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GIS Based Multi-Criteria Decision Making for Landslide Hazard Zonation

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Abstract

Growing population and expansion of settlements over hilly areas have largely increased the impact of natural disasters such as landslide. This paper deals with the use of Geographical Information System (GIS) and Multi-criteria Decision Making (MCDM) technique to map the landslide hazard zones. For this study, ten (10) landslide inducing parameters are considered. Analytical Hierarchical Process (AHP) and rating method are used to determine the weights for each of the parameters used. Two (2) different models which consider different parameter combinations developed by the authors are used. Results obtained are compared to landslide history and the accuracies for the two models i.e. Model 1 and Model 2 are 72% and 64% respectively.

Keywords: Geographical Information System (GIS); Multicriteria Decision Making (MCDM); landslide hazard zonation

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1. Introduction

Landslides are a serious hazard to many parts of the world including Malaysia. Although Malaysia is not considered as a mountainous country (mountains and hills are less than 25% of the territory), slope

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failures are a common phenomenon. Based on report by the Department of Public Works (JKR), landslide can be defined as the movement of soil, rocks down due to the gravity forces. Most landslides in Malaysia are shallow and small-scale failures caused by surface infiltration or erosion during heavy rainfall (Department of Public Work, 2006). According to the National Slope Master Plan 2009-2023 published by the Department of Public Works, the Federal Territory of Kuala Lumpur has the highest landslides occurrence as compare to other states in Malaysia. Based on the available records, 55% of landslide incidents occurred in hilly areas. From 1973 to 2007, 440 landslide incidents were reported to happen in Malaysia and with 31 cases involved fatalities. Malaysian landslides are reported to happen mostly on man-made slopes within the hillside areas.

2. Literature Review

Different researchers used different methods in determining landslide hazard zones. From the literatures, there are at least three different methods (i.e heuristic, statistical and deterministic) used by researchers internationally and locally. Gorsevski *et al.,* (2006) used a heuristic approach for mapping landslide hazard by integrating fuzzy logic with AHP. Nithya and Prasanna (2010) used GIS and remote sensing technique for mapping the landslide hazard zones in the Kundapallam watershed in the Nilgiris District of Tamil Nadu, India. Slope, land use, geology, drainage density, lineament density, run-off and soil criteria are used to map landslide hazard zones. The weights are assigned based on maximum weight where the suitability index is calculated by multiplying the factor of rank with weight. From the suitability index result, the susceptible zones are classified into four groups namely very high, high, moderate and low. Bakhtiar *et al.* (2011) used AHP to determine the weights for each of the criterion used in mapping a landslide susceptibility area in Bostan Abad Country, Iran. In this research slope, aspect, land use, lithology, distance to stream, distance to road, distance to fault and precipitation are important criteria used.

Local research carried out by the IKRAM Group (2009) used heuristic method (expert judgement) in determining a landslide hazard zones. The indicators used are based on direct and indirect approaches. Six (6) criteria namely slope, water seepage, geology, flow accumulation, land cover and landslide historical data are used in mapping a landslide hazard zones. The study area which covers an area of 100 km by 100 km include the Federal Territory of Kuala Lumpur and part of Selangor (Hulu Klang). In the research, a pairwise comparison method as introduced by The Golder Associates (2006) is used to determine the landslide hazard rating. Malaysian Remote Sensing Agency (ARSM) used ten (10) local environment indicators namely land use, slope, geomorphology, lithology, soil texture, rainfall, aspect, lineament, elevation and river buffer in their study. Based on these indicators, the statistical approach is used to determine the landslide hazard zones (ARSM, 2008).

3. Methodology

In general, the overall methodology of this research is summarised in Figure 1. There are five phases namely determine related issues, literature review, data collection, data interpretation and processing and data analysis. Each of the phases describes the process done in achieving the research objectives. In the present paper, multi-criteria decision analysis and GIS techniques are used to perform the landslide hazard zonation mapping.

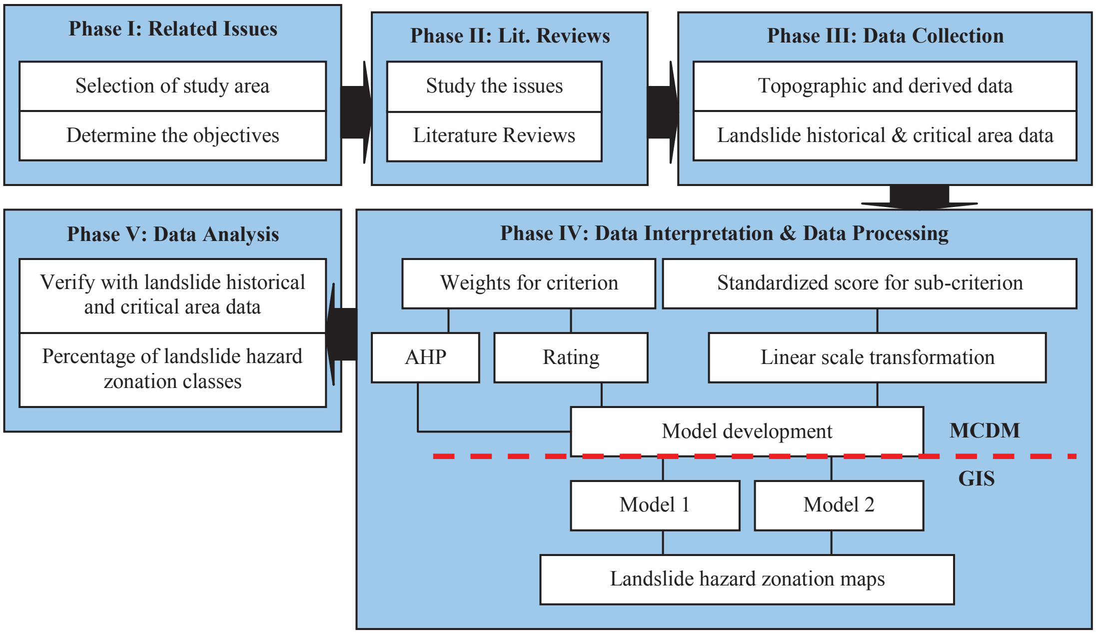

Fig. 1. Research methodology

3.1 Study Area

Developed area under the Ampang Jaya Municipal Council (MPAJ) is selected as the study area (refer to Figure 2). The study area includes Ampang Jaya, Hulu Klang and part of Setapak. The area is located within the Federal Territory of Kuala Lumpur and the Selangor State. Total area under the administration of the MPAJ as reported on the formal website is about 14,350 hectares while the total population is approximately 574,300. This area was chosen because of frequent occurrences of tragic landslides over the past few years, the availability of landslide historical data, the availability of digital topographic map and high resolution satellite imagery. The land use in the study area is mainly forest and developed areas. The elevation ranges from 40 m to 1280 m above mean sea level (MSL) and the maximum slope is approximately 72^{o}.

3.2 Data Collection

Based on the discussion with experts from various government departments and other related agencies, ten (10) different criteria i.e. slope, lithology, soil properties, geomorphology, land use, aspect, elevation, rainfall, proximity to road, proximity to the river and geomorphology were used (refer to Table 1). Digital topographic map (in DXF format) acquired from the Department of Survey and Mapping Malaysia (JUPEM) is the main data source. From this data, four data layers namely contour, river, road and spot height were extracted. The data related to the locations of 25 landslide occurrence area and critical landslide area was obtained from JKR and MPAJ. Figure 2 shows the locations of landslide occurrence and critical landslide areas within the study area.

Table 1. Landslide criteria used and units

Criteria	Unit
Slope	Degree
Aspect	Degree
Soil Properties	Type
Land Use	Type
Lithology	Type
Elevation	Meter
Geomorphology	Type
Proximity to river	Meter
Proximity to road	Meter
Rainfall	Millimetre

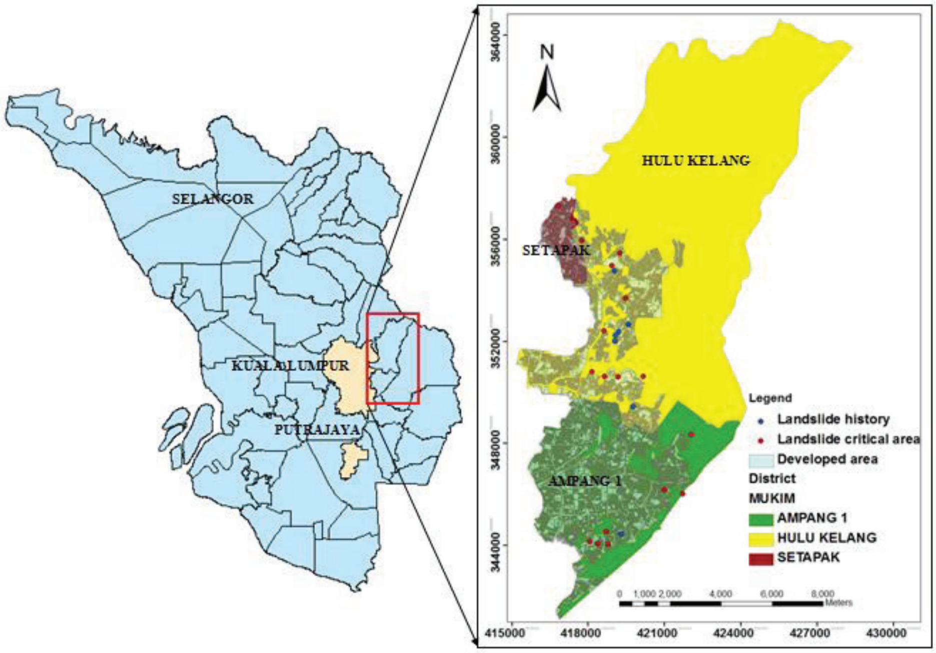

Fig. 2. Location of the study area

All the spatial data are converted into vector format using the GIS software for further processing. Digital Elevation Model (DEM) of the study area is created from the 5-meter contour interval. Data such as slope, aspect and elevation are derived from generated DEM. The proximity to road data is calculated using proximity analysis in GIS. The road buffer criterion is categorized into 6 classes (40-80 m, 80-120 m, 120-160 m, 160-200 m and > 200 m). The proximity to river layer is calculated based on 4 different classes (0-50 m, 50-100 m, 100-150 m and > 150m). The lithology map is prepared from the 1:63,300 scale geological map. SPOT 5 satellite image is used to generate the land use map. The land use is classified into 6 different classes (i.e. natural forest, grassland, unused land, water, urban and associated areas and agriculture land).

3.3 Data Interpretation and Processing

AHP as introduced by Saaty (1990) and rating method are used in this study to determine the weight for each of the criterion used. The value for each criterion is determined from literature, expert opinion and existing guidelines. The main criterion that contributes to landslide disaster in many parts of the world is the slope factor. Most earlier research focused on the slope factor to develop a landslide hazard model. Other factors are landslide history, geology, land use, aspect, lithology and drainage factor. Rainfall and earthquake are considered as the triggering factors. From the interviews and discussions, the experts provide their own score based on their experiences. The value of intensity score shows the relative importance between the criteria proposed by expert. The weights from both models are used in this study to generate landslide hazard zonation maps.

For the first model (Model 1), nine (9) criteria (i.e. slope, land use, lithology, soil properties, aspect, elevation, rainfall, proximity to road and proximity to the river) are used. The landslide hazard zonation model is given in Equation 1.

$$LHZ\ (Model\ 1) = (0.162\ x\ s\_slp) + (0.08\ 2x\ s\_lu) + (0.116\ x\ s\_lito) + (0.277\ x\ s\_sp) + (0.023\ xs\_asp) + (0.061\ x\ s\_elev) + (0.207\ x\ s\_rfal) + (0.041\ x\ s\_priv) + (0.032\ x\ s\_prd) \tag{1}$$

where s_slp is standardized score for slope sub-criterion , s_lu is standardized score for land use sub-criterion, s_lito is standardized score for lithology sub-criterion, s_sp is standardized score for soil properties sub-criterion, s_asp is standardized score for aspect sub-criterion, s_elev is standardized score for elevation sub-criterion, s_rfal is standardized score for rainfall sub-criterion, s_priv is standardized score for proximity to the river sub-criterion and s_prd is standardized score for proximity to road sub- criterion.

The second model (Model 2) use only five (5) criteria (i.e. slope, land use, geomorphology, soil properties and lithology). The derived model is given in Equation 2.

$$LHZ\ (Model\ 2) = (0.335\ x\ s\_slp) + (0.168\ x\ s\_lu) + (0.034\ x\ s\_geomorf) + (0.211\ x\ s\_sp) + (0.252\ x\ s\_lito) \tag{2}$$

where s_slp is standardized score for slope sub-criterion, s_lu is standardized score for landuse sub- criterion, s_lito is standardized score for lithology sub-criterion, s_sp is standardized score for soil properties sub-criterion and s_geomorf is standardized score for geomorphology sub-criterion.

Layer representing the evaluation criteria (attributes associated with objectives) is referred to as sub-criterion (or attributes) map. In this research, the process of generating sub-criterion maps is important. At this stage, a linear scale transformation is used to transform the input data into sub-criterion maps. Later, the process of overlaying each of the criteria is done using the overlay method in GIS. To determine the ranking for each model, the calculated total value are categorised into 4 classes namely low hazard, medium hazard, high hazard and very high hazard.

4. Result and Discussion

The landslide hazard zonation maps generated from the two developed models (Model 1 and Model 2) is shown in Figure 3. Model 1 is generated using the AHP technique. Results from Model 1 have shown that the low (Class 1), medium (Class 2), high (Class 3) and very high hazard (Class 4) zones constitute 3.4%, 37.37%, 54.02% and 5.21% of the study area respectively. It was found that the South Eastern part from the study area can be categorized as high and very high hazard zones. Slope angle of more than 30^o with terrain elevation of greater than 500 meters plus the rainfall factor can be considered as hazardous. Most of the high and very high landslide hazard zones are located within acid intrusive/granite (lithology type). Most of the predicted landslides hazard zones are located within steep slopes with instable soil properties (i.e. sandy clay). The landslide hazard zones (the low, medium, high and very high hazard zones) generated from second model (Model 2) constitute 2.81%, 27.56%, 55.24% and 14.34% of the study area respectively. The accuracies of the developed models have been verified by comparing to the landslide history data obtained from related agencies and site visits. As shown in Table 2, the accuracy of the predicted landslide hazard zones using Model 1 is 72% as compared to Model 2, 64%. Based on these initial findings, the AHP method can be considered as more accurate as compare to rating method to map landslide hazard zones.

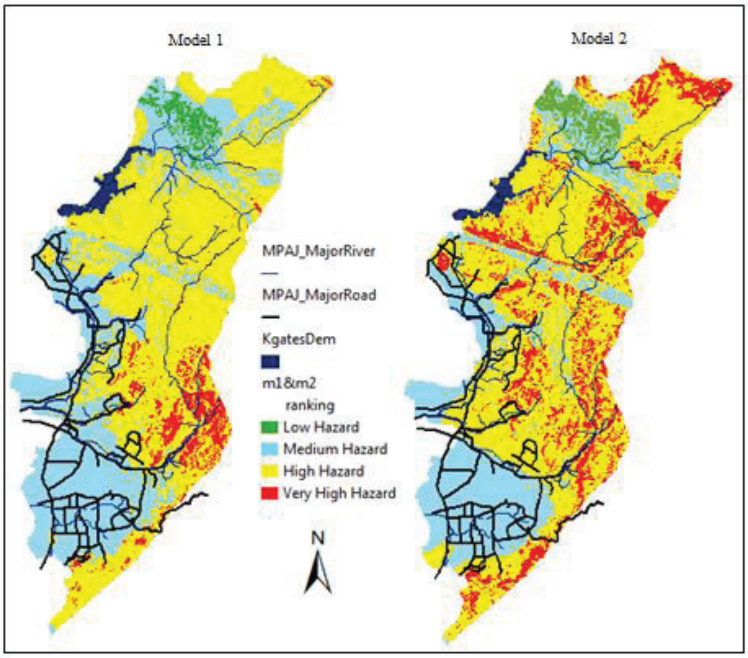

Fig. 3. Landslide hazard zones maps generated from Model 1 and Model 2

Table 2. Comparison between actual and predicted landslide category

NO	LOCATION	Class (Actual)	Model 1 (Predicted)	Model 2 (Predicted)
1	Highland Towers	2	3	3
2	Athaneum Tower	3	3	3
3	Bukit Antarabangsa(2000)	2	2	3
4	Tmn Zooview Kg Pasir	3	3	3
5	Bukit Antarabangsa(2008)	3	3	3
6	Kondo Wangsa Height	4	3	3
7	Taman Bukit Permai	3	2	3
8	Tmn Bukit Indah	2	3	3
9	Taman Bukit Permai	3	3	3
10	Taman Mega Jaya	3	2	3
11	Mutiara Court, Taman Bukit Permai	3	3	3
12	Dataran Ukay	3	3	3
13	Bukit Permai Utama	3	3	4
14	Taman Tun Abdul Razak (TAR)	3	3	3
15	Taman Hijau	4	3	3
16	Taman Melawati	3	3	4
17	Jalan Persiaran Ukay	3	3	3
18	Taman Kelab Ukay	3	3	3
19	Taman Mulia Jaya Ampang	3	3	3
20	Permai Jaya Ampang	3	3	3
21	Kampung Bukit Seputih	4	4	4
22	Taman Melawati	2	2	3
23	Taman Zooview	3	3	4
24	Kampung Kemensah	3	3	3
25	Taman TAR	3	4	4
		Total	18	16
		Percentage	72	64

⬜ Landslide History
🟩 Critical Landslide Areas (Site Visit)
🟥 Same class with real data

5. Conclusion

Landslide disaster like other natural hazard such as earthquake and flood is difficult to be predicted to where and when it will happen. However, landslide can be systematically managed even though cannot be completely prevented. The intensity of impacts from landslide hazard can be minimized if the hazard zones can be predicted and mapped before any development activity takes place. Results from this research can be used by the local authority to manage properly, systematically and plan development within their areas. Multi-criteria decision making together with GIS is a powerful tools which can be applied to predict and map landslide hazard zones. Further research is needed especially on the use of appropriate model/s to accurately map landslide risk areas particularly in the Malaysian context.

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