Journal of Geomatics Vol 8 No. 2 October 2014

Landslide modelling and analysis using remote sensing and GIS: A case study of Cameron highland, Malaysia

Ismail Elmahdy Samy(1), Maged Mahmoud Marghany(2), Mohamed Mostafa Mohamed(1,3)
(1)Civil and Environmental Engineering Department, United Arab Emirates University
Al-Ain P.O. Box 15551, United Arab Emirates
(2)Faculty of Geoinformation and Real Estate, Institute of Geospatial Science and Technology (INSTeG)
University Technology, Malaysia (UTM), Johor 81310, Malaysia
(3)Faculty of Engineering, Irrigation and Hydraulics Department
Cairo University, Giza P.O. Box 12211, Egypt
Email: samy@uaeu.ac.ae

(Received: Sep 10, 2013; in final form: Sep 02, 2014)

Abstract: The Cameron highland is known in Malaysia for having fractured granite that experiences to rock failure and landslides in the region at high frequency. Recently, rock failure and landslides were taking place in the Cameron highland as a result of heavy rainfall and highly weathered and fractured rocks. This paper discusses role of mapping geological lineaments and terrain parameters for landslides susceptibility modeling using remote sensing and Geographic Information System (GIS). Geological lineaments, streams, slope and aspect are important parameters were extracted from LANDSAT ETM+ Imagery and a 5m DEM generated from Spot. These parameters were analyzed in GIS environment to study and investigate the strong spatial relationship of lineaments density, rock slope and landslides occurrence in Cameron highland. The weighted sum of extracted parameters was applied to construct the risk map of landslides occurrence. The landslide susceptibility map was compared with the previous studies and number of reported landslide locations. It shows good coincidences with reported landslide locations.

Keywords: Cameron highland, Landslides, Remote sensing, GIS

1. Introduction

In mountainous and tropical regions, landslides are one of the natural hazards that cause losses to lives and property. In Malaysia, most of landslides and rock fall are mostly occurred due to intensive rainfall and urban development over fractured hilly areas. For example, the Cameron Highlands, Genting Highlands and east cost highway of peninsular Malaysia are locations that experience to several landslides which kill several people. The highland towers collapse was an apartment building collapse on 11 December 1993 caused the death of 48 people and led to complete evacuation of the neighboring blocks. Several studies have been carried out on landslides susceptibility analysis using geographic information system (GIS). Guzzetti et al. (1999) evaluate landslide hazard based on geomorphological relationships between landslide types and the litho-structural setting. Sharifah et al. (2004) conducted landslides zonation in Pos Slim-Cameron highlands district, peninsula Malaysia using remote sensing and GIS. In the last decade, several landslide susceptibility studies have been carried out using probabilistic models such as the frequency ration method (Jibson et al., 2000; Baeza and Corominas, 2001; Zhou et al., 2002; Lee and Choi, 2003; Cevik and Topal, 2003; Lee and Dan, 2005; Pradhan et al., 2006; Akgün and Bulut 2007; Samy and Mohamed 2012), and statistical models such as logistic regression analysis, back- propagation neural network and fuzzy logic models have been applied to landslide susceptibility mapping (Akgün et al., 2008; Tunusluoglu et al., 2008; Pradhan and Saro, 2009). In such mountainous area, predicting and mapping landslides is essential for reducing and minimizing these losses. Of these methods, the integration of remote sensing and Geographic Information System (GIS) has proven to be particularly successful. The Weighted Spatial Probability Model (WSPM) and DEM data, particularly, proved to be a powerful tool in landslides susceptibility mapping. The availability of remote sensing and GIS technologies has greatly helped the construction of natural hazards susceptibility maps with better accuracy than before. This is because, through technologies. Because it is possible to collect, and analyze a variety of spatial data about the contributing parameters responsible for the landslide activity in a regional scale (Varnes, 1984; Carrara et al., 1991; Nagarajan et al., 1998; Guzzetti et al., 1999; van Westen, 2000).

In the present, a modified approach based on remote sensing, GIS and Weighted Spatial Probability Modelling (WSPM) was used to spatially predict the occurrence of landslides in the Cameron Highlands, Malaysia. In the current study, in addition to using reasonable thematic layers of the most important factors for the spatial prediction of the landslides and validation using known landslides was performed to check the accuracy of the obtained map.

The main goal of this study is to recognize regions that are susceptible to landslide occurrence, using known landslide locations and essential geological and geomorphological parameters that are closely associated with landslides occurrences.

2. Study area

The Cameron Highlands is stretched from 101º 20'15" to 101º 27' 31"E and 4º 22' 48" to 4º 36' 54"N in the middle part of granite range that form most of the peninsular Malaysian. It is located between the Pahang and Perak states (Figure 1a).

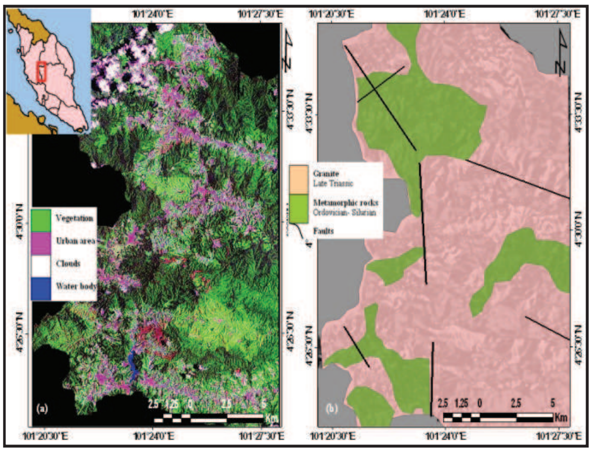


Figure 1: (a) RGB LANDSAT ETM+ image (band combination 7 4 2), and (b) geological map showing the study area and the main lithological units and geological structures of the study area

The area is highly rugged with an elevation ranging from 1000 m to 2000 m (m.s.l), and covers an area of 255.271 km². The area is dominate by slopes ranging from 30° to >60°. The major land use practice in the study area is tea and agriculture mosty on hilly area and most of rain occurs during October and September. The annual rainfall in the area varies from 2,700 to 3100 mm (http://www.water.gov.my/).

The October 2002 landslide in Cameron hill lands which destroyed several houses. Landslides in Cameron highlands mainly triggered by tropical rainfall and flash floods, causing failure of the rock surface along fracture, joint, and cleavage planes.

Landslides mostly occur in Malaysia due to heavy rainfall. In recent years, greater awareness of landslide problems has led to significant changes in the control of development on unstable land, with the Malaysian government and highway authorities stressing the need for local planning authorities to take landslide susceptibility mapping into account at all stages of the planning and development process. It is during these months that soil saturates in hilly areas, and landslides may occur along river valleys (Faisal, 2000). Geologically, most of the area comprises of the hard rocks (e.g. granite and metamorphic rocks) of Paleozoic and Mesozoic era (Figure 1b).

3. Data and methods

Two remotely sensing data were used in this study: (i) LANDSAT ETM+ of 30m spatial resolution and Qucikbird of 0.6m spatial resolution, and (ii) 5 m DEM generated from Spot (acquired from University Putra Malaysia). In addition, ancillary data in terms of geological map of Malaysia at 1:100,000 scale published by Geosciences and Mineral Survey department, Malaysian (Yin, 1991). A total of 273 landslides of varying dimensions (40 to 120 m^2) were mapped from archived data published by Geosciences and Mineral Survey department, Malaysian. Most of the reported landslides in the Cameron Highlands are shallow debris and rock slides.

The aforementioned data sets were used to carry out five layers (thematic maps), which proved to be essential factors for landslide occurrence. These include: (i) stream network, which drains in geological fractures and hence increases mechanical weathering (ii) geological fractures, which serve as channels and hence increase the rock weathering, (iii) cutting slopes, (vi) topographic slope, and (v) land use **(**Table 1).

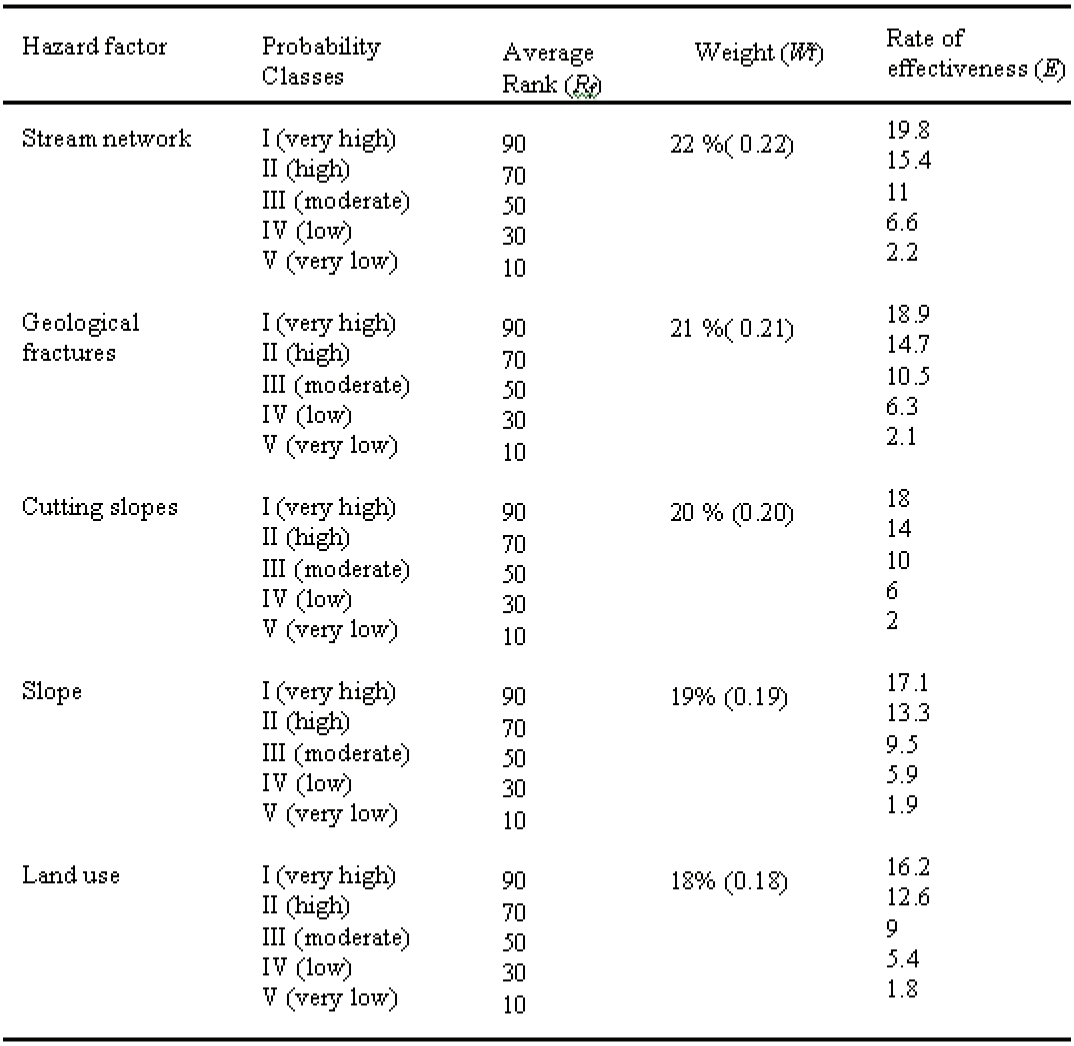
Stream network (Figure 2a) are often associated with geological structures (Ollier, 1981) which may serve as underground channels for downward movement of surface water (runoff) to zones of intersected geological fractures (Kerrich, 1986). The study of this association can be used to provide a better understanding of the relationship between geological fractures, stream network and landslides and rock fall occurrence in the areas under investigation. In addition, it provides an indirect measure of groundwater movement, which have vital role to play in landslide occurrence (Sarkar and Kanungo, 2004).

A D8 flow routing based on the 8-cell neighborhood approach (Jenson and Domingue, 1988), which is implemented in ArcGIS v.9.2 Softwaree, was used to extract flow direction grid from a 5m DEM. Then the major drainage network was delineated through a flow accumulation function, and specified by a threshold value of 30 cells. After that, the stream order and basins were delineated. The resulting stream network density map was categorized into different classes varying from very high to very low. This map was assigned a weight of 0.22 in the weighted spatial probability modeling (Table 1). In the case of spatial association between distance from drainage network and landslides occurrence, in distance zone of 50m shows higher number of reported landslides observed in the very high and shows a rate of effectiveness of 19.8.

Geological structures generally control relief, spatial distribution of stream network, and to some extent erosion (Young, 1972; Gerrard, 1981). Therefore, zones of geological structures such as lineaments intersection, wetness and erosion can coincide with sites of landslide occurrence (Karakhanyan, 1981).

To carry out lineaments crosscutting the entire study area, two modified techniques were applied (Samy et al., 2012). In the first technique, a STRM DEM was used to calculate slope and aspect slope. After that, the derived maps were enhanced by applying percentile stretching.

Table 1: Ranks and weights for factors and their influencing classes used for landslides susceptibility mapping



Hazard factor	Probability Classes	Average Rank (*Ri*)	Weight (*Wf*)	Rate of effectiveness (*E*)
Stream network	I (very high)	90	22 %(0.22)	19.8
	II (high)	70		15.4
	III (moderate)	50		11
	IV (low)	30		6.6
	V (very low)	10		2.2
Geological fractures	I (very high)	90	21 %(0.21)	18.9
	II (high)	70		14.7
	III (moderate)	50		10.5
	IV (low)	30		6.3
	V (very low)	10		2.1
Cutting slopes	I (very high)	90	20 % (0.20)	18
	II (high)	70		14
	III (moderate)	50		10
	IV (low)	30		6
	V (very low)	10		2
Slope	I (very high)	90	19% (0.19)	17.1
	II (high)	70		13.3
	III (moderate)	50		9.5
	IV (low)	30		5.9
	V (very low)	10		1.9
Land use	I (very high)	90	18% (0.18)	16.2
	II (high)	70		12.6
	III (moderate)	50		9
	IV (low)	30		5.4
	V (very low)	10		1.8

In the second approach, a set of shaded relief in all directions (0°, 45°, …, 315°) with 28 times exaggeration in the Z dimension (Jordan and Csillage, 2001). The calculated maps were then enhanced by apply Sobel filter with 10% threshold flowed by equalization enhancement to facilitate the visual interpretation. Since the detection of linear features is partially dependent on the origin of a light source, the geological fractures extracted from different shaded relief maps were then overlaid in one layer in GIS environment to construct map of the extracted surface and subsurface geological fractures.

To spatially analyze the relationship of geological fractures to landslides, maps of geological fractures density and distance from geological fractures were prepared. The maps wee categorized different classes from very low to very high.

The map (layer) was given a weight 0.21 in weighted spatial probability modeling. The very high class, the rate of effectiveness (E) is 19.8, while in the low and very low classes, the rate of effectiveness are 6.3 and 2.1 respectively. With respect to the distance from geological fractures, in a distance of less than 50m, the rate of effectiveness is 19.8, indicating a very high probability of shallow and avalanches landslides occurrence. However, very low class and distance greater than 500m shown low probability of landslides occurrence.

Topographic slope can be defined as the change in elevation of surface and expressed as a percentage or/and in degrees. Slope play vital role in both rock fall and landslide occurrences especially in tropical regions where the rain falls exceeds 2700 mm per annum. In general, there is a close spatial relationship between intense rain fall and slope failures (Tsaparas et al., 2002).

To spatially analyze the relationship of slopes to the landslides, The locations of steep slopes and land use were then screen digitizing from Quickbird and LANDSAT ETM+ images. After that, slope map was derived from DEM. The classification of cutting slopes and land use takes into consideration the characteristics that were be controlling factors for landslides occurrence in the study area. In the case of the spatial association between cutting slopes and slopes and landslides occurrence, the very high and high classes is higher for cutting slopes and steep slopes(>35°), indicating a high probability of landslides occurrence.

The slope maps were classified different classes from very low to very high and were given weight 0.20 and 0.19 respectively (Table 1). It was noted that, gently slopes and distance from cutting slopes greater than 500 m are expected to have low probability of landslides occurrence.

To highlight on the influence of slope to landslides occurrence, a comparative analysis was performed between area at an elevation of >1500 m of high and very high slopes and relatively low slopes areas along the major valleys at an elevation of <1500 m (Figure 4a), and thus the following considerations must taken into account.
The different classes of land use were digitized from landsat and quickbird imageries and the spatial association between land use and landslides occurrence was assigned. The land use map was given a weight 0.18 in weighted spatial probability modeling. The rate of effectiveness of very high class is 16.2, while the very low class is 1.8.

4. Weight Spatial Probability Modeling (WSPM)

Five thematic maps (layers) were ranked according to their level of contribution to the landslides using the Weight Spatial probability Modeling (WSPM). The level of contribution of each WSPM layer to landslides occurrence have been checked against the thematic maps individually. The rank of five classes was classified as 100-80 %, 80-60 %, 60-40 %, 40-20 %, and 20-0 %. The integrated factors of landslides were then given the following weights Weight (Wt): stream network (22%), geological fractures (21 %), cutting slopes (20%), slope (19%), and land use (18%). Thus, the average ranks (R_f) of five classes were classified as 90, 70, 50, 30 and 10 % for classes from I to IIV respectively (Table 1). To calculate the rate of effectiveness and significance contribution (E) for each factor (thematic map), the weight was multiplied by the rank ($W_f \times R_f$). For instance, if the weight of stream network equals 22%, and this is multiplied by the average rank of 90 (class I), the average will be:

$$E = W_f \times R_f = 0.22 \times 90 = 19.8 \qquad (1)$$

Following this formula (1) enables estimation of the rate of effectiveness of each hazard factor (layer), it also provides a relative analysis between various input layers. For the above purpose, the various layers were overlaid and spatially analyzed in GIS environment using Spatial Analyst Model Builder that implemented in ArcGIS v.9.2 software.

5. Validation

The landslide susceptibility map was validated using the location of known landslides. The validation was performed in the GIS environment by comparing the morphometric parameters (slope, curvature and relief) of known landslides and the landslide susceptibility map.

To clarify the spatial correlation between locations of known and predicted landslides, geostatistical analysis using semivariogram models in four directions were performed. It is difficult to construct semivariograms of locations of known and predicted landslides, owing to their small number. For this reason the spatial correlation of known and predicated landslides was clarified by using semivariogram models. In the same context, locations of known and predicted landslides were converted into a density (binary) map, which is defined by the number of landslides per square kilometer.

6. Results

The map of stream network extracted from DEM using D8 algorithm is shown in Figure 2a. According to stream network map, four major trending characterize the valleys crosscutting the entire study in area in: (i) N-S, (ii) WNW-ESE, (iii) NW-SE, and NE-SW. So, sites of high density stream network very closely associate with erosion by water and landslides occurrence.

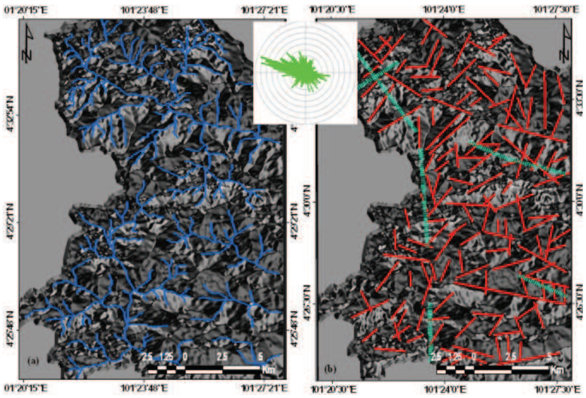


Figure 2: (a) Drainage networks in blue color, and (b) lineaments extracted from DEM. These are draped on shaded relief of the study area. Rose diagram represent trend of lineaments crosscut the area.

The spatial analysis shows that the maximum number of reported landslides is located within 50 m from high density zone of stream network. However, the lower number of landslides is located within 500m from stream network. This shows the need to design proper drainage system to reduce the occurrence of shallow and avalanches landslides.

The maps of geological structures crosscutting the entire study area and density of geological fractures are shown in figure 2b. The directions were found to be in the N-S,NW-SE,NE-SW and WNW-ESE. These directions match the common directions of geological fractures. These features serve as subsurface channels for rain water and increase the mechanical and chemical interactions between hard rocks and rain water during wet periods. Sites of geological fractures intersection, effective porosity and permeability of rocks very closely associate with wetness, and therefore, landslide occurrence (Poletaev, 1992; Karakhanyan, 1981; Samy et al., 2012).

Slope and slope direction maps calculated from DEM is shown in Figure 3. The slope map (Figure 4b) comprises five classes for the Cameron Highlands, where the maximum slope influencing terrain and average slope were 250 % (>86º) and 46% (25º) respectively. In the study area, there is water acceleration and active erosion in highly fractured rock. This in turn will maximize the landslide and rock fall occurrence (Karakhanyan, 1981; Tsaparas et al., 2002), because rain water saturation and infill sediments will be restricted to geological fracture intersections.

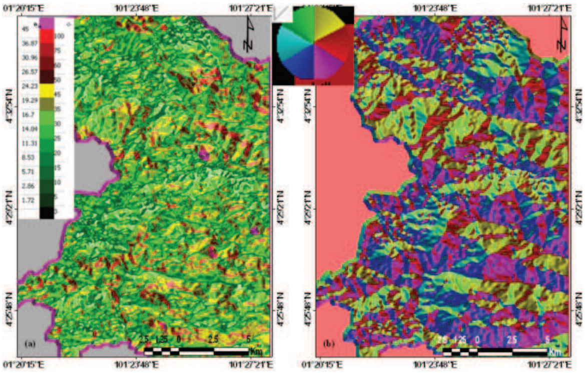


Figure 3: (a) Slope and, (b) aspect maps calculated from DEM for the Cameron Highlands. These are controlled by fault displacements and influence landsides occurrence

The steeper slope directions (aspects) were found to be in the N-S, NW-SE, NE-SW and WNW-ESE (Figure 3b). These directions are in agreement with trends of geological fractures and stream network crosscutting the entire mountainous area and in the same time correspond to the common directions of landslides and rock fall. Site at slope of 0-5°, the rate of effectiveness is 1.9, and therefore, a very low probability of a landslide occurrence. The steeper the slopes, the greater the probability of landslides occurrence.

According to aspect map (Figure 4b), landslides were most abundant on north, east and northeast facing hill slopes while compared to other directions.

The urban development at highly fractured mountainous regions with steep slopes can decrease the slope stability (Gue and Tan, 2006). The spatial analysis shows that for the area under development, which is located on wrong slope deigns are showing maximum number of reported landslides. These areas are located at both sides of main valleys and highways urban areas.

The rate of effectiveness is 16.2 (Table 1). This is a normal result substantiating facts that landslides often relate to wrong slope designs (Figure 4) and land development (Tsaparas et al., 2002; Gue and Tan, 2006; Willenberg et al., 2008).

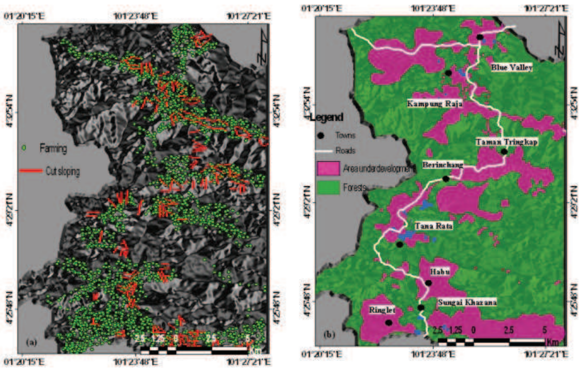


Figure 4: (a) Cutting slopes (red lines) along hilly roads, and (b) land use and land cover maps of the study area. Green points highlight farm locations

The results of landslides susceptibility analysis and mapping (Figure 5 and Table 2) pointed out that the high probability landslides occurrence are located in the areas where density of geological fractures intersection, stream network and steep slope. The result shows that the very high susceptible class covers 33.7 km^2 (13.2 %) of the total area and distributes on sides of major valleys and pass ways. On the other hands, the low susceptible class for the occurrence of landslides is occupied by 37.4 km^2 (14.6%). The high susceptible class occupies an area of 44.3 km^2 (17.3 %), while the moderate susceptible class covers 77.6 km^2 (30.4 %).

The result map depicts the areas with slope greater than 35, facing northeast, east and northwest directions (Figure 3b).

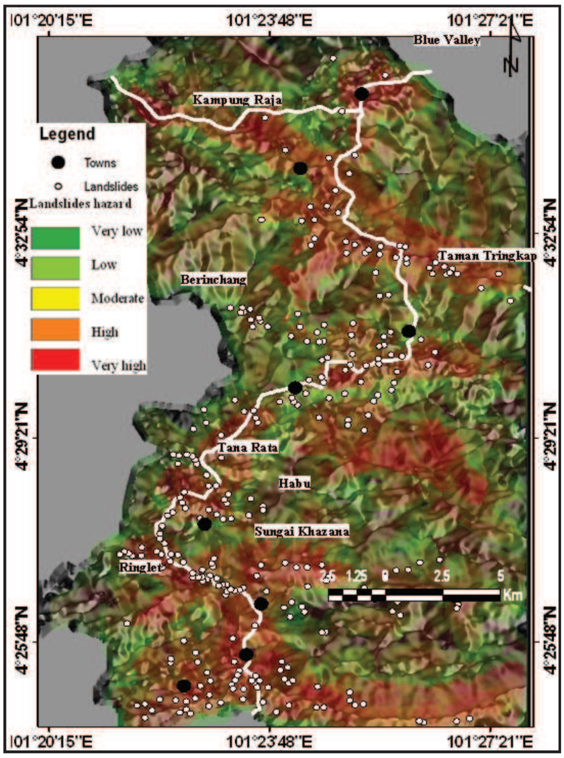


Figure 5: Landslides susceptibility map of Cameron Highlands

Table 2: Area of natural hazard classes (km^2). Total area studied: 255.271 km^2

Landslides	Very high Susceptibility	High susceptibility	Moderate Susceptibility	Low susceptibility	Very low susceptibility
Area (km^2)	33.790	44.321	77.652	37.428	22.055
Area % Of Cameron Highlands	15.6	17.3	30.4	14.66	8.63
No. Landslides Occurred	77/273	82/273	65/273	44/273	21/273
Accuracy (%)	28%	30%	23.8%	16.11%	7.69%

7. Discussion

The WSPM which use DEMs has shown a powerful ability to predict landslides. The drainage networks and wettest zones were found to be the most essential factor effect on landslides occurrence. The stream network showed the highest weight, 0.22. The highly fractured rocks with steep slopes (>35°) within 50m of stream network were found as more susceptible to landslides occurrence. The second essential factor effecting to landslides occurrence is geological fractures intersections (0.21). The third essential factor effecting to landslides occurrence is cutting slope and wrong slope designs (0.20). In general, areas under development were found as the most susceptible land use compared to the other classes. Areas covering the metamorphic rock are the most essential parameters were found the most susceptible and erodable lithology than the igneous rocks.

Areas with concavity (flow and sediment accumulation zones) were found to be the most susceptible to landslides occurrence than areas with convexities.

In order to demonstrate the spatial correlation between locations of known and predicted landslides zones, semivariogram models are the most appropriate procedures with which to model landslides susceptibility and distribution Landslides density, defined by the total number of geological fractures per square kilometre, demonstrated a more distinct trend as illustrated by the semivariogram models (Figure 6).

The 1 km × 1 km size of the unit grid was determined by considering the spatial resolution of the DEM and spacing of geological fractures.

Semivariogram grid-size directly influences the spatial correlation distances and variance of the geological fracture density distributions (Koike and Ichikawab, 2006), although only landslides density was considered as part of this study's spatial pattern analysis. However, the spatial distribution of landslides was analysed and grouped into several classes. The four-directional semivariogram models for the geological fractures show reasonable consistency. Furthermore, a sill value which defines the maximum value of range did not differ greatly between locations of landslides found in the study area. All directional semivariogram models rise from an original point and continue with change at about 1 km with not much variation or dip in the curve with increasing distance. The variogram slopes and fractal dimensions of known and predicted landslides in the NW-SE, NE-SW, N-S and E-W directions had values ranging from 0.62 to 0.87 and 2.56 to 2.68 respectively (Figure 6). These show the strong agreement between location of known landslides and those predicted and modelled using the proposed method.

Geostatistical analysis using semivariogram models and fractal dimensions clearly reflect strong agreement between locations of known and predicted landslides.

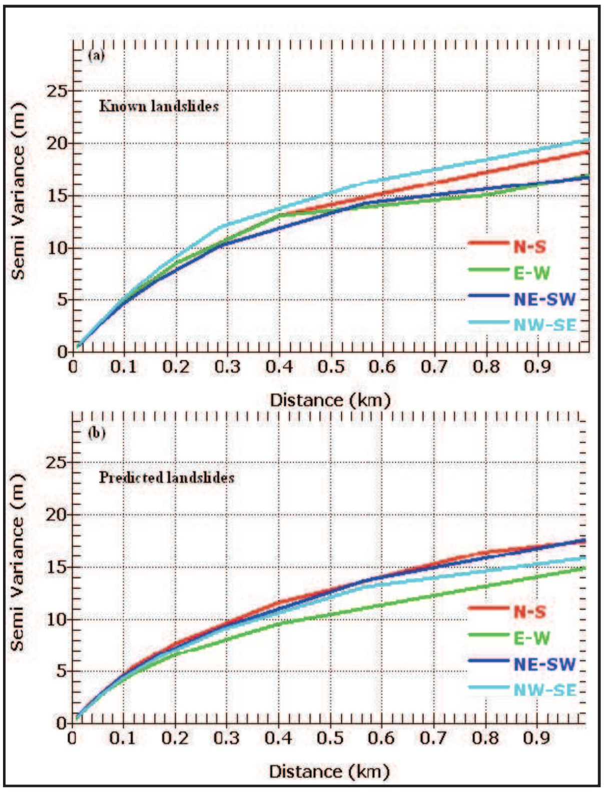


Figure 6: Semivariogram models in four directions of (a) known and (b) predicted landslides

The obtained landslides susceptibility map (Figure 5) was also validated using known landslide locations. Verification of the produced landsides susceptibility map was made by comparing it with locations of the reported landside locations. The verification showed strong agreement between the reported landslide locations and the produced map. Out of 273 reported natural hazards, 224 are falls in very high, high and moderate classes of the constructed landsides map with over all accuracy of 81.8 % (Table 2).

The resultant landslides susceptibility map permit better understanding of probable locations for landslide occurrences in Cameron Highland region. The proposed method using essential geological and geomorphometric factors such as stream network, geological fractures and slope that can be deduced from digital elevation models. Higher natural hazard areas can be simulated and detected by studying the magnitude and contribution of essential factors to the natural hazards.

8. Conclusions

An integration of remote sensing, GIS and WSPM takes benefits of computer assisted computation of morphometric parameters and features (e.g. slope, aspect and stream patterns) to predict areas where landslides occurrence are higher. The landslide susceptibility map is considered significant as it exhibits that areas with higher landslides and proving the ability of WSPM proposed to predict the higher landslides, rock fall and flood hazards areas in Cameron Highlands.

Sites of high density of stream network and highly intensive geological fractures, heavy rainfall and wrong slope designs are very closely associated with landslides occurrence. The rate of effectiveness ranges from16.2 to 19.8. This demonstrates that, within these sites, the landslides are affected by erosion, overload of water saturation and infilling sediments in blocked geological fractures. These sites which are located at an elevation of more than 1000m with slopes ranges from 15° to 26º exhibit high probability landslides and rock fall occurrence.

A significant benefit of the integrated method is considered to be its ability to obtain results using single DEM and archived data. In this way, the methodology can produce results in remote and inaccessible area, which is the case for the majority of the mountainous areas in Malaysia. Utilization of these data can be useful to solve some unpredictable environmental and geotechnical engineering problems.

Acknowledgments

The authors would like to thank Professor Peter Guth from USA Academic Navy, the Earth Remote Sensing Data Analysis Centre (ERSDAC), Japan; the NASA Land Processes Distributed Active Archive Center and the User Services USGS Earth Resources Observation and Science (EROS), and the Consortium for Spatial Information (CSI) of the Consultative Group for International Agricultural Research (CGIAR) for providing and distributing scientific advises and remotely sensed data.

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