# Accuracy assessment of landslide prediction models

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**Abstract**. The increasing population and expansion of settlements over hilly areas has greatly increased the impact of natural disasters such as landslide. Therefore, it is important to developed models which could accurately predict landslide hazard zones. Over the years, various techniques and models have been developed to predict landslide hazard zones. The aim of this paper is to access the accuracy of landslide prediction models developed by the authors. The methodology involved the selection of study area, data acquisition, data processing and model development and also data analysis. The development of these models are based on nine different landslide inducing parameters i.e. slope, land use, lithology, soil properties, geomorphology, flow accumulation, aspect, proximity to river and proximity to road. Rank sum, rating, pairwise comparison and AHP techniques are used to determine the weights for each of the parameters used. Four (4) different models which consider different parameter combinations are developed by the authors. Results obtained are compared to landslide history and accuracies for Model 1, Model 2, Model 3 and Model 4 are 66.7, 66.7%, 60% and 22.9% respectively. From the results, rank sum, rating and pairwise comparison can be useful techniques to predict landslide hazard zones.

## 1. Introduction

Malaysia can be considered as one of the most developed nations among the developing countries and has undergone rapid development in many sectors and one of the consequences of the rapid development is landslides. Landslide can be defined as a movement of a mass of rocks down to earth and also terrain instability [4]. Most landslides in Malaysia are shallow and small-scale failures caused by surface infiltration or erosion during heavy. According to Public Works Department (JKR), Kuala Lumpur has the highest landslides record compare to other states [13]. Based on available records, 55% of landslide incidents occurred in hilly areas. From 1973 to 2007, there were 440 landslides occurrence in Malaysia with 31 cases involved fatalities.

## 2. Literature review

Although Malaysia is not considered as a mountainous country, slope failures are a common phenomenon. In tropical countries such as Malaysia, annual rainfall can reach as high as 4500 millimeters per year and also high temperature throughout the year. This can cause an intense weathering of rock mass and information of soil profiles. The earliest recorded landslide in Malaysia happened on December 7$^{th}$, 1919 which buried 12 lives [6]. According to [3], landslide hazard technique can be categorized into five namely geomorphological, analysis of landslide inventories, heuristic or index based, statistically based and geotechnical or physical based models.

Different researchers used different methods in determining a landslide hazard zone. The three most common methods used by many researchers locally and abroad are heuristic, statistical and deterministic. Research by [2] used GIS in comparing a direct and indirect heuristic landslide hazard

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assessment. Seven parameters namely geomorphology, landslide complexes, phase of landslide complexes, slope angle, land use, proximity to gullies and proximity to reservoir were used to developed landslide hazard maps. Other technique such as Analytical hierarchical process (AHP) has been used by [1] to determine the weights for each of the criterion used in mapping landslide susceptibility areas in Bostan Abad country, Iran. Eight important parameters have been used namely slope, aspect, land use, lithology, distance to stream, distance to road, distance to fault and precipitation. Research by [8] used ten parameters related to the local environment namely land use, slope, geomorphology, lithology, soil texture, rainfall, aspect, lineament, elevation and river buffer. Statistical approach were used and applied to determine the landslide hazard zonation in Ampang Jaya, Selangor. Research carried out by [12] used heuristic method (expert judgement) in determining a landslide hazard zonation. Six criteria used namely slope, water seepage, geology, flow accumulation, land covers and landslide historical data in mapping a landslide hazard zones. Pairwise comparison technique was applied [7] to determine landslide hazard rating. GIS based (or spatial) multi-criteria decision making analysis is defined as a collection of techniques for analyzing geographic events where the results of the analysis (decisions) depend on the spatial arrangement of the events [9]. The theory of decision analysis is designed to help the individual to make a choice among a set of pre-specified alternatives.

## 3. Methodology

In general, the methodology of this research can be briefly be summarised in Figure 1. There are four phases namely identification of the study area, data acquisition, data processing and model development and accuracy assessment of the developed models. In the present paper, multi-criteria decision analysis and GIS techniques are used to perform landslide hazard zonation.

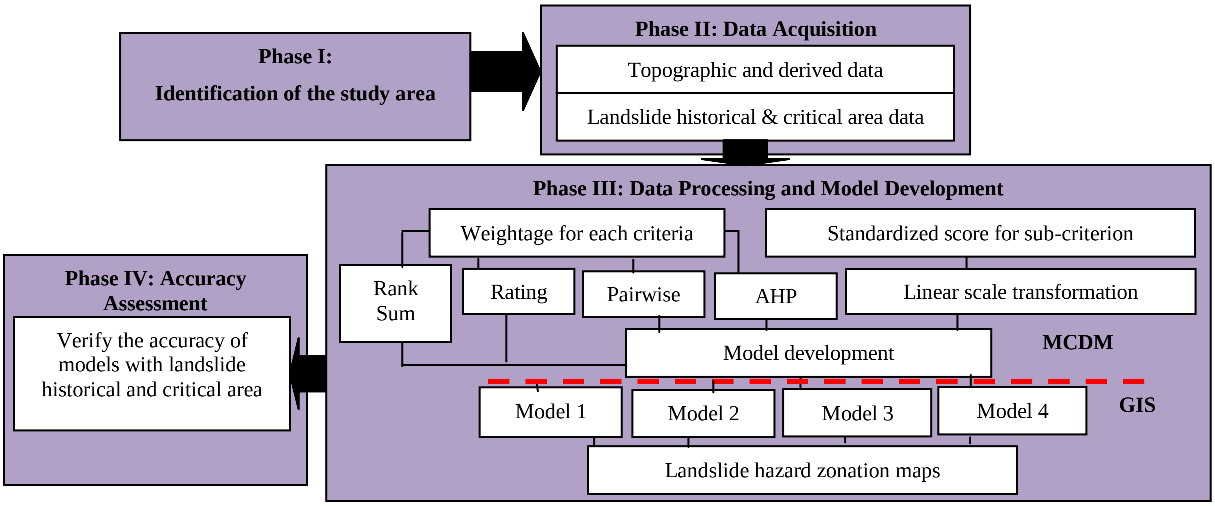


**Figure 1.** Research Methodology.

### *3.1 Identification of the study area*

The areas of Ampang Jaya, Hulu Klang and part of Setapak territories are selected as a study area and the area is located in both the Federal Territory of Kuala Lumpur and Selangor. The area is under the Ampang Jaya Municipal Council (MPAJ) and as reported in the formal MPAJ website of having an area about 14,350 hectares while the total population is approximately 574,300. This area is considered as the most hazardous landslide zone in Malaysia. The elevation ranges from 40 meters to 1300 meters above mean sea level (MSL) and the maximum slope of the study area is 72 degrees. The land use in the study area is mainly a forest and developed area. This area has been selected based on the availability of landslide historical data, the availability of digital topographic data and high resolution satellite images.

*3.2 Data acquisition*

Based on the discussion with experts from various government departments and landslide related agencies, different criteria i.e. slope, aspect, lithology, soil properties, geomorphology, land use, and flow accumulation, proximity to river and proximity to road are used (refer to Table 1). Digital topographic map (in .dxf format) was acquired from the Department of Survey and Mapping Malaysia (JUPEM). From this data, two (2) layers namely contour and spot heights are extracted. A total 35 landslide locations and critical landslide areas were provided by JKR and MPAJ.

All the data are converted into a vector spatial database using the ArcGIS software. Digital Elevation Model (DEM) is created from the 5-meter contour interval. Data such as slope and aspect is derived from the generated DEM. The lithology map is prepared from 1:63,300 scale geological map. Land use map is prepared using SPOT 5 satellite imagery.

There are 6 land use classes identified namely natural forest, grassland, cleared land, water, urban

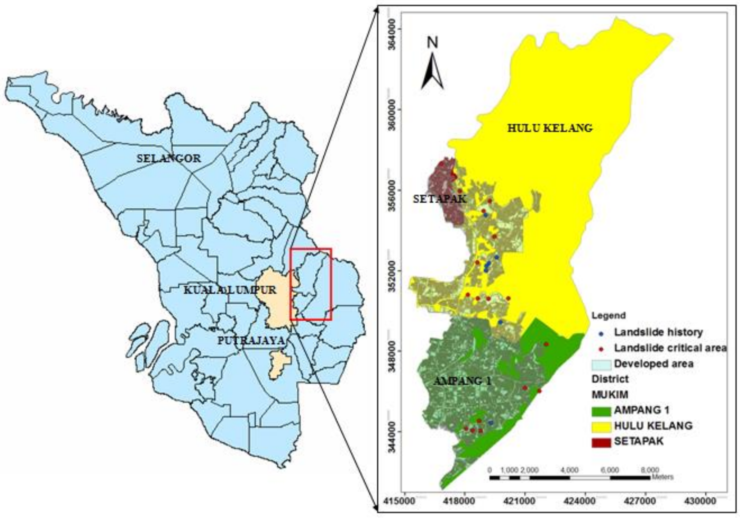


**Figure 2.** Location of the study area

and associated areas and agriculture land. To determine the criteria and score for each of the criteria used, discussions and interview with the expert from different agencies have been conducted. Proximity to river is ranked into different 4 classes with 50 meter range while proximity to road is ranked into 6 classes with range 40 meters.

**Table 1.** Landslide criteria used and units.

| Factors | Unit |
|---|---|
| Slope | Degree |
| Soil Properties | Type |
| Land Use | Type |
| Lithology | Type |
| Geomorphology | Type |
| Flow Accumulation | Pixel |
| Aspect | Degree |
| Proximity to river | Meter |
| Proximity to road | Meter |

*3.3 Data processing and model development*

Rank Sum, Rating, Pairwise Comparison and AHP techniques are used to determine the weight for each of the criteria. The value for each of the criterion is determined from the literature reviews, expert opinion and guidelines. From the review, it was found that the main criterion that contributes to landslide disaster is the slope factor. Most research focused on slope to develop a landslide hazard zonation model. Other factors are landslide history, geomorphology, land use, soil properties, lithology and flow accumulation. Rainfall and earth quake are considered as triggering factors. From the interviews, the expert provided their own score based on their experiences. The value of intensity score shows the relative importance between criteria proposed by expert. The weights value from the models was used to determine a landslide hazard zonation map. For the first model (Model 1), five criteria are used namely slope, land use, lithology, soil properties and geomorphology. The landslide hazard zonation model is given in Equation 1. The second model (Model 2) is also used the same criteria as Model 1 and the derived model is given in Equation 2. The third model (Model 3) use six criteria namely slope, land use, lithology, soil properties, geomorphology and flow accumulation (refer to Equation 3). Model 4 use seven criteria i.e. slope, aspect, lithology, land use, soil properties, proximity to river and proximity to road (refer to Equation 4).

$$\text{LHZ (Model 1)} = (0.333 \times s\_slp) + (0.133 \times s\_lu) + (0.267 \times s\_lito) + (0.2 \times s\_sp) + (0.067 \times s\_geomorf) \quad (1)$$

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

$$\text{LHZ (Model 3)} = (0.294 \times s\_slp) + (0.088 \times s\_lu) + (0.029 \times s\_geomorf) + (0.265 \times s\_sp) + (0.236 \times s\_lito) + (0.088 \times s\_flowacc) \quad (3)$$

$$\text{LHZ (Model 4)} = (0.361 \times s\_slp) + (0.141 \times s\_asp) + (0.091 \times s\_lit) + (0.113 \times s\_lu) + (0.199 \times s\_sp) + (0.051 \times s\_priv) + (0.044 \times s\_prd) \quad (4)$$

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_geomorf is standardized score for geomorphology sub-criterion and s_flowwacc is for flow accumulation, s_asp is for aspect sub-criterion, s_priv is standardized score for proximity to river sub-criterion and s_prd is for proximity to road.

Linear scale transformation is used to transform input data into sub-criteria maps. The process of overlaying each of the criteria is done in the GIS software. To determine the ranking, the calculated total value are categorised into 4 classes namely low hazard, medium hazard, high hazard and very high hazard.

### *3.4 Data analysis: Accuracy assessment of models*

The landslide hazard zonation maps derived from developed models generated in the ArcGIS software and compared between area percentage and hazard class for all developed models. Accuracy assessment of the models is determined by comparing the landslide hazard class of the developed models with the landslide historical data or landslide scar. The landslide hazard zonation maps are overlaid with 35 locations of landslide historical data and landslide critical area. From the analysis, the percentage of accuracy are obtained to determine the best or the most suitable model/s to be used.

## 4. Result and discussion

The landslide hazard zonation maps generated from the developed models are shown in Figure 3. The first model is generated using rank sum technique. Results from Model 1 have shown that the low, medium, high and very high hazard zones constitute 2.1%, 36.86%, 34.95% and 26.09% of the study area respectively. The south part from the study area can be classified as high and very high hazard zones. An elevation of more than 500 meters with slope angle of more than 30 degrees and plus rainfall factor can be considered as hazardous for some area. Most of the high and very high landslide hazard zones are covered with acid intrusive/ granite in lithology types. Most of the landslides occurred in steep slope with instable soil properties. In this study area, most of the landslides occurred in steep land sandy clay and followed with sandy clay. The second model (Model 2) is developed using rating method and low, medium, high and very high hazard zones constitute 1.74%, 35.17%, 47.54% and 15.55% of the study area respectively.

Model 3 used pairwise comparison method and consist of low (1.16%), medium (34%), high (35.4%) and very high hazard zones (28.99%). Model 4 utilize AHP method, where 55.95% of the study area is covered with low hazard, 33.9% with medium hazard while 10.1% and 0.06% each from high and very high hazard. The accuracies of different models are obtained by comparing landslide hazard zones obtained from the generated maps with the actual landslide historical data obtained from related agencies and authorities as well as site visits. Table 2 summarizes the results obtained from the four (4) models tested. The accuracies of the landslide hazard maps using Model 1, Model 2, Model 3 and Model 4 are 66.7%, 66.7%, 60.0% and 22.9% respectively.

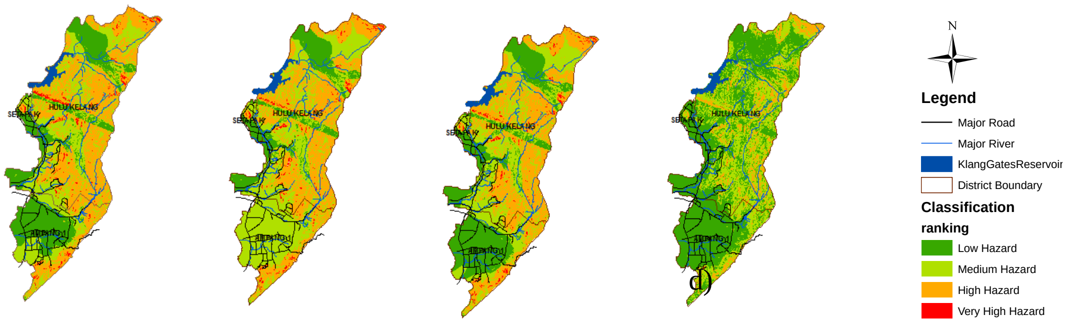


**Figure 3.** Landslide hazard zones generated from a) Model 1, b) Model 2, c) Model 3 and d) Model 4.

**Table 2.** Comparison of landslides category with developed models.

| No | Location | Hazard Class | Model 1 | Model 2 | Model 3 | Model 4 |
|---|---|---|---|---|---|---|
| 1 | Jln Bkt Permai,Tmn Bkt Permai | 2 | 2 | 3 | 2 | 2 |
| 2 | Jln Mega 3&5, Tmn Mega Jaya | 3 | 2 | 2 | 2 | 1 |
| 3 | Mutiara Court, Tmn Bkt Permai | 3 | 3 | 3 | 3 | 2 |
| 4 | No A, Jln Bunga Anggerik, Dataran Ukay | 3 | 3 | 3 | 3 | 2 |
| 5 | No B, Jln Bunga Anggerik, Dataran Ukay | 3 | 3 | 3 | 3 | 2 |
| 6 | Jln Bkt Permai Utama | 3 | 3 | 3 | 3 | 2 |
| 7 | Jln 11&12, Tmn Tun Abd Razak (TAR) | 3 | 2 | 2 | 2 | 1 |
| 8 | Jln Taman Hijau (Tmn Hijau Apartment) | 4 | 3 | 3 | 2 | 2 |
| 9 | Jln Bkt Permai, Mutiara Court | 3 | 3 | 3 | 3 | 3 |
| 10 | Villa Sri Ukay, Jln Persiaran Ukay | 3 | 3 | 3 | 3 | 2 |
| 11 | Jln Kelab Ukay, Tmn Kelab Ukay | 3 | 3 | 3 | 2 | 2 |
| 12 | Jln Kelab Ukay 7, Tmn Kelab Ukay | 3 | 3 | 3 | 2 | 2 |
| 13 | Jln K6, Tmn Melawati | 3 | 3 | 3 | 3 | 3 |
| 14 | Lrg Permai 30, Permai Jaya Ampang | 3 | 2 | 2 | 2 | 2 |
| 15 | Jln Tmn Mulia Jaya Ampang | 3 | 2 | 2 | 3 | 2 |
| 16 | Kg Bkt Seputih | 4 | 3 | 3 | 3 | 2 |
| 17 | Jln H1, Tmn Melawati | 2 | 2 | 2 | 2 | 1 |
| 18 | Jln 1/4B, Bkt Mas | 3 | 3 | 3 | 2 | 2 |
| 19 | AU 1B/1, Tmn Keramat Permai | 3 | 1 | 1 | 1 | 1 |
| 20 | Wangsa Height Kondo | 3 | 2 | 2 | 2 | 1 |
| 21 | Desa Ukay Apartment | 3 | 3 | 3 | 3 | 2 |
| 22 | Jln Lee Woon, Tmn Zooview | 3 | 3 | 3 | 3 | 3 |
| 23 | Jln Hijrah 2, Dataran Sering | 2 | 2 | 2 | 2 | 2 |
| 24 | Jln Tmn Zooview, Kg Kemensah | 3 | 3 | 3 | 3 | 2 |
| 25 | Jln Bunga Cempaka, Kg Kemensah | 3 | 3 | 3 | 2 | 2 |
| 26 | Back area of Medan Bkt Permai, Jln Kuari Cheras | 3 | 3 | 3 | 3 | 2 |
| 27 | Pangsapuri Intan, Jln Kuari Cheras | 3 | 3 | 3 | 2 | 2 |
| 28 | Jln 7, Tmn TAR, Ampang | 3 | 3 | 3 | 3 | 3 |
| 29 | Highland Tower (11.12.1993) | Medium (2) | 3 | 2 | 2 | 2 |
| 30 | Bukit Antarabangsa (14.04.1999) | Medium (2) | 2 | 2 | 2 | 1 |
| 31 | Athaneum Tower (15.05.1999) | High (3) | 2 | 2 | 3 | 2 |
| 32 | Bukit Antarabangsa (5.10.2000) | High (3) | 2 | 2 | 2 | 1 |
| 33 | Taman Hillview (20.11.2002) | Medium (2) | 2 | 2 | 2 | 2 |
| 34 | Kampung Pasir (31.5.2006) | High (3) | 2 | 2 | 2 | 2 |
| 35 | Bukit Antarabangsa (6.12.2008) | High (3) | 2 | 1 | 3 | 2 |
| | | **Percentage** | **66.7** | **66.7** | **60** | **22.9** |

## 5. Conclusion

Various techniques in MCDM can be applied to obtain the weights of the related criteria. In this research, rank sum, rating, pairwise comparison and AHP techniques with different sets of criteria are tested. Accuracy assessment carried have shown that the rank sum (Model 1) and rating (Model 2) techniques produce higher accuracy models as compared to pairwise comparison (Model 3) and AHP (Model 4) techniques. The development of accurate landslide prediction models can help the related government agencies to identify the risk areas for future development and to prepare mitigation measures if development is to be carried out in high risk area.

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