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Landslide Susceptibility Mapping Using Averaged Weightage Score and GIS: A Case Study at Kuala Lumpur

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ABSTRACT

Many residential areas of Kuala Lumpur are susceptible to landslides; this is seen in the frequency of landslide occurences in these areas. The objective of this study is to delineate landslide risk areas in support of development planning, monitoring and control of unstable areas. In this study, five landslide causative factors were extracted from satellite imagery and maps provided by the Geological Survey Department of Malaysia. Factors included in the study including land use, river density and lineament derived from Landsat ETM image, precipitation amount from rain gauge stations and lithology, were extracted from the geological map of the study area. Layers were analyzed and divided into subclasses. An average weightage score was applied to calculate the subclasses into percentage weights of influence on landslide. Overlay, geo-processing and geo-statistic techniques in GIS were used to discriminate these weighted subclasses into landslide susceptibility at low, medium and high levels of risk areas. Results showed very high susceptible areas covering 0.21% of Kuala Lumpur of which 5.02% were found in the highly urbanized areas. Meanwhile, a landslide susceptibility map was generated to show low, medium and high susceptible areas in Kuala Lumpur. Results were verified using recorded cases of landslides in Kuala Lumpur which showed a 77% agreement with the study.

Keywords: Landslide, weightage score, GIS, Landsat data, susceptibility mapping, Kuala Lumpur

INTRODUCTION

Landslides are one of the disasters that reshape the surface of the earth through natural processes and adversely impact on the economic lives of people. In recent years, there have been many occurrences of landslide in areas in Kuala Lumpur and in Malaysia in general. Most of these have occurred on cut slopes or on embankments alongside

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roads and highways in mountainous areas. Some of these landslides occurred near high-rise apartments and in residential areas, as shown in Fig.1. According to Pradhan *et al.* (2010a), many major and catastrophic landslides have occurred and continued to occur in Kuala Lumpur within the last decade. In the last quarter of 2008 alone, five major landslides occurred in Kuala Lumpur during the south-east monsoon season with a combined casualty of 331 and 8 deaths. Although landslide related deaths have gradually reduced over the years, what is alarming is the increasing frequency of its occurrence. For land developers, the choice is to build or not to build the housing project, but because of the increasing demands for housing, building developments still continue. In this study, five major factors causing landslides in Malaysia have been analyzed in GIS to map and delineate land areas that are susceptible to landslides in Kuala Lumpur. The aims of the study are to weight the level of influence of each of the five factors in combination with other landslide triggering factors and to generate a landslide susceptibility map for development controls.

Fig.1: Landslides in Bukit Antarabangsa & Damansara Kuala Lumpur (Source: New Strait Times, Dec. 2008)

Landslide Susceptibility Mapping

In the literature, many attempts have been made to predict landslides and to prepare susceptibility maps by using different methods. Earlier attempts to reduce landslide risk were largely a history of management of landslide terrains, construction of protective structures, and the use of in-situ sensors for monitoring and warning systems. Generally, landslide phenomenon is treated as a natural process affecting the environment, according to Toshiyuki *et al*. (2008); however, when it occurs in populated regions, it becomes a serious matter to be investigated. There are three steps in landslide analysis: susceptibility, hazard, and risk (Van Westen, 2008). Susceptibility involves the weighing of various factors influencing the phenomenon to determine the likelihood of the occurrence of a landslide, while hazard determines the danger to lives and property, and risk determines costs and financial implication of landslide.

Landslide susceptibility mapping involves the use of various deterministic and heuristic approaches which have been summarized by Yilmaz (2010) and Van Westen, 2008. Some of these approaches include data mining based ANFIS, fuzzy logic and artificial neural networks (Lee & Evangelista, 2006; Lee, 2007b; Lee & Pradhan, 2007; Pradhan & Lee, 2010a,2010b, 2010c; Van Westen, 2008; Yao *et al*., 2008; Pradhan *et al*., 2009; Pradhan *et al*., 2010a; Oh & Pradhan, 2011; Das *et al*., 2010), and the original weights-of-evidence method (Akgun *et al*., 2011; Pradhan *et al*., 2010b). The weights-of-evidence model has particularly been effectively used for landslide susceptibility mapping, coupled with geographical information systems (GIS). In the landslide literature, many examples of landslide susceptibility mapping can be seen (Lee *et al*., 2007; Lee & Pradhan, 2006, 2007; Pradhan *et al*., 2006, 2008; Youssef *et al*., 2009; Pradhan & Youssef, 2010; Das *et al*., 2010; Pradhan, 2010d,e; Pradhan & Lee, 2010d; Nandi & Shakoor, 2010). Regmi *et al*. (2010) have applied probabilistic and statistical methods such as frequency ratio, multivariate, Bayes' theory based weight-of-evidence and logistic regression to landslide susceptibility and hazard mapping.

Pradhan *et al*. (2011a), based on their extensive study of landslides in Malaysia, concluded that only a few studies have been carried out on landslide susceptibility and risk analysis (Pradhan *et al.* (2011b; Pradhan & Bachroithner, 2010; Oh & Pradhan, 2011; Sezer *et al*., 2010). Lee and Pradhan (2006) performed landslide susceptibility and risk analyses for Penang Island using a frequency ratio and logistic regression model. The use of inventory such as site conditions, geology, hydrology, and geomorphology to establish the statistical correlation of landslide frequency was also studied. In the study by Pradhan and Lee (2009), artificial neural network (ANN) was applied in analyzing landslide hazard based on location, topographical and geological factors, as well as other factors obtained from satellite imagery. Landslide hazard indices were calculated using the trained back-propagation weights to finally create a hazard map that was verified using the landslide locations data. The accuracies achieved in this study were between 72%-83%. The ANN technique was again used for landslide in Penang Island (Pradhan & Lee, 2009). Other studies have involved the validation and cross-validation of the frequency ratio and the logistic regression model in three test areas in Malaysia (Pradhan *et al.,* 2010a,b). In a GIS-based landslide hazard analysis using a back propagation ANN model, the bias effect of the model was compared with the weights-of-evidence concept (Pradhan & Lee, 2010d; Pradhan *et al.,* 2006; Pradhan & Pirasteh, 2010).

Study Area and Causes of Landslides in Malaysia

The study area is Kuala Lumpur, which is located within latitude 03º 2´N to 03º 12´N and longitude 101º 38´E to 101º 46´E. It is a part of the Klang Valley district in the state of Selangor, covering an area of 243.6 km^2 with a population of 1.3 million people. The study area of Kuala Lumpur, as a part of Peninsular Malaysia, is shown in Fig.2.

As land for development becomes limited, the need for improved ways for mapping and monitoring of potential landslide areas has become more important. Thus, zoning is used to demarcate and map areas for development control. Many of the landslide studies carried out in Malaysia have been focusing on the areas in Penang Island and Cameron Highlands, where the impacts of landslides on the population are minimal as compared to Kuala Lumpur. Kuala

Lumpur is a highly urbanized area, and together with the Klang Valley region, comprises of about 20% of the built0up areas in the country (Farisham, 2007). The region attracts a huge population as it is the epicentre of development in Malaysia. This has put a heavy strain on land and property development, the consequences of which any major landslide events will result in the loss of many lives and property. Although there is an increasing frequency of landslides in the recent years due to development pressure on land, very few landslide studies have been carried out in this area.

Landslide is the rapid slipping of a mass of earth or rocks from a higher elevation to a lower level under the influence of gravity and water lubrication. Depending on its size and magnitude, it may become a disaster that affects lives and property. Landslides are a frequent occurrence in Malaysia, and these can generally be observed during and after heavy rainfall, mostly in hilly and cut slope areas. Toshiyuki *et al*. (2008) noted that 90% of 1310 landslide disasters along national highways in Japan were due to the impacts of rainfall. Many studies (for instance, Das *et al*., 2010; Pradhan & Lee, 2009; Vanwesten *et al*., 2008, etc) have shown that other factors related to geological structure, density of faults and lineament, slope angle and river density have triggered landslides in Malaysia. Developments are taking place in hilly areas around Kuala Lumpur due to housing demands. During these developments, however, landslide causative factors such as slope, drainage and vegetation are disturbed, resulting in possible landslide occurrence.

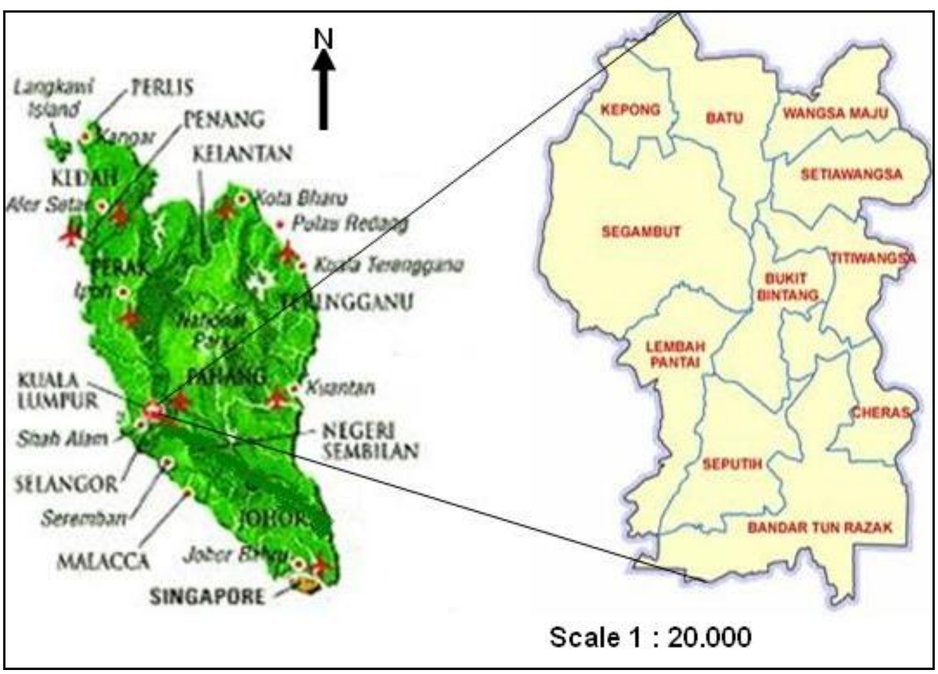

Fig.2: Malaysia and the study area, Kuala Lumpur. (Source: http://www.geographia.com/malaysia/map.gif)

MATERIALS AND METHODS

In this study, an attempt was made to develop a landslide susceptibility map of the Kuala Lumpur city using an average weight-age score method. Firstly, landslide causative factors such as the density of faults and lineament, slope and river density were extracted from satellite data. Landsat TM data, 2004 (Fig.3), with 15 meter resolution (fusion of multispectral band of 30 meter resolution with the panchromatic of 15 meter resolution), were processed to extract the lineaments and the river density, and also for land-use classification. Rainfall data were obtained from the Metrological Department (JPS) of Kuala Lumpur and were further interpolated into grid form. River density and rainfall are important parameters, i.e. storm-water activities caused slopes failures and landslides at many sites in hillside development in Malaysia (Mokhtar, 2006). A Lothology map was digitized from the geological map of Kuala Lumpur and converted into grid. Contour data of 10m interval were used to construct a digital elevation model (DEM) from which the slope map was generated. Table 1 shows the dataset used and the various landslide factors processed into spatial data.

The methodology adopted includes image enhancement, filtering, classifications, overlays, geo-processing and geo-statistic techniques through image processing and GIS. The flow chart in Fig.4 illustrates the remote sensing and GIS steps through which data were processed and thematic maps of landslide factors were generated. The river data represent the numerous rivers and water bodies present across the city of Kuala Lumpur and their sources. Land-use data were

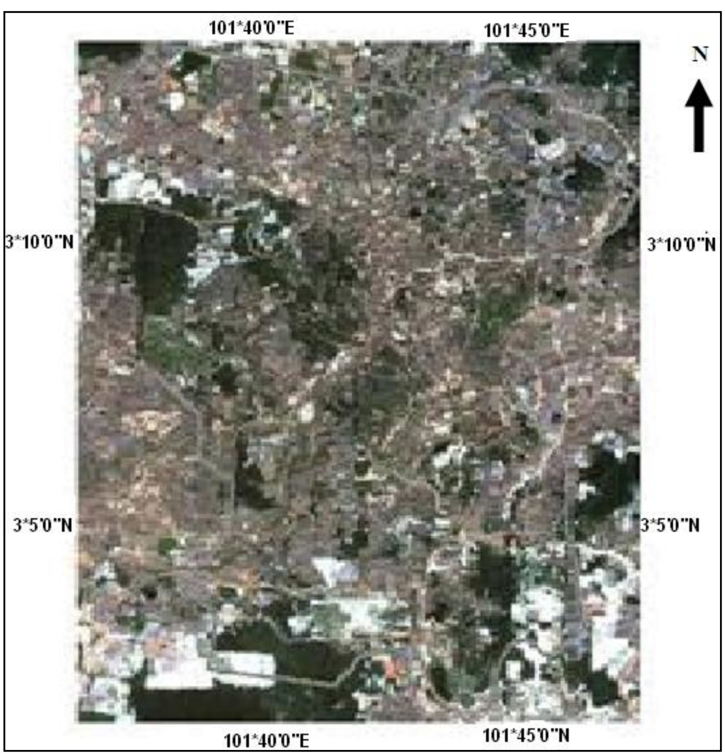

Fig.3: Landsat TM data (Kuala Lumpur) (Source: Malaysia Remote Sensing Agency)

classified into four classes; namely, green land, open area, urban area and water bodies. In the geological data, the geological structure was classified into 5 classes: acid intrusive, alluvium, schist, limestone and quartz. The rainfall data of 2009 were classified into 5 class levels between 94 and 122 mm. This was done to quantify the degree of rainfall erosive action with regards to the historical records of landslide occurrences in the country, and also to establish a pattern of rainfall triggered landslides (Pradhan *et al*., 2008; Farisham, 2007). The landslide factors and their classifications are shown in Fig.5, while lineaments extracted from the Landsat image are shown in Fig.6. These classifications were further discriminated using an average weightage score to show landslide susceptible areas for Kuala Lumpur.

The average weightage score method was applied on the factors by weighting a high score of 5 to the factor that has greater influence on landslide occurrence and the one with a smaller influence with a factor of 1. Thus, the score of 1 (very low impact) to 5 (very high impact) was given to the classes developed for the five factors, and then by using the standard deviation and geo-processing, the high impact areas for landslide occurrence were identified. All these weights

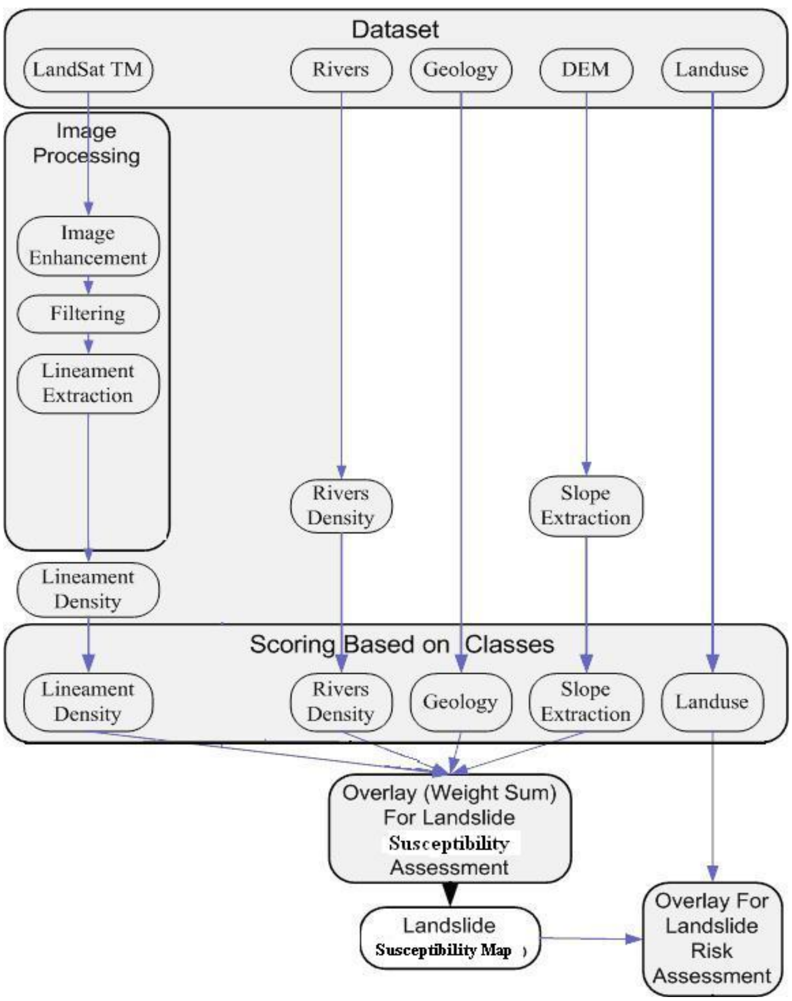

Fig.4: The methodological processes of landslide susceptibility mapping

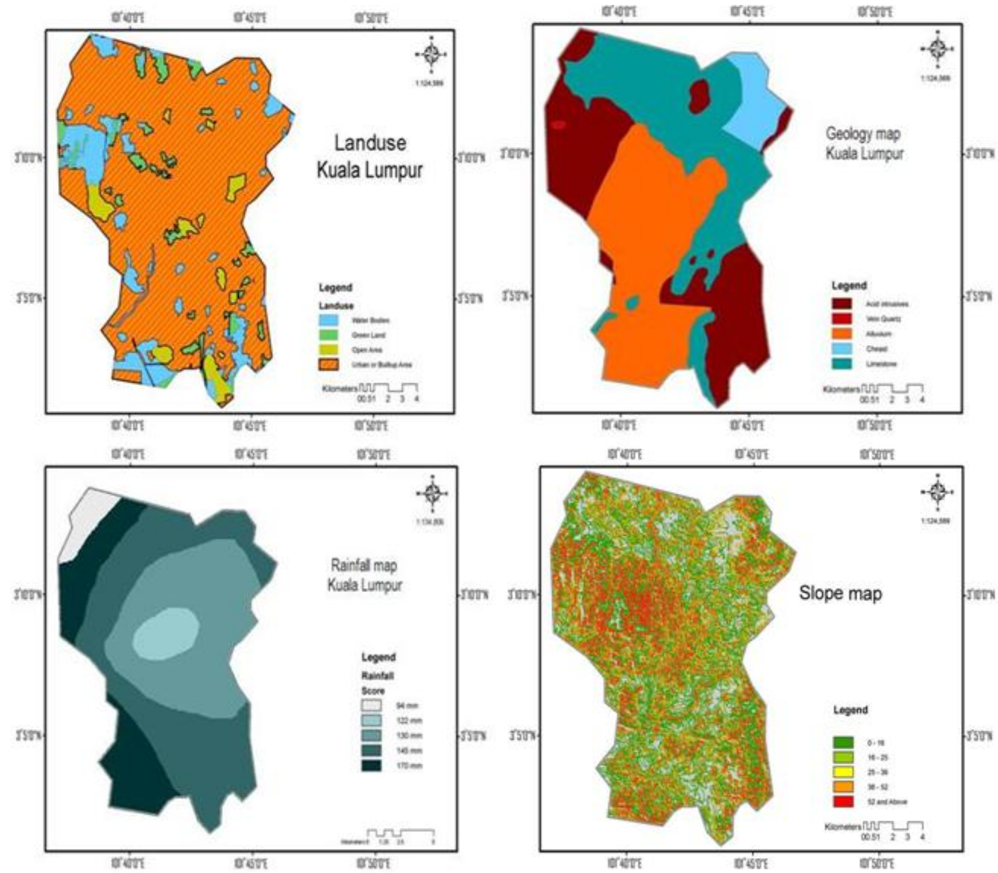

Fig.5: The thematic maps of factors land use, geology, rainfall and slope

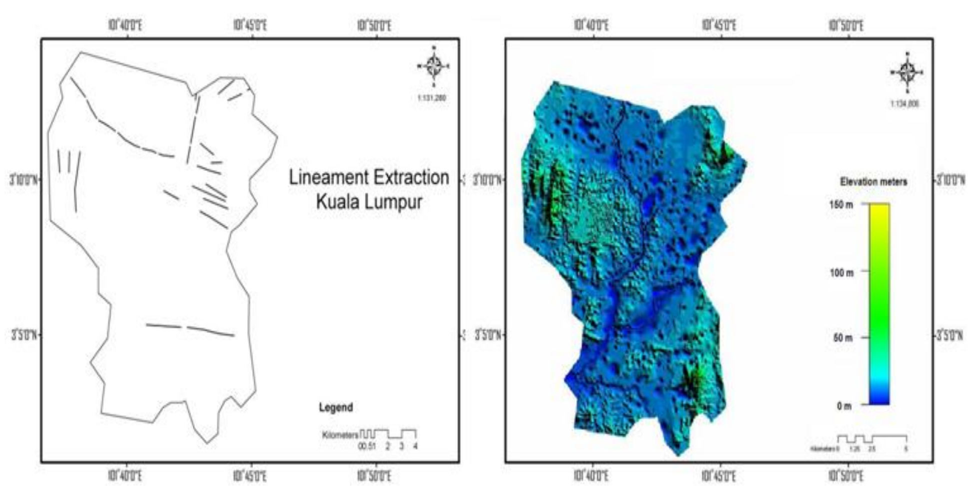

Fig.6: Lineaments extracted from Landsat and DEM from contours

were assigned manually. High density of lineaments was found to be in the congested urban areas and places of human activities, especially in the north east of Kuala Lumpur, as shown in Fig.7. This complements the citations in most literature that areas with more fracturing and faulting are always prone to landslide occurrences.

The river density of a watershed is an important geomorphic parameter to understanding the extent of debris flow and seepage, possible consequences of landslide occurrence. River density (Fig.7) was classified into five levels of 0.2 km^2 difference. Table 2 shows various factors, the classifications given, the score attributed to them, and the percentage area of coverage for each classification.

TABLE 1
Type of Data

Data type	Format	Scale / Resolution
Rainfall	Raster	50 x 50 meter
LandSat TM	Raster	15 x 15 meter
River	Vector	1: 100,000
DEM/slope	Grid	10 x 10 meter
Geology	Grid	1: 100,000
Landuse	Grid	1: 100,000

TABLE 2
Weightage score for the landslide factors

Factor	Classes	Score	Pixels Count	Percentage %
Lineament Density	0.0 – 0.3 /km^2	1	102400	17.97
	0.3 – 0.6 /km^2	2	135692	23.81
	0.6 – 0.8 /km^2	3	126621	22.22
	0.8 – 1.0 /km^2	4	128664	22.58
	1.0 < /km^2	5	76486	13.42
Landuse	Water Bodies	1	29973	10.83
	Green Land	2	13719	4.99
	Open Area	2	12355	4.47
	Urban or Built up Area	5	220678	79.71
Rainfall	94mm	1	3715	3.75
	122 mm	3	18457	18.65
	130 mm	3	38576	38.98
	145 mm	4	33331	33.68
	170 mm	5	4884	4.94
Geology Structure	Acid intrusive	1	178108	28.61
	Granite	2	782	0.12
	Vein Quartz	3	210778	33.85
	Schist	4	33852	5.44
	Limestone	5	199099	31.97

TABLE 2 (*continue*)

Slope º (degrees)	0 – 15 º	1	236252	46.70
	16 º – 25 º	2	73933	14.61
	26 º – 35 º	3	48205	9.53
	36 º – 50 º	4	67593	13.36
	51 º– 90 º	5	79942	15.80
River Density	0.0 – 0.2 /km^2	1	22885	16.60
	0.2 – 0.4 /km^2	2	32482	23.56
	0.4 – 0.6 /km^2	3	25933	18.81
	0.6 – 0.8 /km^2	4	30954	22.45
	0.8 < /km^2	5	25629	18.59

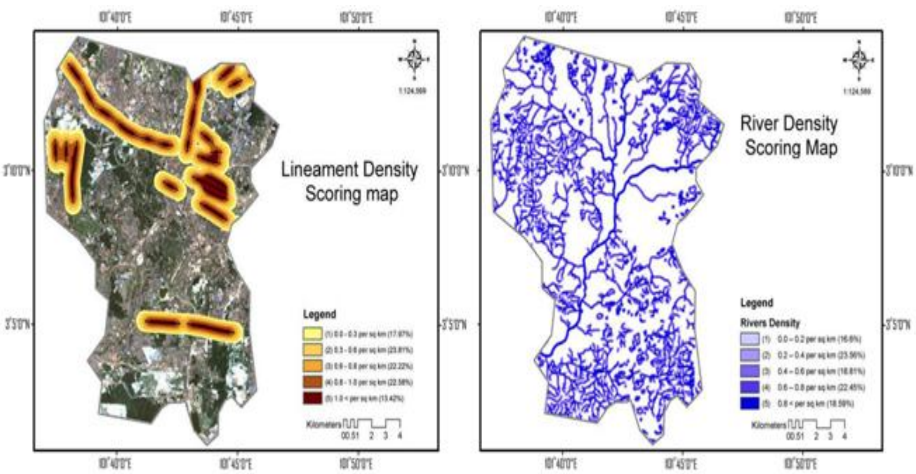

Fig.7: Lineaments and river density in Kuala Lumpur

RESULTS AND DISCUSSION

A map (Fig.8) was generated to show areas that are susceptible to landslide in five classifications (very high, high, moderate, low and very low), with the details of these classes shown in Table 3. The table also illustrates the percentage area of landslide susceptibility as 0.21% (very high), 5.69% (high), 39.77% (moderate), 47.96% (low) and 6.37% (very low). Through spatial overlay and geo-processing, very high susceptible landslide areas were identified as where thematic layer of factors coincide in the range of above 52^{o} (very steep slopes), 139mm and above rainfall rate and in a dense lineaments/fault area. Such areas are seen to include North Kuala Lumpur which makes up about 0.21% of the study area. This map shows areas that are likely to have the potential for landslides. The landuse of such area may determine the consequent of an event of landslide in terms of loss of lives and property. The map shows the extent of urban area found within the landslide susceptible areas. Few developments were found to be in areas that are safe from landslides; this may be attributed to a planning strategy that aims to avoid the consequence of floods, which is another major significant disaster occurrence in Kuala Lumpur.

The landslide susceptibility map developed was verified using the records of landslide occurrence in Kuala Lumpur from 1999 to 2009. Records were obtained from the National Disaster Management Centre and the coordinates of the locations were confirmed from the geological survey of Malaysia. The result of the verification showed that out of 43 documented cases of landslide in the ten-year period, 33 cases fell within the landslide susceptible areas, indicating a 77% agreement with the results of the study. The one scene Landsat imagery (85km x 85km) covers the whole area of Kuala Lumpur and at 15m resolution, the level of accuracy for the extracted factors (land-use, river density, lineament, etc.) for this landslide study were considered to be good. It is also believed that the techniques and methods adopted in this study can achieve a higher accuracy with the use of high resolution data (3m) from satellite sensor such as Quickbird.

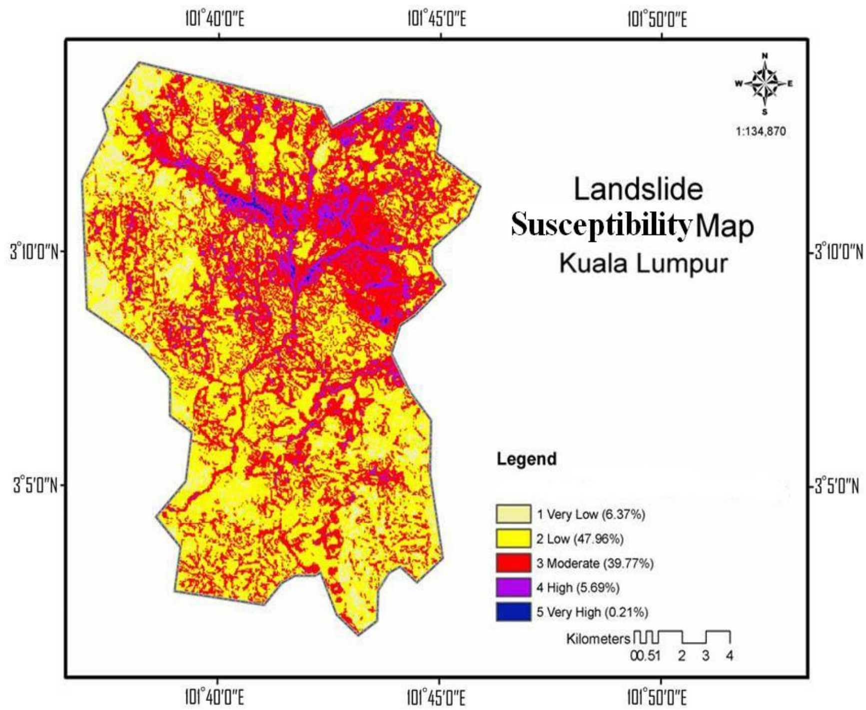

Fig.8: Landslide susceptibility map of Kuala Lumpur

TABLE 3
Level of landslide susceptibility (Kuala Lumpur)

Susceptibility level	Percentage Area (Kuala Lumpur)
1. Very Low	6.37 %
2. Low	47.96 %
3. Moderate	39.77 %
4. High	5.69 %
5. Very High	0.21 %

CONCLUSION

Factors causing landslides in Malaysia include geology, degree of slope, rainfall intensity, density of lineaments and faults and density of rivers. These factors were extracted from Landsat ETM imagery, while others obtained from the various government departments. The factors were processed using image processing, geo-processing and geo-statistic. Thematic layers were analyzed using average weightage score, overlay and geo-statistical processes to generate a landslide susceptibility map for Kuala Lumpur. The results showed that 0.21% of the areas in Kuala Lumpur have a very high susceptibility to landslides, and these cover about 5.02% of the urbanized area. A comparison of the recorded landslides in Kuala Lumpur showed 77% agreement with the study. The study has demonstrated that through streamlining of the main factors using remote sensing and GIS, landslide susceptibility maps can be developed for regular updates of development control maps. The susceptibility map clearly discriminates landslide prone areas by showing urban residential areas within the highly susceptible areas. The limitation of the study is that it uses only five major factors impacting on landslides in Malaysia and assumes these factors as having the same level of influence on landslide occurrence. Hence, the study is not applicable to other regions where the climatic and environmental conditions are different from those of Malaysia and areas where earthquakes and tremors are the major trigger of landslides.

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