ISSN: 2521-0920 (Print)
ISSN: 2521-0602 (online)

Contents List available at RAZI Publishing

Malaysian Journal of Geosciences

Journal Homepage: http://www.razipublishing.com/journals/malaysian-journal-of-geosciences-mjg/

https://doi.org/10.26480/mjg.02.2017.13.19

LANDSLIDE SUSCEPTIBILITY ANALYSIS (LSA) USING WEIGHTED OVERLAY METHOD (WOM) ALONG THE GENTING SEMPAH TO BENTONG HIGHWAY, PAHANG

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ARTICLE DETAILS

ARTICLE HISTORY:

Received 12 May2017
Accepted 12 July 2017
Available online 10 September 2017

KEYWORDS:

Landslide Susceptibility Analysis (LSA)
Weighted Overlay Method (WOM)
Pahang

ABSTRACT

This study focused on the Landslide Susceptibility Analysis (LSA) of the Karak highway, which link the Genting Sempah to Bentong area, Pahang. The physical relief of the study area is largely flat to undulating and moderately rough to steep mostly. The aims of this study are to identify the landslide prone area and to produce the Landslide Susceptibility Level (LSL) map using Weighted Overlay Method (WOM) integrated with Geographic Information System (GIS) and remote sensing techniques. Landslide locations were identified in the study area from imagery and aerial photograph interpretations followed by field work observation. The topographic, geologic data and satellite images were collected, processed and constructed into a spatial database using image processing. The factors that influence landslide occurrences such as slope gradient, slope aspect, topographic curvature and distance from drainage were retrieved from the topographic database. Geomorphology, lithology and geological structure were generated from the geologic database; whereas land use and soil types from SPOT satellite data image. Several areas are considered as susceptible, such as areas of Ladang Fook Who, Kg. Temiang, Ladang Ng Chin Siu, Kemajuan Tanah Genting Pandak, Kg. Lentang, Kg. Baharu Bt. Tinggi and Ladang Pandak. To avoid or minimize the landslide occurrences, development planning has to consider the hazard and environmental management program. This engineering geological study may play a vital role in Landslide Risk Management (LRM) to ensure the public safety.

1. INTRODUCTION

Flooding Landslide is among the major geohazards in Malaysia. As with flooding, tsunami, siltation and coastal erosion, these have repeatedly occurred in the region with disastrous effect. Landslide is a general term for a variety of earth processes by which large masses of rock and earth material spontaneously move downward, either slowly or quickly by gravitation [1]. Such earth processes become geologic hazards when their direct interaction with the material environment is capable of causing significant negative impact on a human's wellbeing.

Landslide processes take place when the slope materials are no longer able to resist the force of gravity. This decrease in shear resistance resulting in landslide is due to either to internal or external causes. Internal causes involve some change in either the physical or the chemical properties of the rock or soil or its water content. External causes, which lead to an increase in shear stress on the slope usually, involve a form of disturbance that may be either natural or induced by man. With the growth of human population and the expansion of the scope of human's activities in Malaysia, we find ourselves increasingly in conflict along steeply area [2]. A landslide zoning provides information on the susceptibility of the terrain to slope failures and can be used for the estimation of the loss of fertile soil due to slope failures (in agriculture areas), the selection of new construction sites and road alignments (in urban or rural areas) and the preparation of landslide prevention, evacuation and mitigation plans. Natural hazard mapping concerns not only delineation of pas occurrences of natural hazards such as landslide, but it also includes predicting such occurrences [3].

In the literature, there are four different approaches to the analysis of LSL: landslide inventory-based probabilistic, heuristic (which can be direct geomorphological mapping, or indirect qualitative map combination), statistical (bivariate or multivariate statistics) and geotechnical approach [4-6]. LSL analysis using probabilistic models were published by some researcher [7,8]. Most of the above studies have been conducted using the regional landslide inventories derived from aerial photographs and remotely sensed images.

The heuristic approach is considered to be useful for obtaining qualitative LSL maps for large areas in a relatively short time. It does not require the collection of geotechnical data, although detailed geomorphological mapping is essential. The qualitative approach is based on expert opinion and the susceptible areas are categorized by such terms as "very high", "high", "moderate", "low" and "very low". The increasing popularity of Geographic Information Systems (GIS) has led to many studies, mainly using indirect susceptibility-mapping approaches [9]. As a consequence, fewer investigations use GIS in combination with a heuristic approach, either geomorphological mapping, or index overlay mapping and analytical hierarchy process [10-20].

Statistical analyses are popular because they provide a more quantitative analysis and can examine the various effects of each factor on an individual basis. Statistical analyses of LSL can include bivariate and multivariate methods. The bivariate methods, are a modified form of the qualitative map combination with the exception that weights are assigned based upon statistical relationships between past landslides and various factor maps; alternatively, these statistics can be used to develop decision rules [21]. The main difference among the specific bivariate methods is the manner in which the weights are produced. Different methods have been proposed, including: general instability index, frequency index, surface percentage index, statistical index method, weighting factor, certainty factor, conditional analysis, weights of evidence, landslide susceptibility analysis, and information value method [22-72]. These indices measure, directly or in a weighted form, the relative or absolute abundance of landslide area or number in different terrain categories. This information is then used by the investigator to establish susceptibility levels. Meanwhile, multivariate methods have been used for LSL. The prominent techniques used in multivariate methods are: multiple linear regression analysis, discriminant analysis, and logistic regression analysis [73-104]. When many factors are available, to reduce the number of variables and to limit their interdependence, principal component analysis (PCA) is an option [105,106]. More advanced methods employ a variety of classifications techniques such as fuzzy systems, artificial neural networks (ANN), expert systems and Factor Analysis Model [107-109].

Various approaches to geotechnical analysis for LSL have been developed. Some of the earliest studies in a GIS environment were carried out [110-115]. Their use of a GIS environment made it possible to extend the conventional, site specific deterministic model into larger areas, where the spatial distribution of input parameters is taken into account. However, a study observed that geotechnical approaches for LSA in a GIS environment have not been checked with traditional methods of analysis, neither have they been validated with results of landslide monitoring [116,117]. Comprehensive studies concerning regional slope stability assessment supported by deterministic approaches in a GIS environment have also been carried out. Some researcher combines a slope stability model (Stability INdex MAPping, SINMAP) with a steady-state hydrology model in selected watersheds of northern Vancouver Island, British Columbia and in the central highlands of Honduras, respectively [118]. High attention should be paid to the accuracy and variability associated with the input parameters. Similar examples of regional modeling and prediction of shallow landslides using a transient rainfall infiltration model in combination with slope stability calculation (Transient Rainfall Infiltration and Grid-based Regional Slope-stability analysis; TRIGRS) were applied for the Seattle area, Washington State, USA and the Umbria Region, central Italy [119]. The TRIGRS model predicts a larger area of instability than the area that actually failed, mainly due to uncertainty in soil thickness, local variation in soil properties, and Digital Elevation Model (DEM) errors.

2. STUDY AREA

The study area, located along the Karak highway, which link the Genting Sempah to the Bentong, Pahang. It is bounded by longitude line E 101° 45' to E 101° 55' and latitude line N 03° 20' to N 03° 25' (Figure 1 & 2). The physical relief of this study area is largely flat to undulating and moderately rough to steep mostly and has altitude ranging from mean sea level to 1317m. Mt Kolam Berengga is the highest peak.

Figure 1: Location of study area in Pahang State

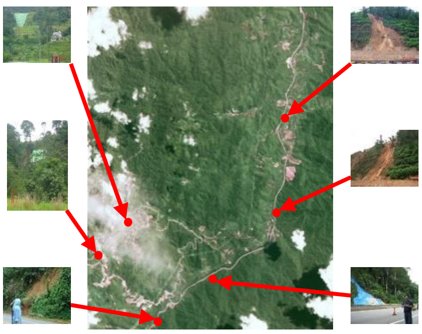

Figure 2: Landslide locations area

3. MATERIALS AND METHODOLOGY

In LSA, data were provided and stored into a spatial database. The analysis was carried out based on eight attributes: slope gradient, slope aspect, lithological, soil types, geologic structural, geomorphology setting, drainage and land use. All of these factor attributes was extracted and analysis based on the knowledge of weightage overlay. Each given weightage on the attributes was summed altogether and reclassified to generate a landslide susceptibility map. Lastly this LSL map needed to be verified. In this study, all attributes factor are consider equal important.

A key assumption using probabilistic model, weightage overlay approach, is that the potential of landslides will be comparable to the actual frequency of landslides based on the attributes factor. These weightage on the attributes are subject to the combination degree of landslide occurrences. Landslide susceptible areas are observed and detected by the imagery and aerial photograph interpretations followed by fieldwork verification. For this study, detail landslide history areas were reviewed and acting as a control factor. By given topographic database, the digital elevation model (DEM) with 20 m resolutions, slope gradient and slope aspect maps were produced. Using the topographic database also, the distance from drainage and lineament (geologic structural) were calculated. The buffer interval used for distance calculation was in 50 m range and presented to a raster map. All the attribute factors were given as weightage accordingly to their criteria and priority (Table 1). All the calculated and extracted weightage were converted to raster map for analysis. Using the weightage overlay approach, the spatial relationships between each landslide-factor were analysed. The entire factor's rating (weightage) was summed to produce LSL map. Finally, a ground checking was conducted on field to verify the LSL map (Figure 3).

Table 1: Attribute weightage

Geomorphology (GGM_DESC)	
Wt	**Description**
4	Denudational hill
10	Structure denudational hill
Soil (AST_SERIES)	
Wt	**Description**
4	Renggam
10	Steepland
6	Telemong
River (DISTANCE)	
Wt	**Meters**
10	50
8	100
6	150
4	200
2	250
1	1000

Structure/ Lineament (Distance)	
Wt	**Meters**
10	50
8	100
6	150
4	200
2	250
1	10000
Land use (ALU_DESC)	
Wt	**Description**
8	Urban & associated areas
4	Rubber
3	Orchard
1	Natural forest
5	Scrub
2	Bush
6	Mixed horticulture
7	Recreational areas
Litology (LITO_TYPE)	
Wt	**Description**
10	Schist
4	Acid intrusive (undifferentiated)

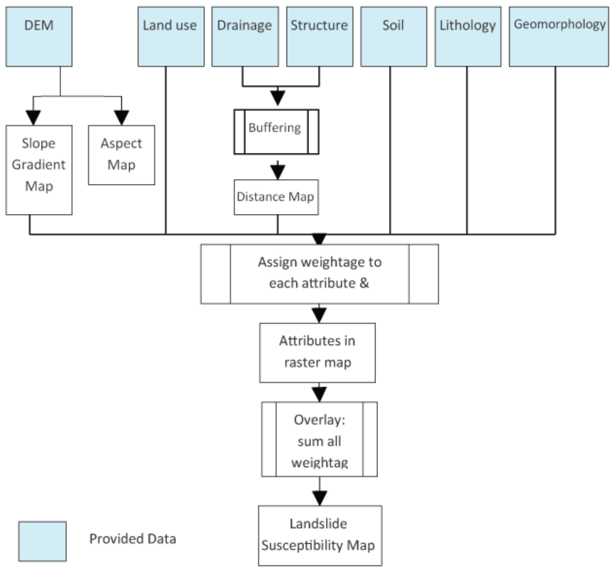

Figure 3: Flowchart of methodology

4. GEOLOGICAL BACKGROUND

The study area is essentially made up of granitic rocks as the main underlying geology (Figure 4). The granite body is postulated to be Triassic in age which is part of the Main Range Granite [28]. Ong described termed it as the Gombak Granite which consist mainly of coarse to medium grained biotite muscovite granite, fine to medium grained tourmaline granite, pegmatite and greisen [89]. Beside the granite body, older rock formations are the Hawthornden Formation of Middle-Upper Silurian in age and co-exist with the Kuala Lumpur Limestone Formation, although the latter is postulated to be younger and lies unconformably above the former. The Hawthornden Formation comprises mainly of phyllite, slate and schist, whereas the Kuala Lumpur Limestone has been metamorposed and recrystalised to form coarse grained white to pale coloured marble.

The alteration process of the granite country rock and the formation of the quartz dyke were believed to take place during the Post-Triassic era. There is no certain age given to the Quartz Reef except that it is younger than the surrounding Triassic granite (Figure 5). However, from radioactive dating of K?Ar of two generations of muscovite in quartz reef sample from the Seri Gombak area it is believed to be as old as Mid-Cretaceous to Jurassic. More than half geomorphological landforms of the state comprises of alluvial plain and fluvial landforms whereas the others were occupied by denudational landforms namely residual hill, structural hill denudational hill etc. Landslide features were found and recorded at several localities especially at the newly developed hilly area. There have been several landslides occurrences in this surrounding area recently (Figure 2).

Figure 4: Granitic rocks in the study area

Figure 5: Quartz reef at Taman Melawati Area

5. RESULTS AND DISSCUSSION

5.1 Causes of landslide in the study area

The main factors causing of landslide in the study area include preparatory mechanism and triggering factors:

5.1.1 Preparatory mechanisms

Preparatory mechanisms are cumulative events, which prepare the slope for failure but do not necessarily produce movement. These includes the geology, slope gradient, elevation, soil geotechnical properties, vegetation cover, long – term drainage system / pattern and weathering. The study of the preparatory or conditioning factors should be based on a systematic inventory conducive to the creation of a database, which will allow the quantification of the relationship between slope failure and the geological and geomorphological characteristics of the terrain.

5.1.2 Triggering factors

Triggering factors or variables are which shift the slope from a marginally stable to an unstable state and thereby initiating failure in an area of given susceptibilities such as heavy rainfall and tremors. These variables can change over a short time span and are thus very difficult to estimate. If triggering variables are not taken into account the term susceptibility may be employed to define the likelihood of the landslide event occurrence. Susceptibility to failure is determined by the geological structure and lithology of the slope, hydrogeological conditions and the stage of morphological of the study area.

5.2 Application of Weightage Overlay Method (WOM) and Landslide Susceptibility Level (LSL) map

Landslide occurrence is determined from landslide related factor and the future landslide can occur in the same condition with past landslide. Based on the assumption using probability method, the relationship between areas with landslide occurrences and landslide related factors could be distinguished from the relationship between area without occurrences of landslide and landslide related factors. To present the distinction quantitatively, the weightage overlay method was used for this study.

The analysis and calculation processes in the analysis and modelling part were similar for all the parameter maps. To avoid longer time for doing the calculation and redundant task, the scripts or batch files as shown in Tab. 1 were used in the analysis. The weightage value shows that the most causative factor that influenced landslide occurrences is slope gradient. Figs. 6 to 9 show the weightage value polygon to land use, distance from drainage, distance from lineament, soil lithology and geomorphology.

Five classes of LSL were adopted: very low (10 %), low (50 %), medium (15 %), high (15 %) and very high (10 %) (Figs. 6 to 9). The very low to low LSL reflects the probability of occurrence of landslides are very limited even with existence strong triggering factors, such as heavy rainfall and tremendous land use changes. On the other hand, moderate LSL means that, some landslide will be generated under the influence of intense triggering factors whereas the high to very high hazard means a considerable number of landslides will occur even with the presence of weak triggering factor. In the study area, most of the high to very high LSL area are elongated along the hilly terrain area in the eastern part of the state.

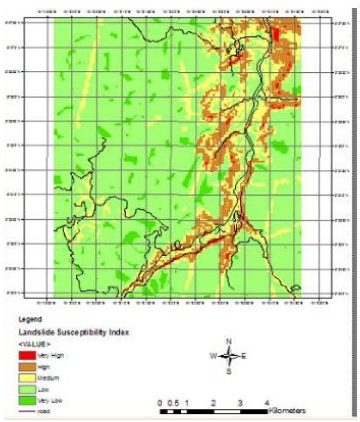

Figure 6: Landslide hazard zoning map of the study area

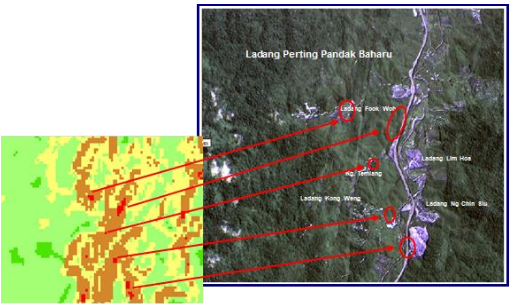

Figure 7: Landslide hazard zoning map at Ladang Perting Pandak Baharu area.

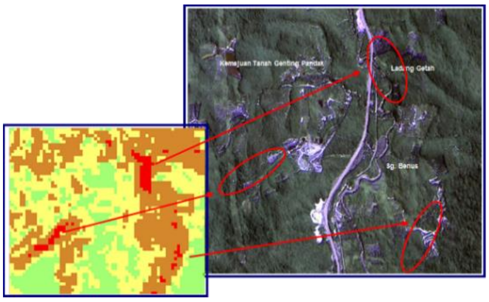

Figure 8: Landslide hazard zoning map at Kemajuan Tanah Genting Pandak area

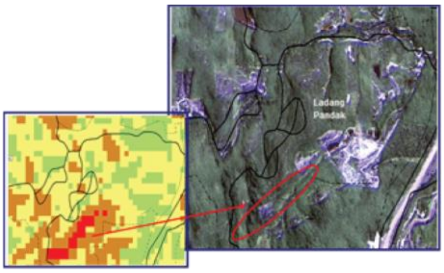

Figure 9: Landslide hazard zoning map at Ladang Pandak

6. CONCLUSION

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

a. Engineering geologic evaluation of the study area indicates that the landslide took place when slope materials are no longer able to resist the attraction of gravity due to a decrease in shear strength and increase the shear stresses resulting landslide, which is due to preparatory mechanism and triggering factors. Preparatory mechanisms are cumulative events, which prepare the slope for failure but do not necessarily produce movement. These include the geology, slope gradient, elevation, soil geotechnical properties, vegetation cover, long – term drainage system / pattern and weathering. Triggering factors or variables are which shift the slope from a marginally stable to an unstable state and thereby initiating failure in an area of given susceptibilities such as heavy rainfall and tremors.

b. High (15 %) to very high (10 %) LSL means a considerable number of landslides will occur even with the presence of weak triggering factor. Mostly these areas have been totally or partially cleared for utilized for other associated infrastructure developments. High to very high LSL is not so suitable for development and would encounter high geotechnical constraints, requires intensive site investigations and thus would incur high development costs.

c. LSL maps are useful to planners and engineers for choosing suitable locations to implement developments. Although the results can be used as a basic data to assist slope management and land use planning, the methods used in the study area only valid for generalized planning and assessment purposes, and may be less useful at the site-specific scale where local geological and geographic heterogeneities prevail.

7. RECOMMENDATION

Landslide occurrences have been the most critical issues in Malaysia. Frequency, size and impact the community kept on increasing. Landslide incidents mostly are due to human activities. Therefore by planning, management and proper construction, this landslide problem can be avoided. Settlement of the landslide issues required multi-purpose approach and long term planning. Cooperation among government agencies such as local universities, Department of Public of Work (DPW), Department of Irrigation and Drainage (DID), Department of Natural Environmental (DNE), Department of Mineral and Geosciences (DMG), Department of Meteorological (DM) and local authorities are needed at all levels and should be continuously. Research therefore needs to have integration approach and need to be performed systemically. In spite of that geology discipline can contribute at all levels of avoidance and control of this geohazards occurrences.

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