GIS IN STUDYING SLOPE FAILURE IN PENANG: CHALLENGES AND POTENTIAL

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ABSTRACT: Geographic Information System (GIS) is an information system that is used to store, display, analyse and manipulate spatial data. Geographic information system (GIS) can help users to visualise, question, analyse, and interpret data to understand patterns, trends, and relationships. GIS-based maps and visualizations have greatly assisted understanding of situations. In recent years, slope failure hazard assessment has played an important role in developing land utilisation planning aimed at minimizing the loss of lives and damages to property. There are various GIS-based slope failure studies that involve many approaches. These approaches can be classified into qualitative factor overlay, geotechnical process models, and statistical models. At present, not many studies have satisfactorily studied the integration of these models with GIS to map slope failure. This paper deals with several aspects of landslide by presenting a focused review of GIS-based slope failure hazard zone. The paper starts with a framework for GIS-based study of slope failure, followed by a critical review of the state-of-the-art applications of GIS and digital elevation models (DEM) for mapping and modelling landslide hazards. The paper ends with a description of an integrated system for effective landslide hazard zonation. The adoption of a GIS-based framework for knowledge discovery allows designers to identify the suitability of development within certain areas. The usage of GIS can be beneficial in various fields, including the issue of slope failure. Moreover, GIS is also beneficial to organisations of all sizes and in virtually every industry. GIS is important in understanding what is happening and forecasting future trend in a geographic space.
Keywords: Geographic Information Systems (GIS), challenges, potential, slope failure

INTRODUCTION

Increasing population has resulted in the opening and development of the areas for residential, industrial, agricultural and other infrastructure development to accommodate the needs and population growth. Physical developments on flat and lowland areas in Penang have now encroached into highland, and the encroachment is causing disruption to the stability of the slope. The phenomenon of slope failure will not only result in adverse impacts on the property, but would also caused fatalities such as the Highland Towers incident in 1993, Gunung Tempurung 1997 and 2004, Pos Dipang 1996, Sandakan 1996, Bukit Antarabangsa 2002 and Bukit Lanjan of New Klang Valley Expressway 2003 (Utusan Malaysia, 2011). The latest slope failure event in Madrasah Al-Taqwa, Hulu Langat has caused the death of 16 orphans and another 24 buried (Utusan Malaysia, 2011).

THE STUDY AREA

Penang State is located at Straits of Malacca between the latitudes of 50^{o} 8' N-50^{o} 35'N and longitudes 100^{o} 8'W-100^{o} 32'W. The State's total land area is 1048 square kilometres, consisting of 121 square kilometre of Northeast district, 176 square kilometre Southwest, 269 square kilometre Northern Seberang Perai, 239 square kilometre Central Seberang Perai and 243 square kilometre Southern Seberang Perai. According to the Department of Statistics (2009), the total population in Penang is 1.6 million people which is 5.7 per cent of the estimated total population of Malaysia. Population density in Penang stands at 1,508 persons per square kilometre.

Penang Island as one of the nation's earliest urban areas is expanding rapidly. Growing population has increased the demand for developmental projects to meet the needs for settlements. With approximately 50 per cent of Penang land area identified as highland, Penang is experiencing population growth in the northern region that possesses hilly topography.

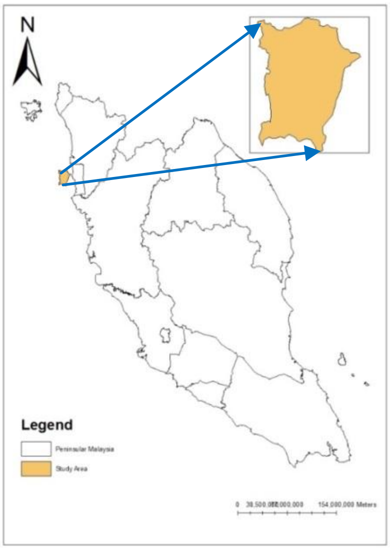

Figure 1: Location of study area
Source: Malaysia Physical Map (2015)

SLOPE FAILURE

Slope failure is a geomorphological process acting on the earth's surface (exogenous) resulting from the degradation of land depletion. Land depletion is a movement of large stones, soil mixed with stones or rocks due to the action of gravity (Tjia, 1987). According to Chung and Fabbri (1999) slope failure is due to spatial factors. Development slope can be a natural phenomenon or human induced (Komoo, 1995). Most of the ruins in Malaysia are classified as slope failure (Komoo, 1995).

The potential slope failure occurred in a certain time and certain areas are affected by the steepness of the slope and weathering processes (Varnes, 1984). According to Tjia (1987), terrain changes depend on the steepness of the slope weathering processes. Avalanche slope failures occurring in the hills and steep mountains will, under some circumstances, lead to mountain slopes into the ground (Ismail, 2001).Slope failure is the degradation of the earth's surface. It has caused significant damage in Malaysia (Wan Ibrahim, 2005). This process acts on earth, either naturally or through external forces, and the result of reaction generated in the depletion shore restore the stability of a slope. The World Landslide Inventory 1996 Commission defines slope failure as pulled by gravity with movement of rock debris down the slope (Sassa, Fukuoka, Wang and Wang, 2005).

According to Komoo (1995), landslide incidents in Malaysia are usually classified as slope failure. Slope failure occurring on the slopes are usually kind of weathered granite rock on the slope of > 20 degree involving small scale but there is no sign before the occurrence of slope failure (Public Works Research Institute (PWRI), 1981).

SLOPE FAILURE IN PENANG

In landslide literature, there are many GIS-based studies on landslide susceptibility and hazard mapping. Different approaches have been employed to measure landslide hazard, including direct or indirect heuristic, deterministic, probabilistic, statistical and data mining. Examples of Penang slope failure studies are Ahmad et al. (2005) and Pradhan (2013).

Landslides remain a major threat in Penang, especially during raining seasons. Since September 1995, Penang has been shocked by 60 landslides incidents in the Penang Hill area following a freak storm that had damaged the pathway near the Penang Botanical Gardens. Landslides occurrences in Penang are mainly due to heavy tropical rainfall. Table 1 below shows record of slope failures in Penang between 1998 and 2015. According to local daily reports, slope failures in Penang Island tend to occur at Paya Terubong, Balik Pulau and Bukit Bendera. Land clearing activities involving hill slopes in Penang State also require serious attention from the authorities as the land became more susceptible to erosion. The situation worsens during monsoon season as greater rainfall affects the movement of soil on the excavated hillsides.

Table 1: Record of slope failure in Penang between 1998 and 2015

Date	Location	Occurrence	Causes
28/11/1998	Paya Terubong	Ruin at Block 8, Sun Moon City	Heavy rain and slope $6^0 > 60^0$
08/09/2008	Balik Pulau	Sedimentation and landslide occurred in Jalan Tun Sardon, Tanjung Bungah, Batu Feringghi	Heavy rain
06/09/2008	Bukit Bendera	Landslide	Heavy rain
09/09/2008	Balik Pulau	Landslide	Heavy rain
09/09/2008	Balik Pulau	Landslide from the slope of the hill country camp service centres (Sri Mutiara)	Heavy rain
22/10/2008	Paya Terubong	10 meter high hillside collapsed	Landslide, Soil erosion, soil instability and the impact of geological hazards
2 /10/2009	Solok Tan Jit Seng at Tanjung Bungah, Pulau Pinang	Landslide	Rain
2 /11/ 2009	War Museum in Batu Maung	Landslide	Construction of housing Project
23 /4/ 2009	30 landslide prone locations are tracked along a 5 km line of vehicles heading from Jalan Kebun Bunga to Bukit Bendera	Landslide	Heavy rain Erosion
14/9/2013	Bukit Bendera hit by 13 landslides, Tanjung Bungah	Landslide	Soil erosion and slope failure
23/9/2015	Paya Terubong	Landslide water gushed down from a hill slope near the Green Garden apartment in Paya Terubong	Water gushed down from a hill slope near the Green Garden apartment in Paya Terubong

Source: Utusan Malaysia (2015)

APLICATION OF GIS IN THE SLOPE FAILURE

GIS helps to predict the occurrence of slope failures by warning potential slope failures and providing a decision-making support system to evaluate the suitability of physical development in the area. GIS can predict the location of potential slope failure in the future. Information and knowledge of the area such as the degree of sensitivity and physical suitability for development are very important to enable more orderly planning and safer development (Harun, 2006). Simon et al. (2009) uses GIS and engineering factors of slope failure disaster assessment to map the zone of potential slope failure along the East Coast Expressway, between kilometre 160 and 190 in the State of Pahang.

This study uses six slope failure factors that are lithology, soil type, land use, topography, slope gradient and total annual rainfall. This study divides the study area into four zones of potential slope failure. The study found that rainfall is the dominant factor in causing slope failure. Other examples of GIS-based slope failure studies include, but is not limited to, Ahmad (2005), Crozier (2010), Alrowaimi (2006), Robin et al. (2008), Rahman et al. (2009), Mantovani et al. (2010), Pareek et al. (2010) and Das et al. (2010). This study maps areas with potential risk of slope failure. This map can help designers and planners to identify areas with potential slope failure and provide precautionary warning to any developmental plan involving these high risk areas.

METHODOLOGY

GIS and Database of the Landslide

In order to perform the landslide analysis, landslide characteristics need to be extracted from the raw data, and undergo pre-processing in order to be quantified.

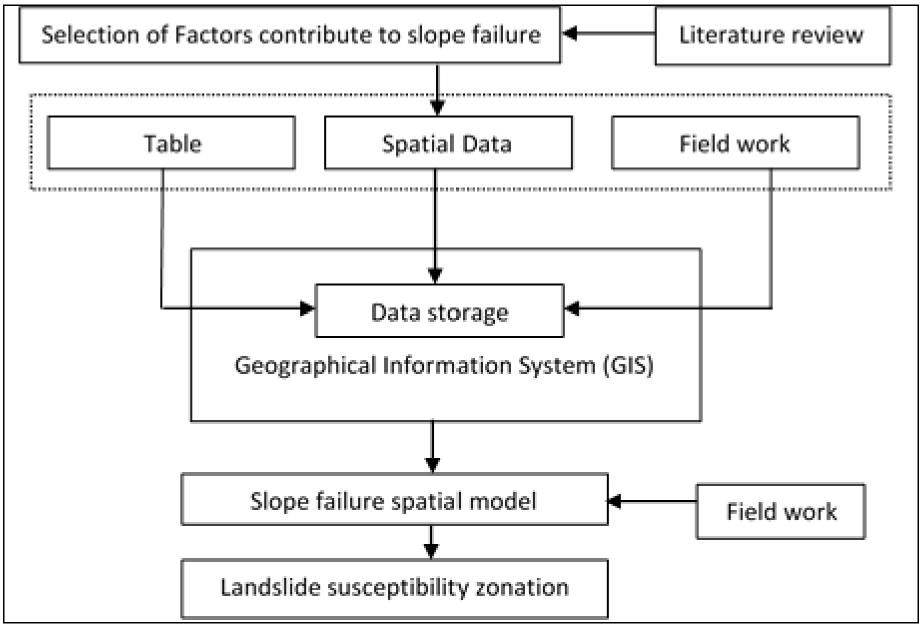

Figure 1: Framework for Landslide Analysis

Through density analysis, line density tool calculates the density of linear features in the neighbourhood of each output raster cell. Density is calculated in units of length per area unit. Conceptually, a circle is drawn around each raster cell centre using search radius. The length of the portion of each line that falls within the circle is multiplied by its landslide field value. These figures are summed, and the total is divided by the circle's area. Figure 2 below illustrates this concept.

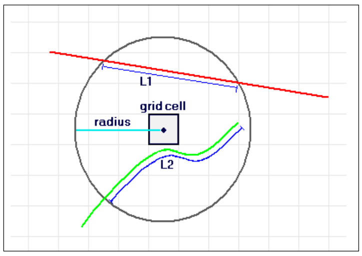

Figure 2: Determining line length using line density tool
Source: ArcGIS Pro, 2015

A raster cell is shown with its circular neighbourhood in Figure 2. Lines L1 and L2 represent the length of the portion of each line that falls within the circle. The corresponding population field values are V1 and V2 respectively. Thus:
Density = ((L1 * V1) + (L2 * V2)) / (area of circle)

The density of point features around each output raster cell. Conceptually, a neighbourhood is defined around each raster cell centre, and the number of points that fall within the neighbourhood is summed and divided by the area of the neighbourhood. Increasing the radius will not greatly change the calculated density values. Although more points will fall inside the larger neighbourhood, this number will be divided by a larger area when calculating density. The main effect of a larger radius is that density is calculated considering a larger number of points, which can be farther from the raster cell. This results in a more generalised output raster.

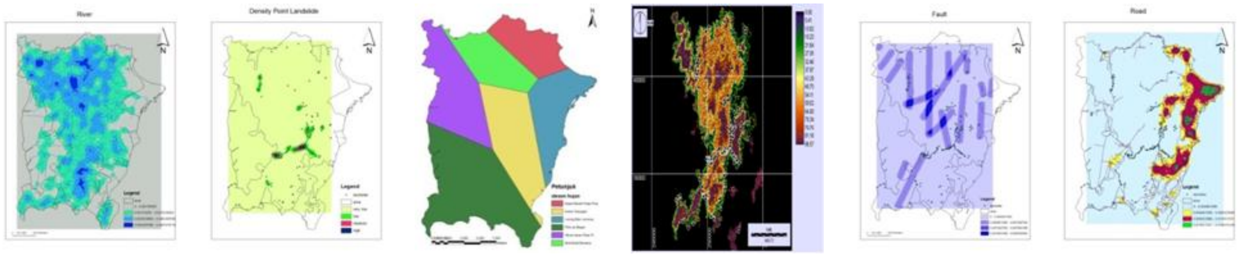

Figure 3: Maps of causal factors in slope failure

Clearly, a useful hazard zonation map should also depend on other factors that affect the mechanism of landslide occurrence such as river, road, fault and rainfall. Therefore, the next step is to incorporate these factors and other relevant parameters in hazard analysis. In order to analyse hazard systematically and efficiently, the use of GIS is essential (Van Westen and Lulie Getahun, 2003).

DISCUSSION AND CONCLUSION

A framework for analysing slope failure based on landslide records through the use of GIS technology is proposed for Penang State. A landslide hazard zonation map is also proposed based on data collected. GIS enables incorporation of various layers in the framework of landslide hazard analysis in Penang. The incorporation of dynamic slope failure analysis with GIS will produce a more reliable landslide hazard map for city planning and potential planning error can be minimised. Table 2 shows the derivation of layers and their respective weight value. Table 3 shows susceptibility map zone analysis of slope failure and Figure 3 displays susceptibility map zone analysis of slope failure.

Table 2: Derivation of the layers and influence assigned to each Weighted Overlay operation

Data source	Geoprocessing Tool	Process Output	Raster Classification Tool	Weight
Drainage	Line Density	Drainage Density	Drainage Reclassify	0.033
Lineament	Line Density	Lineament Density	Lineament Reclassify	0.040
Topography	Feature to Raster	Karst Raster	Karst Reclassify	0.200
Geological	Feature to Raster	Lithology	Reclassify	0.050
Rainfall	Point	Rainfall Thiessen	Reclassify	0.070
Road	Line Density	Road Density	Reclassify	0.640

Table 3: Susceptibility Map Zone Analysis of Slope Failure

Zone	Value P	Category	% Width	% SF	Total SF
1	0-0.3	Very low	48.13	0	0
2	0.03-0.6	Low	33.90	0.95	2
3	0.6-0.75	Moderate	12.54	3.81	8
4	0.75-0.95	High	4.07	9.52	20
5	0.95-1.00	Very High	1.36	85.71	180
Total			100	100	210

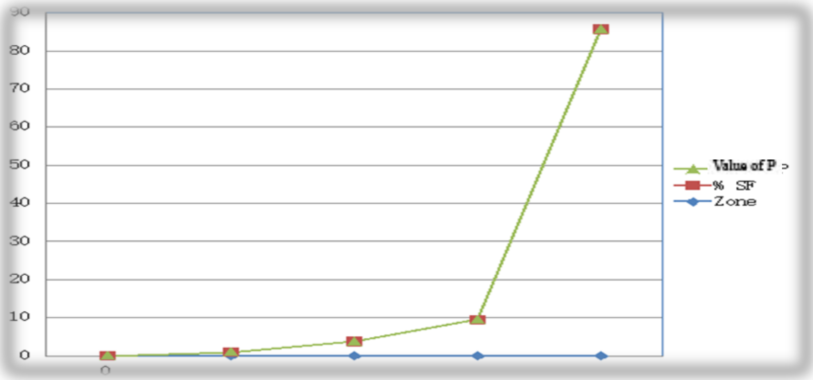

Figure 4: Susceptibility Map Zone Analysis of Slope Failure

Table 4: Analysis of slope failure susceptibility zone map based on field data

Zone	P-value	Category	% Width	% SF	Total SF
1	0-0.3	Very low	48.13	0	0
2	0.3-0.6	Low	33.90	2.63	1
3	0.6-0.75	Moderate	12.54	10.53	4
4	0.75-0.95	High	4.07	13.15	5
5	0.95-1.00	Very High	1.36	73.69	28
Total			100	100	38

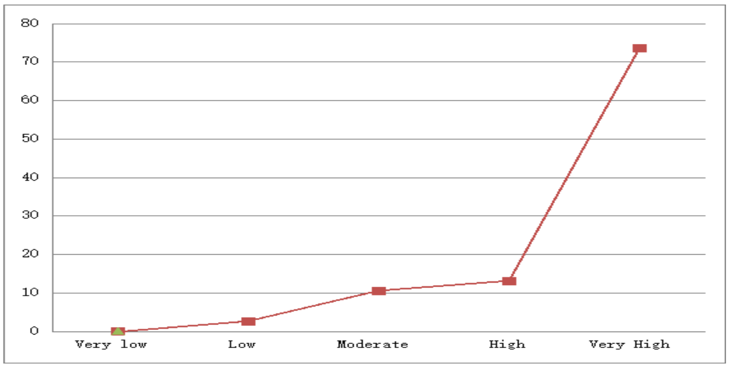

Figure 5: Slope Failure susceptibility zone map based on field data

Nominal data serves as quantitative representation that excludes the minimum and maximum values of the actual data. Chapin and Kaiser (1979) states that data must be divided into two parts for model development and model testing, but they did not specify the breakup of percentage among the parts. Although landslides can destroy human infrastructure and be potentially deadly, with the exception for a few incidents, their impact is generally localised and predictable. Slope failure in Penang is a challenging environmental problem that threatens the well-being of the population. Potential slope failures mapping illustrates the importance of slope failure disaster zone mapping by documenting the most dangerous zones for human settlement. In conclusion, the formation of the space model using GIS can successfully produce models that are capable of categorising zones according to the level of hazard.

The study found the model's accuracy satisfactory. From the field trials, 73.69 per cent of the slope failure occurred in Zone 4, making it the most dangerous zone. 10.56 per cent of the failure are to be found in the moderate Zone 3, and 5.26 per cent in Zone 2. No slope failure was detected in Zone 1. These results indicate well-classified slope failure occurrences. In this study, five classification systems were considered: very high at 85.71 per cent, high zone 9.52 per cent, moderate 3.81 per cent and low 0.95 per cent. Again, no slope failure occurred in Zone 1. This indicates well-classified results.

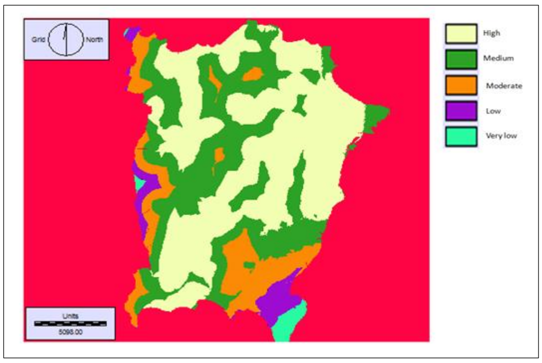

Figure 6: Slope Failure Susceptibility Zonation Map

This paper has described the methodology to generate a landslide susceptibility map using the following factors: drainage, lineament, topography, geological, rainfall and road. Landslide susceptibility map are of great help to planners and engineers for choosing suitable locations to implement developments. These results demonstrate how susceptible map can assist in slope management and future land planning. The models used in this study are valid for generalised planning and assessment purposes. They may be less useful at site-specific scale where local geological and geographic heterogeneities may prevail.

REFERENCES

Ahmad, F. S. (2005). *Penggunaan Sistem Maklumat Geografi Untuk Meramal Keruntuhan Cerun Di Pulau Pinang*. Ijazah Sarjana Kejuruteraan (Geoteknik) Fakulti Kejuruteraan Awam Universiti Teknologi Malaysia

Ahmad, F., Yahaya, A. S., & Farooqi, M. A. (2006). Characterization and Geotechnical Properties of Penang residual Soil with Emphasis on landslides. *American Journal of Environmental Science, 2*(4), 121-128.

Alrowaimi, R. M. M. (2006).*The Compressibility of Fill Subjected to Applied Stress and Inundation*. Faculty of Civil Engineering. Universiti Teknologi Malaysia. Tesis Sarjana. [online]. Available: http:// eprints. utm.my/ 2194/1/ Mohamed MuftahRAlrowaimi [17.07.2010]

ArcGIS (2015). *How Line Density Works*. Retreived from http://pro.arcgis.com/en/pro-app/tool-reference/spatial-analyst/how-line-density-works.htm

Chapin, F.S. & Kaiser, E.J. (1979). *Urban Landuse Planning*. Urbana: University of Illinois Press.

Crozier, M.J. (2010). Deciphering the effect of climate change on landslide activity: A review. [doi: DOI: 10.1016/j.geomorph.2010.04.009]. *Geomorphology, 124*(3-4), 260-267.

Chung, C.F. & Fabbri, A.G. (1999). Probabilistic Prediction Models for Landslide Hazard Mapping, *Photogrammetric Engineering and Remote Sensing, 65*(12): 1389–1399.

Das, I., Sahoo, S., van Westen, C., Stein, A., & Hack, R. (2010). Landslide Susceptibility Assessment Using Logistic Regression and its Comparison with a Rock Mass Classification System, Along a Road Section in the Northern Himalayas (India). *Geomorphology, 114*(4): 627-637.

Department of Statistics, Malaysia (2009). *Demografi dan Penduduk*. Jabatan Perangkaan Malaysia.

Harun, N. H. (2006). *Kajian Penentuan Kawasan Bukit Berisiko Menggunakan Sistem Maklumat Geografi (GIS)*. Universiti Teknologi Malaysia. (Tesis Sarjana). Tidak diterbitkan

Ismail, N. H. (2001). *Tanah Runtuh Dan Masalah Alam Sekitar Yang Terpinggir*. (Tesis Sarjana). Universiti Sains Malaysia. Tidak diterbitkan

Komoo, Ibrahim. (1995). *Geologi Kejuruteraan Perspektif Rantau Tropika*. Bangi: Penerbit Universiti Kebangsaan Malaysia. Syarahan Perdana Jawatan Profesor.

Malaysia Physical Map. (2015). Retrieved from http://malaysiamap.facts.co/malaysiamapof/ malaysiamap.php

Mantovani, F., Gracia, F.J., Cosmo, P.D. & Suma, A. (2010). A New Approach to Landslide Geomorphological Mapping Using the Open Source Software in the Olvera Area (Cadiz, Spain). *Landslides, 7(1)*: 69-74.

Pareek, N., Sharma, M.L., & Arora, M.K. (2010). Impact of Seismic Factors on Landslide Susceptibility Zonation: A Case Study in Part of Indian Himalayas. *Landslide*. 7: 191–201.

Pradhan, Biswajeet. (2013). A comparative study on the predictive ability of the decision tree, support vector machine and neuro-fuzzy model in landslide susceptibility mapping using GIS. *Computer & Geosciences, 51*, 350-365.

Public Works Research Institute (PWRI) (1981). *Slope Failure in Japan*. Japan: Slope Failure Division, Public Works Research Institute.

Rahman, Zulfahmi Ali, Abd. Rahim, Sahibin, Yaakob, Jasni and Idris, Wan Muhd Razi (2007). Tinjauan Awal Potensi Ketidakstabilan Cerun dan Cirian Fiziko-Kimia Tanah di Cameron Highland, Pahang. *Sains Malaysiana*. 36(2): 105-116.

Robin, F., Corominas, J., Bonnard, C., Cascini, L., Leroi, E., & Savage, W. Z. (2008). Guidelines for Landslide Susceptibility, Hazard and Risk Zoning for Land Use Planning. *Engineering Geology*. *102*: 85–98.

Sassa, K. Fukuoka, H., Wang, F., & Wang, G. (2005). *Landslides Risk Analaysis and Sustainable Disaster Management*. NewYork: Springer Berlin Heidelberg.

Simon N, Mat Akhhir, J., Napiah, Azlikamil & Tan, Han Kee. (2009). Pemetaan Potensi Bencana Tanah Runtuh Menggunakan Faktor Penilaian Bencana Tanah Runtuh Dengan Pendekatan GIS. *Geological Society of Malaysia, 55*, 47–53.

Tjia, H.D. (1987). *Geomorfologi*: Dewan Bahasa Dan Pustaka Kementerian Pendidikan Malaysia Kuala Lumpur.

Utusan Malaysia (2015).Trageditanahruntuh[online],Available:http://ww1.utusan.com.my/utusan/in fo.a sp?y=2011&dt=0808&sec=Muka_Hadapan&pg=mh_01.htm [online] 26.08.2015

Varnes, C.J. (1984). Landslide Hazard Zonation: A Review of Principal and Practice Commission on Landslide of the IAEG, UNESCO. *Natural Hazards*. 3:61.

Van Westen, C. J., & Lulie Getahun, F. (2003). *Analyzing the evolution of the Tessina landslide using aerial photographs and digital elevation models*. *Geomorphology, 54*(1-2), 77-89. DOI: 10.1016/S0169-555X(03)00057-6

Wan Ibrahim, Wan Mohd Muhiyuddin (2005). *Pembentukan Model Ruangan Kegagalan Cerun Bagi Sub Lembangan Hulu Sungai Langat*. (Tesis PhD). Universiti Sains Malaysia. Tidak diterbitkan.