information attributes. The values are also used for the spatial analysis in GIS from the thematic data layers. Later the Landslide Potential Index (LPI) for each 5x5 m cell can be obtained using the summation of the respective ranks multiplications as shown in Equation 1.

$$LPI = \sum^{9} (Ri) \qquad (1)$$

Where Ri represents the rank for factor, *I* and *Wij* is the weight of class *j* of factor *i*. In order to solve the equation, the adaptation of the arithmetic overlay approach built into Arc View was done. Because, of the acceptance of both continuous and grid layers, the process of arithmetic overlay derived data in a continuous grid data layer. The range of the landslide potential index is from 39 to 323, which could be categorized into multiple classes susceptible to landslides.

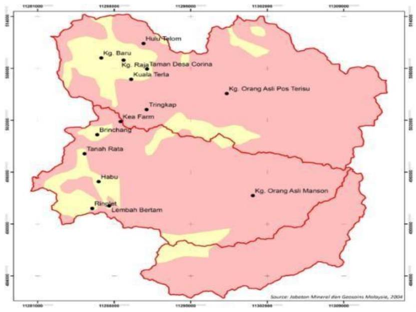
In this way, search for sudden changes in values for such classification can be done in a more realistic manner [23].

The LPI frequency graph showed many oscillations moving averages with average window lengths of 3, 7 and 11. Therefore, the methods are considered in order to smooth the curve for a better classification.

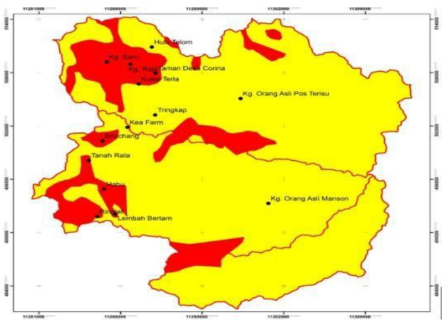
IV. RESULTS AND DISCUSSIONS

Numerical Rating Scheme

Lithology such as Schist, Phyllite, slate, and calcareous are highly susceptible to landslides than intrusive rocks. Therefore, lithology weights were appropriately assigned. Figures 4(a) and 4(b) show the geological lithology map and the geological lithology weighted area for Cameron Highland. Due to the existence of weathered and broken rock masses, the presence of a accountability in an area indicates a weak zone. Based on signs of instability observed along the faults within this range, a fault buffer of 250 m around the landslide inventory data was considered to account for the influence of fault zones. Since steeper slopes are more vulnerable to landslides, weight in descending order was given to the slope classes. The slope map and the slope-weighted zone generated for this area are shown in Figures 5(a) and 5(b).



(a)



(b)

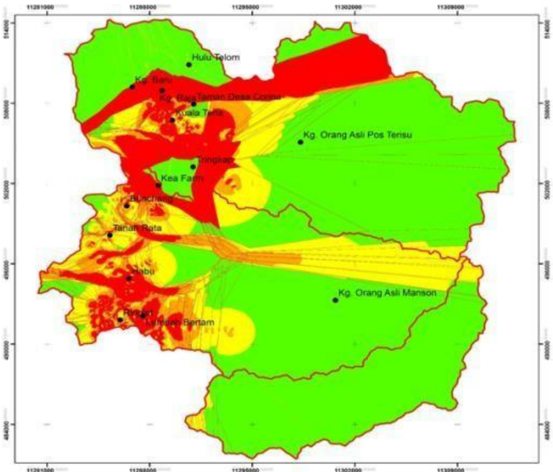
Fig. 4 (a) Geological Map for Cameron Highlands (b) Geological Weighted Zone Map for Cameron Highlands

(a)

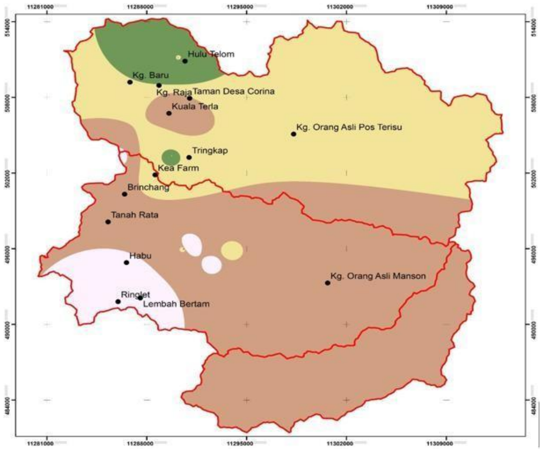
(b)

Fig. 5 (a) Slope Map for Cameron Highlands (b) Slope Weighted Zone Map for Cameron Highlands

Historical information from ground surveys (landslide inventory) indicates that landslide movement is triggered by rainfall, and erosion caused by rivers. Prolonged rainfall periods cause groundwater levels to rise, resulting in a reduction in the strength of the materials that form the landslide slip plane (clay layer). Therefore, this reduction in strength actually primes the motion of the landslide. Movement is often less than a few millimeters in response to each rainfall event, causing damage to the cumulative movement from many rainfall events. Therefore, the landslide movement is linked to events of rainfall. Rainfall classes were given weights accordingly, taking into account these facts and field observation. Figure 6(a) and 6(b) shows the average annual rainfall map and its weighted zone.



(a)



(b)

Fig. 6 (a) Average annual rainfall Map for Cameron Highlands (b) Average annual rainfall Weighted Zone Map for Cameron Highlands

Data Integration and Landslide Susceptibility Mapping

The area classified as high, moderate, low and very low susceptibility to landslides. Figure 7 shows mapping of landslide susceptibility, which outlines the relative potential landslide occurrence zones.

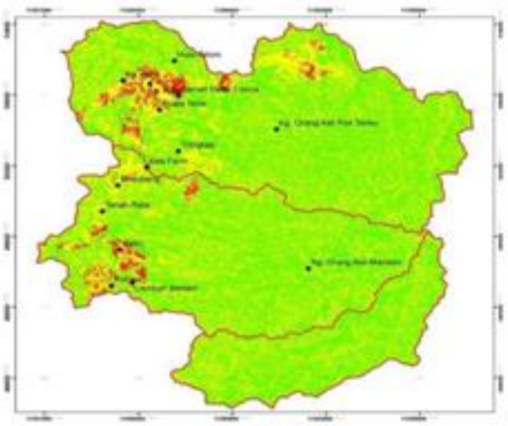


Fig. 7 Landslide Susceptibility Map for Cameron Highlands

In this study, newly developed landslide susceptibility has been developed using IFSAR as a based DEM. Meanwhile, landslide susceptibility studied which developed by JMG was using LiDAR data as a based DEM and was expected to have more accurate land susceptibility map. LIDAR samples are pointed as a point compared to IFSAR pointed as elevation samples. Depending on altitude and other factors, the LIDAR lights up and able to capture the distance 10-100 cm within extending diameter. Subject on the different operating parameters, the spot separation is usually 2-5 meters, although higher spot are required and completed for some applications. The subsequent data set is an irregular or semi-regular co-ordinate grid (x,y,z). These are regularly collectived into a regular, gridded DEM using an interpolating tools for visualization and other purposes. On the other hand, IFSAR directly establishes a regular grid of elevation samples. All the dispersing elements within each of the adjacent resolution cells contribute to the cell's observed elevation [19]. Therefore, the resulting DEM samples result from integration instead of interpolation. In the present case, in the upstream processing stage, the interferogram has undergone some filtering, so that the sample spacing at the output is about 5 meters, double the thickness of the basic resolution unit. Due to this interpolation versus integration factors, all other factors being equal, a LIDAR DEM is differ from an IFSAR DEM in zones of topography transformation. The decision to use IFSAR is due to some area that has not been covered by Landslide Susceptibility map developed using LiDAR. Based on this, it has been decided to fuse the landslide susceptibility developed by JMG, into the new landslide susceptibility so that the accuracy can be preserved. If there is any update of landslide susceptibility from JMG using LiDAR, the erosion-induced landslide risk map to develop in this study will be considered to be updated accordingly.

The comparison between two landslide susceptibilities for the same area is shown in Figure 8(a) and 8(b). From both maps, some difference between these two landslide susceptibility maps can be detected visually. The differentiation is expected because of differences in DEM resolution and less parameter used in the latest Landslide Susceptibility. From the analysis, the different percentage of uncertainty for Medium Zone is 17.5%, while for High is 2.7% (see Table 2). From the analysis, the overall percentage of the High zone in Land Susceptibility Map developed from IFSAR is only 2.1% while the area that covered by LiDAR contains 1.7%. This means the uncertainty is only for the 0.3% for the area, which is not covered by LiDAR

Table. 2 Comparison of Land Susceptibility by Zone

Zone	LS from LiDAR	LS from IFSAR
Very Low	26.8%	35.4%
Low	35.9%	47.5%
Medium	28.7%	11.2%
High	8.6%	5.9%

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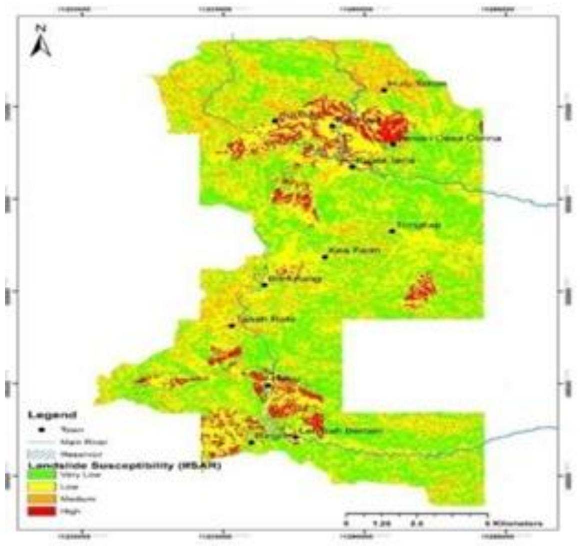
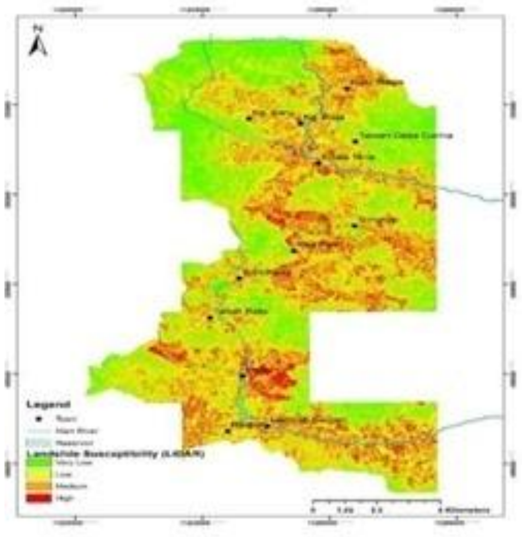


(a)



(b)

Fig. 8 (a) Landslide Susceptibility Map developed from LiDAR (b) Landslide Susceptibility Map developed from IFSAR

Data Fusion

Vector and raster data sets can be processed through ArcGIS software where comprising spectral information including geospatial data fusion. Geospatial analysis can be improved particularly for multispectral and hyper spectral ranging data. Nevertheless, through geospatial information, spectral analysis can be improved. The combination of geospatial material and spectral data can lead to more accurate product analysis.. The fusion landslide susceptibility is shown in Figure 9. This land susceptibility map was then used together with soil erosion map to develop erosion induced landslide risk map at a later stage.

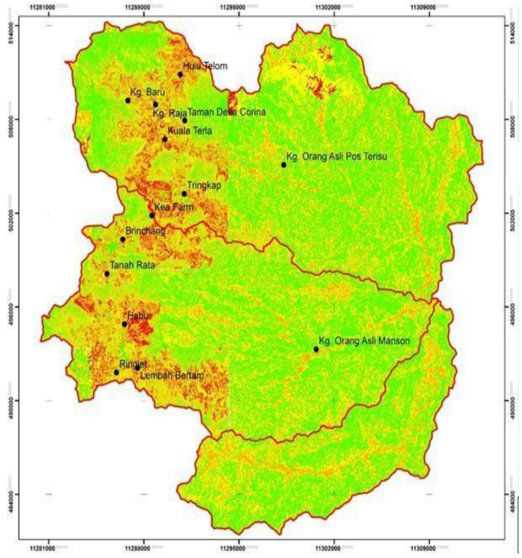


Fig. 9 Landslide Susceptibility (Fusion) Map for Cameron Highlands

V. CONCLUSIONS

The landslide susceptibility map identifies the risk of landslide within a massive region with sufficient accuracy and within general areas where landslides can be expected. The susceptibility map offers substantial benefits as a regional-scale tool over earlier susceptibility maps and Cameron Highland landslide-susceptible terrain zoning. The susceptibility map provides 4 zones (deficient, low, medium, high) with variable, relative degrees of susceptibility to landslides. This has the advantage of assisting with the implementation of suitable efforts to prevent landslides. Efforts in municipal and public education are also benefited as different types of landslides are often caused by different mechanisms and pose various hazards. This map's ability to identify and characterize the sensitivity of the different zones to different types of landfills can help focus and define appropriate landslide mitigation efforts in hazardous areas in general and specific areas.

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