

## A comparative study of Analytical Hierarchy Process and Ordinary Least Square methods for landslide susceptibility mapping using GIS technology

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**Abstract:** This work presents Analytical Hierarchy Process (AHP) method available in Geographic Information System (GIS) to identify and classify the Penang Island according to the grade of present or potential danger of land failure happening. Landslide susceptibility zonation map has been generated by considering seven factors. Sensitivity analysis was performed in detail by varying the contributing factors weights and their effects on defined landslide susceptible locations.

In other part of the analysis, ordinary least square (OLS) technique has been used to estimate weights of point parameters then its result compared with AHP technique result. Finally, the landslide susceptibility maps resulted from AHP and OLS method has been compared to the landslide inventory map containing 355 real occurred landslides in order to verify the practicality of susceptibility maps. The outcome was that the 75% of occurred land failures fit into the very high and high susceptibility class of AHP map (using seven parameters), while this is 73.8% in the case of AHP with point parameters (using four parameters), and 65.8% for the OLS map. As conclusion, the AHP method yields reasonable results which make it reliable and credible approach in comparison with OLS, especially in the case of using large number of landslide contributing factors.

**Key Words:** GIS (Geographic Information System), Landslide, Susceptibility, AHP (Analytical Hierarchy Process), OLS (Ordinary Least Square), Sensitivity Analysis

### Introduction

Landslide hazard resulted in loss of lives and extensive property damages, is the main problem of many countries. Since Penang Island in Malaysia country is the area which frequently experiences heavy rainfall and subsequently much landslide harm, it has been selected as suitable region to study landslide susceptibility (S. Lee & Pradhan, 2006). Tropical rainfall as triggering factor plus uncontrolled urbanization and deforestation play an effective role to aggravate slope destabilization in this island. In order to forecast and specify the region where future land failure is likely to happen, it is necessary to mapping the landslide prone areas (Althuwaynee, Pradhan, & Lee, 2012). Reliable and accurate landslide susceptibility map can be helpful for land planners, decision makers, and risk assessment.

Over the last few decades, Geographic Information System (GIS) has become a compulsory tool in landslide hazard and risk assessment, thus many landslide susceptibility maps have been produced using different GIS-based methods including the analytical hierarchy process (AHP), frequency ratio, bivariate, multivariate, Logistics regression, fuzzy logic, and artificial neural network (Matori, Basith, & Harahap, 2011). Although, all techniques have advantages, incomplete knowledge applied through qualitative methods makes the expert decisions inaccurate or wrong, and imprecise or inaccurate data have the similar impact in the case of using quantitative approaches (Vahidnia, Alesheikh, Alimohammadi, & Hosseinali, 2010). Therefore, the results from the different mixture of qualitative and quantitative techniques, known as semi-quantitative approaches, which merge ranking and weighting, may be more credible (Ayalew & Yamagishi, 2005). The analytic hierarchy process (AHP) (Saaty, 1980), and analytic network process (ANP) (Saaty, 1999), weighted linear combination (WLC) (Ayalew, Yamagishi, & Ugawa, 2004), and fuzzy logic theory (Zadeh, 1965), are the examples of semi-quantitative techniques.

In this study the AHP and OLS methods have been chosen for making landslide susceptibility mapping. When AHP as popular and reliable method in landslide susceptibility mapping is integrated with GIS, it results in precise values for criteria. On the other hand, the ordinary least squares approach is considered as a basic prediction technique which is commonly used in various application fields. This method can be very quickly applied even to problems with hundreds of features and thousands of data points. However, linear models are not perfect since it is not reasonable to fit a simple line or planes to real world relationships. Although OLS has some weaknesses but it has been chosen for this research as a method to compare with AHP, because some distance factors have been discussed in this study are appropriate for OLS approach. Finally, it is noticeable that the quality and validity of landslide susceptibility zonation depend on the used methods and also the followed sampling strategies (Yilmaz, 2009). Thus, it is necessary to do comparative studies in order to find the best

method for landslide susceptibility zonation (LSZ) mapping (Tien Bui, Pradhan, Lofman, Revhaug, & Dick, 2012).

In summary the results of this study suggest that the AHP method is the reliable method that can be used for landslide susceptibility mapping. And also, using more number of landslide contributing parameters increases the validation and reliability of susceptibility map.

## Study Area

Penang Island is located in the west coast of Peninsular Malaysia. This Island with the area of 293 Sq.km is the fourth-largest in the Malaysia country and the most populated as well. It is located almost between the latitude of 5°15'N to 5°30'N and longitudes 100°10'E to 100°21'E. The altitude changes from 0 to 817 meters above sea level and slope degree varies from 0° to 61.598°. The climate is tropical and the mean value of annual rainfall varies from 2400 to 2700 mm. There are three main lithological formations in the study area; alluvium, granite and micro-granite (Pradhan & Youssef, 2009). The terrain is mainly represented by coastal plains, hills and mountains with much developed lowland areas.

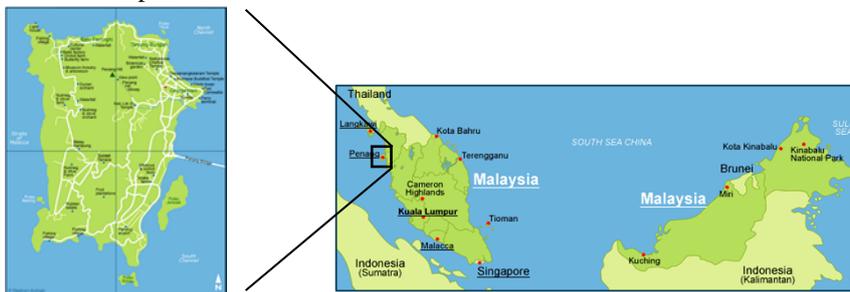


Figure 1: Malaysia, Penang Island Map

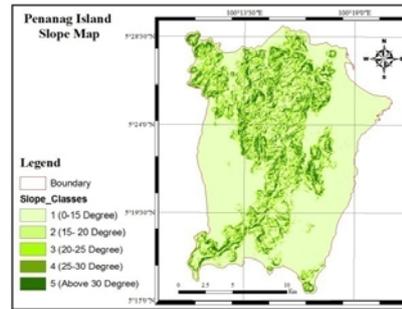
## Materials and Method

Since 1970's, many researchers have applied GIS-based techniques to depict the spatial dispersion of landslide-prone areas. In general, all the models generated from all the methods rely on two assumptions: 1) future slope failures in a particular area will occur in the approximately same situation in which previous landslides have happened. 2) Casual factors that exist in GIS database can be utilized for evaluating the future landslides (Tangestani, 2009). Slope degree, distance to rivers, roads, and faults, lithology, land use/land cover, and precipitation are the causative factors considered in in this peojct based on availability, relevance, and scales.

### Landslide causative factors

#### Slope

Since, the slope degree is straightly related to landslide, it is frequently applied in providing landslide susceptibility maps (Cevik & Topal, 2003; Dia, Lee, Li, & Xu, 2001; Lee, 2005; Yalcin, Reis, Aydinoglu, & Yomralioglu, 2011; Yalcin, 2008). Hence, the slope map of the study area was derived from digital elevation model (DEM) with a pixel size of 30 m by 30 m, and the terrain classified to five different zones according to the slope angle.



**Figure 2:** Penang Island Slope Map

### **Distance to Road**

Constructing roads beside a slope results in some tensions, load decreasing on the slope heels, and landslide happening eventually (Ayalew & Yamagishi, 2005; Pachari, Gupta, Chander, 1998; Pourghasemi, Pradhan, & Gokceoglu, 2012). Therefore, the road proximity has been taken in account as a casual factor for landsliding. Road lines have been digitized from the hard copy of road network map that had been provided from Department of Survey and Mapping Malaysia (JUPEM), in the scale of 1:50,000. Then Euclidean Distance approach was applied to make different classes over the study area. The closest regions to the roads were classified to 5 zones based on the distance.

### **Distance to Rivers**

Hydrological condition of the area or the saturation degree of the soil on slopes has been defined as a stability contributing parameter in landslide initiation in Penang Island. Water infiltration in soil, runoff, and groundwater flows were all happened under the hydrological circumstance (Thanh & De Smedt, 2011). Closeness of the slopes to river lines may affect its stability, because the proximity to rivers would activate the erosion process along the slope (Mancini, Ceppi, & Ritrovato, 2010). In this project five different zones have been buffered around river lines with 50 and 100 meters interval distance. The rivers map required for this part of the project had been provided from Department of Survey and Mapping Malaysia (JUPEM), in the scale of 1:50,000.

### **Lithology**

Different lithological specifications of an area lead to different strength and penetrance of rocks. The soft copy of geological map in .pdf format and with the scale of 1:63,300, had been collected from Mineral and Geoscience Department of Malaysia. Then, it has been converted to IMAGINE Image format for further analysis in ArcGIS software. The lithology map was classified to three lithological units of Alluvium, Micro granite, and Granite.

### **Distance to Faults**

The fractured rocks exist in faults form week zones that present favorable conditions for landslides. Landslides promotes in study area due to flow of water along fault planes and the erosion occurrence consequently. At first, the soft copy of geological map in .pdf format (scale 1:63,300) had been prepared from Mineral and Geoscience Department of Malaysia, and then converted to IMAGINE Image. The classified fault distance map has been extracted through Euclidean Distance method with 100 meter interval.

### **Land use/ Land cover**

In this study the image of Penang Island has been downloaded from USGS website, clipped and prepared in ENVI 4.7 software and then classified to four classes of water bodies, clear land, vegetation, and urban area through Maximum Likelihood classification method. Finally converted to shapefile and exported to ArcGIS software.

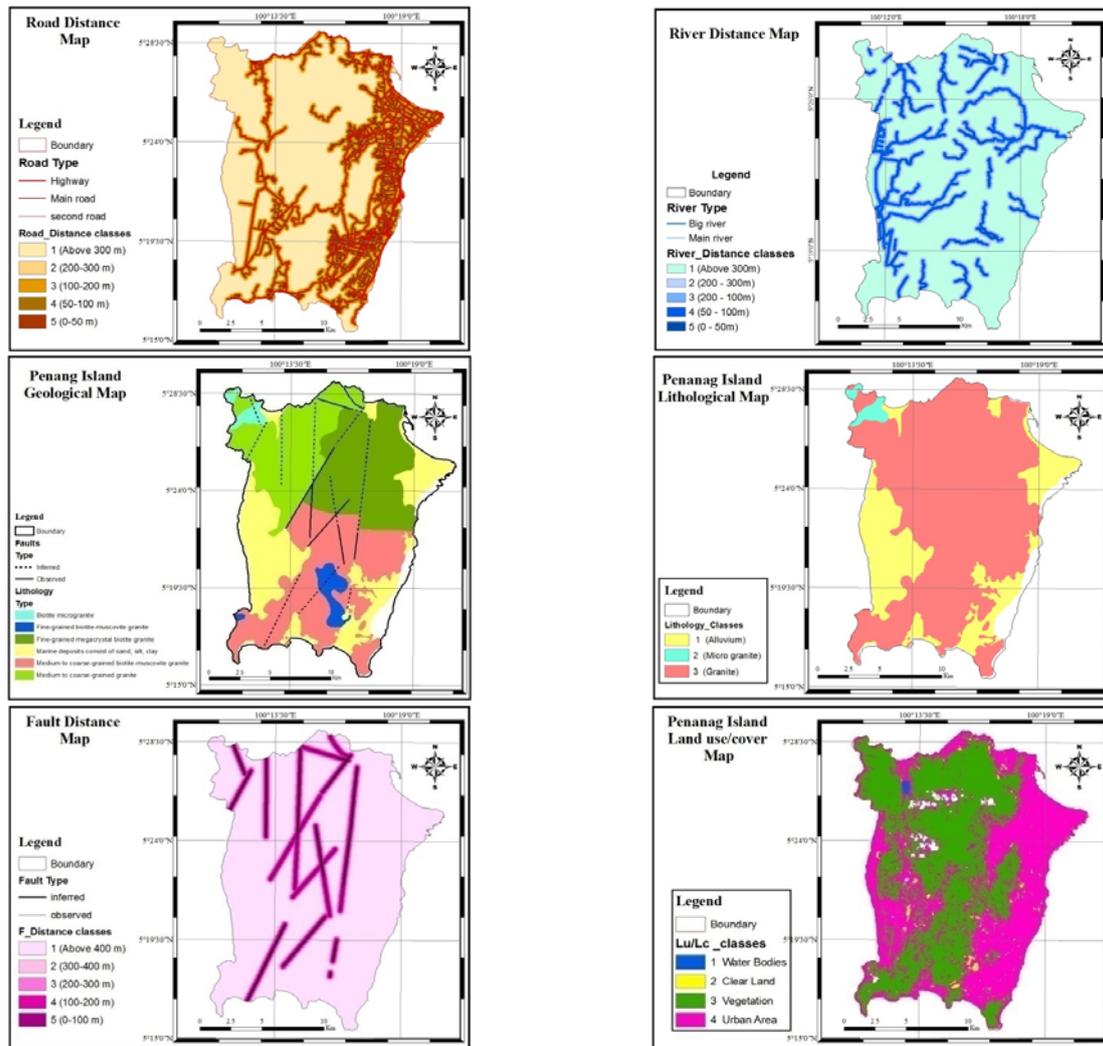


Figure 3: A) Road Distance Map, B) River Distance Map, C) Geological Map, D) Classified Lithological Map, E) Fault Distance Map, F) Land use/covers Map

**Precipitation**

Precipitation is initiation factor in landslide occurrence due to its major influence on runoff and pore water pressure. Total rainfall, short-term intensity, antecedent precipitation, and storm duration are the main rainfall measurements considered as effective factor in landslide initiation. Choosing from these factors for subsequent analyzing usually depends on rainfall records availability. In this study the average monthly rainfall data from three existing weather stations, was collected for the past ten years (2003 to 2012). The stations located in northwest, northeast, and southeast of Island have recorded the annual average rainfall of 2608 mm, 2677 mm, and 2381 mm respectively. An annual precipitation map of Penang Island was produced by Inverse Distance weighting (IDW) method over the three stations. This method is one of the spatial interpolation methods that are available in ArcGIS software spatial analyst tools.

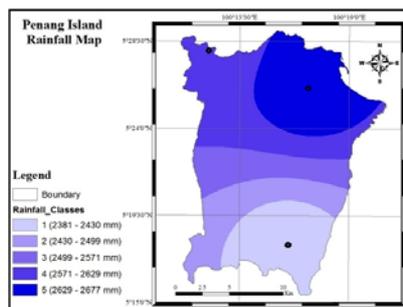


Figure 4: Rainfall Map of Penang Island

### AHP analysis

AHP is widely applied in regional planning, resource allocation, routing modeling, suitability analysis, site selection, and landslide susceptibility analysis (Ayalew, Yamagishi, Marui, & Kanno, 2005). AHP uses pair-wise comparison to define weights or values for factors. Through pair-wise comparison each element compared to one another, and then the numerical weights are assigned to each factor due to their relative importance.

In this study the landslide causative parameters were put in sequence of importance. The relative importance of each parameter has been evaluated according to scientist researches especially for Penang Island (S. Lee & Pradhan, 2006; Oh & Pradhan, 2011; Pradhan, Lee, & Buchroithner, 2010). The following sequence indicates the priority of each parameter compare to others: Slope, Precipitation, Distance to roads, Distance to rivers, Land use/ Land cover, Lithology, Distance to faults. Then the preference matrix (Pair-wise comparison matrix) was created and AHP analysis was executed. Table 2 illustrates the weights calculated by AHP technique.

### Sensitivity Analysis

Sensitivity analysis through simulation models helps researchers to specify the credibility of the result in cases where multi-criteria weights have been investigated (Abdullahi, Rodzi, & Pradhan, 2013; Chen, Yu, Shahbaz, & Xevi, 2009). It aims to identify the effects of changes in the inputs which are geographical data and the priorities on the outputs. If the changes do not result in significant effect on outputs, then the ranking is considered as robust and satisfactory. For this reason sensitivity analyses were performed to explore the response of the overall priority of landslide susceptible locations as alternatives to change in the relative synthesis value of each parameter. To perform sensitivity analysis three random points were chosen to act as alternatives.

### Ordinary Least Square Technique

Ordinary least square method is used in order to investigate the relation of current landslides and defined criteria, such as high slope regions, areas with high road density, area with high river density and so on. By using this method the effect of various criteria on existing landslides were found, and the coefficients for each landslide occurrence parameter is shown in a table generated by OLS function (Table 2). These coefficients calculated by OLS, are based on the average distance between each happened landslides to parameters. For this reason, the point layers were created for landslide contributing factors. So, the land use/ land cover, lithology, and rainfall were eliminated, because point layers resulted from these factors were not reliable. Thus, the four independent factors used in OLS approach were slope, distance to road, river, and fault. The inventory map which had been produced by scientists through interpretation of aerial photographs, reports and field surveys, has been used for digitizing the location points of land failures occurred in Penang Island. Then the OLS measurements between existing landslides to road network density and rivers, high slope regions, and regions on faults were produced. Calculated coefficients of each parameter has been normalized and converted to Satty scale in order to apply in ArcGIS software (Table 2).

**Table 1:** Aggregate pair-wise comparison

	Slope	Rainfall	D-Road	D-River	LU/LC	Litho	D-Fault	Weight
Slope	1	2	3	3.5	4	5	5	<b>0.3419</b>
Rainfall	0.5	1	2	2.5	3	4	4	<b>0.2254</b>
D-Road	0.3333	0.5	1	1.5	2	2.5	3	<b>0.1368</b>
D-River	0.2857	0.4	0.6667	1	2	3	3	<b>0.1204</b>
LU/LC	0.25	0.3333	0.5	0.5	1	1	1.5	<b>0.0689</b>
Litho	0.2	0.25	0.4	0.3333	1	1	1	<b>0.0555</b>
D-Fault	0.2	0.25	0.3333	0.3333	0.6667	1	1	<b>0.051</b>
CR	0.0146							

**Table 2:** Ordinary Least Square calculation

Parameters	Coefficients	Normalized Coef	Saaty's Scale
Distance to Slope	-0.018677	1	9
Distance to Road	-0.01182	0.632864	6
Distance to River	0.006463	0.3460406	3
Distance to Fault	-0.000838	0.0447074	1

**Validation**

Validation of landslide susceptibility maps was an absolutely essential component in this study. Without a validation, the maps are useless and have no value. For this reason, landslide inventory map which shows the previous landslide locations, were used to validate the landslide susceptibility maps. In order to verify the output maps, they were first converted to vector format then overlaid with the landslide inventory map by means of GIS software. From attribute table, the number of previous landslides that fell into each class of susceptibility was calculated easily. This procedure was done for three susceptibility maps generated in this research.

**Result and Discussion**

In first part of the research, AHP method was applied using seven factors. Figure 5 shows the output map. Sensitivity analysis was performed by Expert choice software. Figure 6A illustrates the numerical original condition of parameters and alternatives in Dynamic graph of Expert Choice software. Point 1 is 42.1% susceptible, point 2 is 30.7% and point 3 is 27.2% susceptible, with slope, rainfall, distance to road, distance to river, land use/cover, lithology, and distance to fault criteria priorities of 34.2% , 22.5% , 13.7%, 12%, 6.9%, 5.6%, and 5.1% respectively. As shown in figure 6 B, C, D, E, F, G, and H, the priority of each criterion is increased up to 50%; while susceptibility and priority of alternatives (locations) does not change significantly.

In another part of the research, the weights calculated by OLS approach for four factors were used to make landslide susceptibility map (Figure 7A). In order to do practical comparison between AHP and OLS, a landslide susceptibility map has been made by AHP with the same factors used in OLS approach (Figure 7B). According to the validation result summarized in table 4, 75% of occurred land failures fit into the very high and high susceptibility class of AHP map (using seven parameters), while this is 73.8% in the case of AHP with point parameters, and 65.8% for the OLS map. The weakness of OLS technique is that, only point parameters can be evaluated, because the evaluation of criteria by this technique is based on average distance of point parameters (as independent variable) to existing landslides (as dependent variable). However, the aim of performing this technique was to make challenge for AHP weighting technique with other approaches.

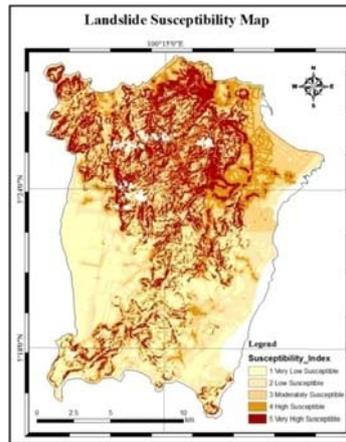
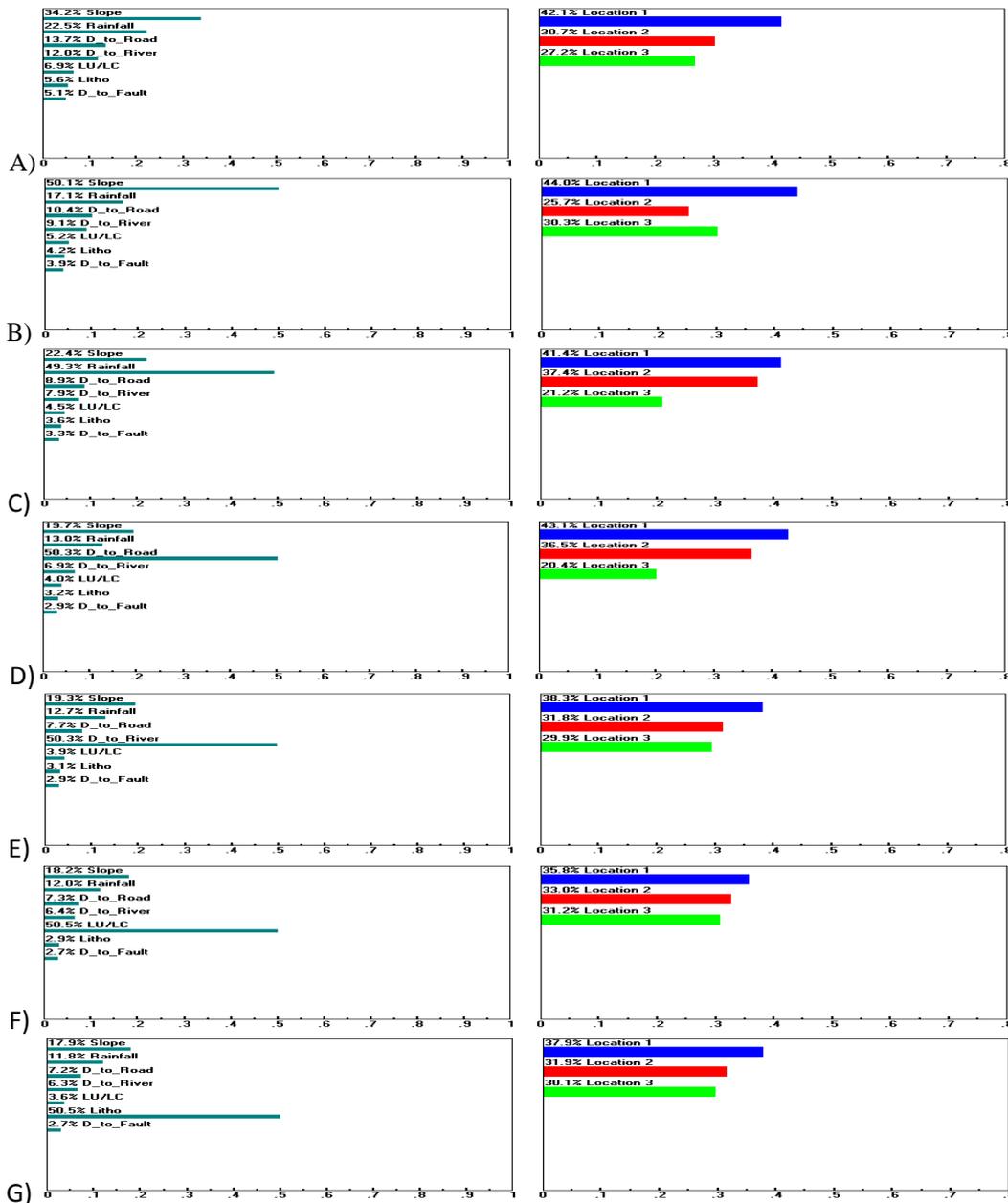


Figure 5: Landslide Susceptibility Map generated by AHP method



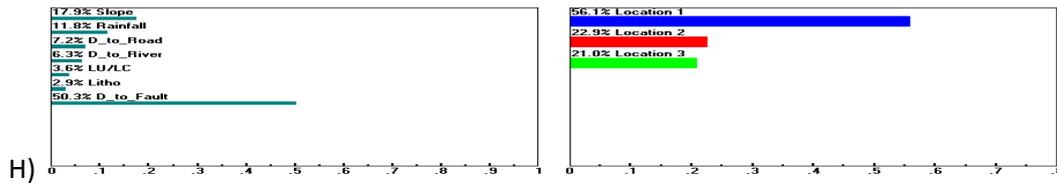


Figure 6: Numerical assessment of sensitivity analysis (Dynamic graph), A) Present condition

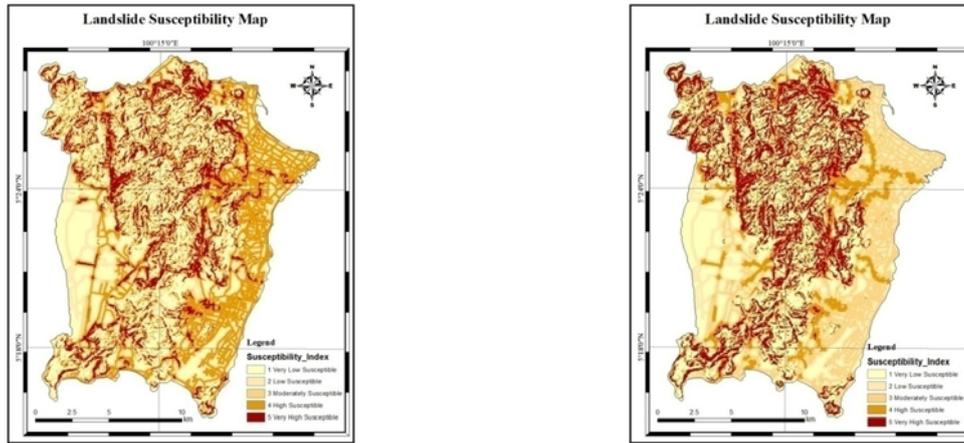


Figure 7: A) Landslide Susceptibility Map generated by OLS scales, B) Landslide Susceptibility Map resulted from AHP using four factors

Table 4: Comparison of different susceptibility map

	Past occurred landslides fall into Very High Susceptibility class		Past occurred landslides fall into High Susceptibility class		Past occurred landslides fall into Moderate Susceptibility class		Past occurred landslides fall into Low susceptibility class		Past occurred landslides fall into Very Low susceptible class	
	%	count	%	count	%	count	%	count	%	Count
AHP (seven parameters)	53.5%	187	21.5%	75	15.4%	54	6.8%	24	2.8%	10
AHP(point parameters)	52%	185	21.8%	77	6.9%	25	13.3%	47	6%	21
OLS	44.3%	157	21.5%	76	14.6%	52	13.6%	49	6%	21

### Conclusion

As conclusion the AHP method is the reliable method that can be used for landslide susceptibility mapping. And also, using more number of parameters contributing in landslide happening, increase the validation and reliability of susceptibility map. For comparing the results from OLS and AHP using same parameters (four parameters), AHP shows the better result in very high susceptible class (52%) , but from low susceptible to moderate class, the number of landslide decreases from 21.8% to 9.6% which shows the invalid result. Actually this problem may be solved by considering more number of factors in landslide susceptibility analysis, like what has been done in the first part of the study applying AHP Using seven factors.

Sensitivity analysis was done to evaluate the overall priority of the parameters or objectives. Results of sensitivity analysis for first part of research were acceptable and showed that by changing the degree of preferences for each objective or factor, no significant changes has been occurred on alternatives.

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