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A Review on Landslide Susceptibility Mapping in Malaysia: Recent Trend and Approaches

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ABSTRACT

The accelerating economic growth has assisted rapid urban development and expansion of construction sites into the landslide vulnerable zones in Malaysia. Thus landslide susceptibility mapping has now become an important part of project designing work for landslide zone areas. There are several models that are used for susceptibility mapping, especially in the peninsular region. Every model has its own set of selected computing variables and characteristics to generate a map. To date, there is no single method applicable to assess and predict all landslides, as there are variations of geomorphological conditions set by the nature. This paper has reviewed recent research publications on landslide susceptibility mapping in Malaysia. Results show that there are 16 models that are being used to describe landslide risk mapping and among them, the Fuzzy model, Neural Network combined with Fuzzy logic, evidential belief function model, probability analysis (e.g. Weights-of-Evidence, and regression), and Support Vector Machine models are proved to be effective even in the areas with limited information. It is observed that most of the susceptible models use curvature, slope angles, distance from drainage, altitude, slope gradient, road distance, aspects as variable factors, and prolonged rainfall as the prime triggering factors. Furthermore, it is observed that the maximum number of research has been conducted in Cameron Highlands (28%) and Penang (20%), because of their high frequencies of landslide occurring and vulnerabilities. Sabah and Sarawak are covered by a negligible number of susceptibility research. Further, a comparison study between the selected models presents the limitations of each model and their benefits and some suggestions are also made based on the author's recommendations works.

Keywords: Approaches, Landslide, Models, Peninsular region, Susceptibility mapping, and Slope gradient.

INTRODUCTION:

Landslide is now a considerable geological hazard (Nhu *et al.,* 2020b; Selamat *et al.,* 2022) that causes damages to the built-environment and fatalities, and potential to cause a catastrophic disaster (Tien Bui *et al.,* 2018) when it occurs in some highly developed region such as Peninsular Malaysia (Nhu *et al.,* 2020a). According to the report presented in EM-DAT, (2015) landslide and mass movement is 10.4% and associate mortality is 24.3% among all the disasters in this area. However, 90% of landslide damages can be avoided if the prediction is made before the occurrence (Brabb,

1993). Hence, landslide susceptibility mapping is very crucial for the landslide vulnerable areas (Al-Najjar *et al.,* 2021; Selamat *et al.,* 2022). Susceptibility mapping is an identification of susceptible zone which possesses some inherent characteristics potential of landslide (Tien Bui *et al.,* 2018; Nhu *et al.,* 2020b; Hashim *et al.,* 2018; Shahabi *et al.,* 2015). For this reason, this susceptibility calculation is very common practice in supporting planning and development projects (Giraud & Shaw, 2007). To reduce the landslide risk, different organizations such as Malaysian Centre for Remote Sensing (MACRES), Public Work Department (PWD), Malaysian Meteorological Service (MMS), Drainage and Irrigation Department, Social Welfare Department, Special Malaysia Disaster Assistance and Rescue Team, National Security Council, Civil Defense Department, national and international corporation, the local Authorities, Non-Governmental Organization (NGO) are working by operating and functioning in landslide monitoring, predicting, forecasting or warning by the map of landslide susceptibility. For this reason, the available database from the published articles needs to be reviewed to recognize the development points in landslide susceptibility mapping methodology in Malaysia.

A lot of works have been conducted on the area of susceptibility mapping and those relevant literatures are used to understand current works. From the survey of literature on susceptibility mapping on Malaysian Landslides that found 16 distinct models that are being used to describe how the risk mapped and computing techniques namely, 1-Neuro-fuzzy model, 2- Evidential Believe Function Model, 3- Decision Tree 4-Suppert Vector model, 5-Adaptive Neuro-Fuzzy Interference system 6-Probablistic based frequency ratio model, 7-Advanced fuzzy logic model 8-artificial neural Network model 9-Back propagation artificial neural Network model 10-Multivariate logistic regression model 11-Geographic Information system and Remote sensing 12-Digital elevation model 13-Binomial Logistic regression model 14-TRIGRS model 15-Spatial Based Statistical Model 16-Weighted Spatial probability Modeling. It is observed that susceptible models are being done using curvature, slope gradient, slope angles, distance from drainage, & distance from road, precipitation distribution, and distance from faults, soil type, aspects, altitude, surface roughness and land cover as variable factors. Instead, prolonged rainfall as the prime triggering factors is considered by most of the research (Nhu *et al.,* 2020). The susceptibility mapping covered all the part of Cameron Highlands, Penang, Selangor, Kuala Lumpur, Hulu Kelang, Kelang Valley and Phang because of their higher number of experience and vulnerabilities. This study reviews firstly the recent advancement in mapping methods for both qualitative and quantitative models, the factor used in the model as a triggering and transgenic factor, purpose of the map development and distribution of papers. Secondly, it summarizes the results on number of variables, their accuracy percentages and area coverage.

Further, a list of benefit and limitations of better performing models has been presented. To the best of our knowledge, this is the first review on landslide susceptibility mapping on Malaysian perspective. Finally, a direction on future research by the authors is provided. The rest of the paper is organized orderly as follows: chapter-2 provides landslide susceptibility mapping approaches, chapter-3 methodology, chapter- 4 landslide susceptibility mapping in Malaysia, chapter-5 distribution of paper based on the locality, chapter- 6 comparative analysis of techniques and chapter- 7 conclusions followed by a future recommendation.

Landside Susceptibility Mapping Approaches

Landslide susceptibility mapping can be done in diversified ways (Selamat *et al.,* 2022; Tien Bui *et al.,* 2018) dependent on the particular landscape, use and financial resource to provide the work. In generally, a landslide susceptibility mapping can be either by direct or indirect method. In direct mapping a geo-morphologist, based on his/her wisdom and experience of the topography conditions regulates the degree of susceptibility directly (Van-Westen *et al.,* 2003a). This direct method often referred to as distribution approach or qualitative approach, which is simply obtained through field survey mapping and historical records well known as landslide inventory (Pardeshi *et al.,* 2013). In indirect mapping, statistical or deterministic models are used to predict the landslide prone areas based on the information obtained from the interrelation among the landslide conditioning factors (Van-Westen *et al.,* 2003b). This quantitative method can be broadly categorized in to three categories namely deterministic analysis, statistical method and artificial intelligence technique (Sonam

et al., 2015). The Malaysian landslide susceptibility mapping research grouped in to the following categories by (Kanungo *et al.,* 2009). The advantage of this classification is easy stated as a taxonomic development and separate sequencing of each qualitative and quantitative approach which might helped to sub divide the susceptibility mapping research conducted in Malaysia.

Qualitative Analysis

This method includes a lot of prejudice during preparation, numerous thematic data layers which contributes a landslide occurrence are integrated. This is an early stage assessment of landslide susceptibility mapping when soft computing system and mathematical theory were not in practices. Distribution analysis, geomorphic analysis and map combination are included in qualitative approaches (Kanungo *et al.,* 2009).

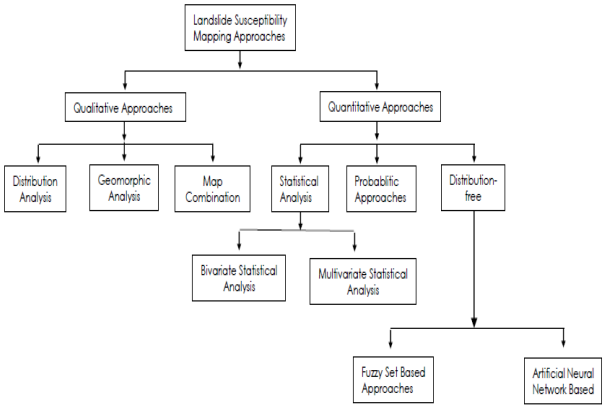

Fig. 1: Graphical classification of landslide susceptibility mapping.

Distribution Analysis

Distribution analysis which is known as landslide inventory shows the distribution of current landslides mapped from aerial photographs field survey and historical data on landslide occurrences. This map is used as a basis of other landslide susceptibility mapping of spatial distribution of other similar circumstances (Kanungo *et al.,* 2009).

Geomorphic Analysis

Geomorphological analysis is a direct approach in which a detailed field recording and field survey are required to produce the map. Professional ability based descriptive information is being produced by expert decision. This mapping varies expert to expert with the varying of experience and subjects that are considered (Bhusan *et al.,* 2022; Kanungo *et al.,* 2009).

Map combination

Map combination has been done on the basis of selection of causative factors and preparation of thematic data layer with the assistance of those factors. Commonly these factors include lithology, lineament, slope, aspect, land use, land cover and drainage. After then giving a weight and rating the factors, integration of data layer can produce the susceptibility map (Kanungo *et al.,* 2009; Yusof *et al.,* 2011) used this approach for early stage planning along the Simpang Pulai to Kg Raja Highway in Malaysia.

Quantitative Analysis

This method includes computing tools to produce the susceptibility map. One of the key purposes of this approach is to lessen the subjectivity or relay on expertise. Quantitative analysis has been developed by summarizing a degree of hybridization of Statistical analysis, probabilistic approaches and distribution-free approaches. This is a broadly used approach due to its available computing packages and even if available information is limited, it can produce a map. It may be a powerful tool if combined with information obtained by any statistical or mathematical analytical approach (Geological Survey of Ireland, 2011).

Statistical Analysis

This approach ensures the prediction of future landslide using statistics of variables. The review of the recent literature has identified 15 commonly used statistical or mathematical techniques for susceptibility map development even though there are variations in algorithms implemented. This can be further sub-categorized as bivariate statistical analysis and multivariate statistical analysis (**Table 1**).

Bivariate Statistical Analysis

In bivariate statistical analysis usually used techniques are weight of evidence, evidence value and frequency ratio. Pradhan *et al.* using this approach to produce prediction map in Ulu kelang, Klang valley, and Cameron Highlands respectively (Pradhan *et al.,* 2012; Pradhan and Lee, 2010; Pradham, 2010). Lee has also used the same model for Selangor area (Lee and Pradhan, 2007).

Multivariate Statistical Analysis

In multivariate statistical analysis, normally used techniques are logistic regression, discriminant analysis and cluster analysis. Pradhan and Lee used this approach combined with other models to produce the landslide susceptibility map (Pradhan and Lee, 2010; Lee and Pradhan, 2007; Pradhan *et al.,* 2008). Some research articles (Zulhaidi *et al.,* 2010; Moussa *et al.,* 2010; Saadatkhan *et al.,* 2014; Pradhan and Youseef, 2010; Razak *et al.,* 2013) are commonly used GIS and Remote Sensing information by using TRIGRS model and spatial-based statistical model to produce hazards map for Malaysia.

Probabilistic Approach

The probabilistic approach relates the spatial distribution of landslide in relation to different causative factors in a probabilistic framework. In probabilistic approach, mostly used techniques are probability models, weight of evidence methods certainty factor method under favorability mapping model and evidential believe functional model. Althuwaynee *et al.* (2012) used evidential believe functional model. Pradhan used this approach combined with airborne LiDAR derived parameters and evidential believe functional model (Pradhan *et al.,* 2010; Pradhan *et al.,* 2014).

Elmahdy & Mostafa practiced weighted spatial probability modeling with the digital elevation model to produce susceptibility mapping in Kualalumpur (Elmahdy and Mostafa, 2013). Jebur *et al.* utilized novel ensemble evidential believes model united with support vector machine model to produce the map (Jebur *et al.,* 2015).

Distribution-free/ soft computing Techniques

To reduce the complexity of landslide phenomena in prediction, application of various soft computing techniques has been used in recent times. Actually, the trend of practicing such techniques has been largely used. However, success of these approaches is greater than any other conventional techniques.

In this case fuzzy set based approach and artificial neural network have been implemented to map the susceptibility of landslide. In recent times, fuzzy set and neural network combined to get more precious data to predict future landslide.

Fuzzy set based & Artificial Neural Network based Approach

These two (2) approaches are found as recent trend of susceptibility mapping in Malaysian Landslide. Most of the researchs are conducted by (Pradhan *et al.,* 2010; Pradhan, 2013; Oh and Pradhan, 2011; Pradhan, 2010a; Pradhan and Lee, 2010; Pradhan, 2010b; Pradhan and Buchroithhner, 2010; Selamat *et al.,* 2022) also use Artificial Neural Network approach for the assessment of landslide susceptibility in Langat river basin, Selangor, Malaysia.

Remote Sensing and Machine Learning Approach

Machine learning algorithm in combination with remote sensing techniques is the most protruding and newly used tools for landslide susceptibility mapping in Malaysia. Nhu *et al.* uses this method for mapping the landslide susceptibility in the Cameron Highland, Malaysia (Nhu *et al.,* 2020a; Nhu *et al.,* 2020b). Tien Bui *et al.* also used remote sensing techniques for mapping the landslide susceptibility in the Cameron Highland by Support Vector Machine (SVM) and Entropy Models(TienBui*etal.,*2018).

Other than these approaches physics based model or Slop stability Analysis are also used for special cases. This approach has very limited use because of its capability in slope stability analyses. The model has been used to evaluate the stability of peat in Penang Island (Oh and Pradhan, 2011a; Pradhan *et al.,* 2010; and Lee and Pradhan, 2007).

METHODOLOGY:

A systematic reviews on landslide susceptibility mapping focusing on Malysian experience was conducted by a searching the web of Science (WoS) publications database (apps.webofknowledge.com) in September 2015 to complete the study. The multi-disciplinary database was used to identify different models used in the landslide susceptibility mapping; literatures within the 10 years' time frame between 2005 and 2015 were surveyed.

The following term was used as key words for searching the articles. "Landslide Susceptibility Mapping, Malaysia." The yield was again filtered by following the titles possessing the key word Susceptibility Mapping.

Landslide Susceptibility Mapping

Twenty three susceptibility mapping analysis have been organized, reviewed, analyzed and presented in the **Table 1**. The table contains author's name, using models, number of factors, region under study, no. of events so far consider in the investigation, study location accuracy percentage, application and uses of the models and references. After the tabulation the information of the study has analyzed, the results are discussed in the next sessions.

Table 1: Feature presented among the techniques used in the landslide susceptibility mapping system.

No.	Name of the Author and Year	Using model	*Factors	Area	No. of events	Study location	**Accuracy (%)	Application and Uses	Reference
1	Pradhan *et al.* 2010	Neuro-fuzzy model	8	26.7 sq.km	70	Cameron Highlands	97	Preliminary land use planning	(Pradhan *et al.*, 2010)
2	Althuwaynee *et al.* 2012	Evidential belief function model	14	1975 sq.km.	220	Kuala Lumpur	82	Guide for planners for future zoning	(Althuwaynee *et al.*, 2012)
3	Pradhan, 2013	Decision Tree, Support Vector Model (SVM) and Adaptive Neuro-fuzzy inference system	7	34 sq.km	113	Penang	Satisfactory	Decision making and policy planning	(Pradhan, 2013)
4	Oh & Pradhan, 2011	Adaptive Neuro-fuzzy Inference System (ANFIS)	8	8.064	48	Penang	84.39	Slope and land-use planning	(Oh and Pradhan, 2011)
5	Pradhan *et al.* 2012	Probabilistic Based Frequency Ratio model	-	600 hectares	-	Ulu Klang	huge potential	Classification of map for landslide mitigation	(Pradhan *et al.*, 2012)
6	Yusof *et al.* 2011	Satellite Imagery as lineaments	-	200 m Radius	20	Simpang - Kg Raja highway	High	Early stages of planning	(Yusof *et al.*, 2011)
7	Pradhan, 2010	Advanced Fuzzy Logic Model	-	-	-	Klang	91	-	(Pradhan, 2010a)
8	Pradhan & Lee, 2013	Back-propagation Artificial Neural Network model	11	-	398	Klang	91	slope management and land use planning	(Pradhan and Lee, 2013)
9	Pradhan, 2010	Frequency Ratio, Fuzzy Logic And Multivariate Logistic Regression Model	-	265 sq.km	324	Cameron Highlands	84	Preliminary landslide hazard mapping	(Pradhan, 2010b)
10	Pradhan *et al.* 2010	Back-Propagation Neural Network Model	4	-	-	Penang, Cameron Highlands, Selangor	-	To observe the landslide residues	(Pradhan *et al.*, 2010)
11	Pradhan *et al.* 2010	Artificial neural network model	11	285, 660, 8,179 sq.km	-	Penang Cameron Highlands, Selangor	83.99	-	(Pradhan *et al.*, 2010)
12	Pradhan & Lee, 2010	GIS and RS	-	293 sq.km	324	Cameron Highlands	83	Planning and assessment	(Pradhan and Lee, 2010)
13	Lee & Pradhan, 2007	GIS and RS	9	-	-	Selangor	93.04	Slope and land-use planning	(Lee and Pradhan, 2007)
14	Zulhaidi *et al.* 2010	GIS and RS	8	-	-	Pahang	-	Monitoring the susceptible area	(Zulhaidi *et al.*, 2010)
15	Pradhan *et al.* 2010	GIS and RS	4	293 sq.km	389	Tropical Hilly area	97	-	(Pradhan *et al.*, 2010)
16	Elmahdy & Mostafa, 2013	Digital Elevation Model (DEM) and Weighted Spatial Probability Modeling	5	52 sq. km	-	Kuala Lumpur	-	Helps to validate geotechnical map	(Elmahdy and Mostafa, 2013)
17	Moussa *et al.* 2010	3D Electrical Resistivity Imaging	2	-	-	Penang	-	-	(Moussa *et al.*, 2010)
18	Pradhan *et al.* 2008	Binomial Logistic Regression Model	-	-	-	Cameron Highlands	-	To estimate the risk to population, property	(Pradhan *et al.*, 2008)
19	Saadatkhah *et al.* 2014	TRIGRS Model	-	-	-	Hulu Kelang	-	To give rise to landslide regional modeling	(Saadatkhah *et al.*, 2014)

20	Pradhan & Youssef, 2010	Spatial-Based Statistical Models	7	660 sq.km	324	-	85.73	-	(Pradhan and Youssef, 2010)
21	Jebur *et al.* 2015	Evidential Belief Functions and Support Vector Machine Models	10	53sq.km	-	Ulu Klang	83.04	-	(Jebur *et al.*, 2015)
22	Razak *et al.* 2013	-	-	100 sq.km	-	Cameron Highlands	-	Forested terrain map	(Razak *et al.*, 2013)
23	Pradhan *et al.* 2014	Evidential Belief Function Model	-	1,955 sq.km	19	Perak	79.45	Helps to develop public awareness	(Pradhan *et al.*, 2014)

* Number of factors considered in the model

** Accuracy as defined by AUC (Area under the curvature) and ROC (Receiver Operating Characteristics) approach

RESULTS AND DISCUSSION:

Table 2: Contribution of authors for susceptibility mapping.

Authors Name	Contribution (as a first author)
Pradhan *et al.*	56.6 %
Althuwaynee *et al.*	4.34 %
Oh *et al.*	4.34%
Yusof *et al.*	4.34%
Lee *et al.*	4.34%
Zulhaidi *et al.*	4.34%
Elmahadi *et al.*	4.34%
Moussa *et al.*	4.34%
Sadatkhan *et al.*	4.34%
Razak *et al.*	4.34%
Jebur *et al.*	4.34%

From **Table 2**, Pradhan *et al.* has contributed mostly in the susceptibility mapping (56.6 %). And the rest of the authors contributed as 4.34 % of each.

Table 3: Model types used in the review.

Model Types	Approaches	Frequency
Qualitative	Distribution	0
	Map-combinations	1
	Geomorphic	4
Quantitative	Statistical Analysis	12
	Probabilistic Analysis	5
	Soft Computing	9

From the **Table 3** Other than GIS and Remote sensing methods the Malaysian landslide susceptibility mapping techniques used mostly quantitative approach and very less of qualitative approach. This information indicated that, there is a good chance to combine with quantitative approach with qualitative approach to get a good model for future prediction. From the **Fig. 2**, we have found that, Fuzzy logic and neural network both of the model are used under 5 studies of each as single and combined mode.

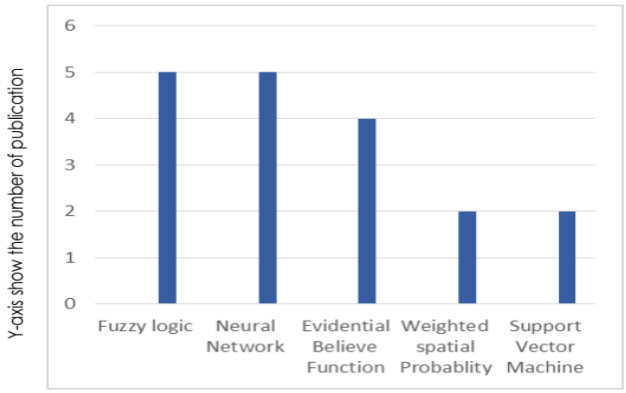

Fig. 2: Model used in the study how many times.

Whereas, evidential believe function model have been used by 4 authors. Probability analysis and Support vector machine model have 2 users for each under the current study. So, a message received from here that fuzzy logic and neural network based model is popular and most used in Malaysian landslide susceptibility analysis. On the other hand, it can be specified that combining the fuzzy logic and Neural network model with other's like evidential believe functional model, probability analysis and support vector machine can have a better predictable capacity.

Table 4: Number of factors used in the study.

Factors	Frequency
Curvature	8
Slope angle	7
Distance from drainage	6
Altitude	5
Slope gradient	4
Distance from road	4
Aspect	4
Distance from faults	3
Difference vegetation index	3
Soil type	3
Land cover	2

Here in **Table 4** have discussed the frequency of factors is used by this study. The following factors are very commonly used by the susceptible mapping researcher's like curvature (8), slope angle (7), distance from drainage (6), altitude (5), slope gradient (4), distance from road (4), aspects (4), and distance from faults (3), difference vegetation index (3), soil type (3) and land cover (2). Which indicates a chronological importance of each factor for susceptibility mapping. So, shows a clear idea about selecting the factors for future mapping.

Table 5: Average accuracy of the model.

Name of the Model	Average accuracy
Fuzzy logic	89.09%
Neural Network	86.46%
Probability Based	84.86%
Support Vector Machine	83.04%
Evidential Believe function	81.49%

Table 5 discuses about the average accuracy percentages of the each model in the review. It pointing to mixing capacity and clearly have a preliminary idea about the mixing performance of each model. Many susceptibility mapping works have covered (**Fig. 3**) Cameron Highlands (28%) and Penang (20%) hilly areas followed by Selangor (16%), Kuala Lumpur (12%) and Hulu Kelang (12%).

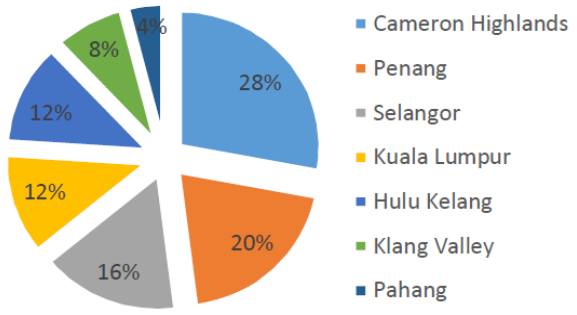

Fig. 3: Distribution of papers on the basis of susceptibility map.

But few works has been completed in the part of Kelang Valley (8%) and Pahang (4%). Considering the other two states of Malaysia Sabah and Sarawak, the study matched no research regarding susceptibility mapping analysis for landslides.

Comparative Analysis of Techniques

The purpose of the benefit-limitation (**Table 6**) is to visualize the combining performance with each other model. Because merging one or more model to produce susceptible map can easily avoid the present limitations in future research.

Table 6: Benefit-Limitation visualizing table.

Techniques	Benefits considered during mapping	Limitations to get high accuracy
Adaptive Neuro - fuzzy model (Pradhan *et al.,* 2010; Oh and Pradhan, 2011)	Suitable and powerful inference system, It can yield higher separation of susceptible zone. Useful tool for regional assessment	To prevent over learning, membership, functions of the inputs, epochs should select optimal and careful
Evidential Belief Functional Model (Althuwaynee *et al.,* 2012; Pradhan *et al.,* 2014),	It can provide a quick yet comprehensive assessment of failure	It will not be sufficient for site specific scale
Probabilistic Frequency Ratio model (Pradhan *et al.,* 2012)	Acquired over large areas and Reduce the cost of field data collection	Interpolated data is used
Artificial Neural Network (Pradhan and Buchroithner, 2010)	It allows nonlinear relationship between the landslide and susceptibility factor	Careful assessment is very important
Advanced Fuzzy Logic (Pradhan, 2010a)	Subjective degree of membership, leads to high prediction	Less useful at site specific scale where heterogeneity prevail
Support Vector Machine (Jebur *et al.,* 2015)	This can easily make use large input data with fast learning capacity	It possess very high algorithmic exercise and complexity

CONCLUSION:

Susceptibility mapping has made contributions to national acts and policies for preparation of hillside area guide line, national building code, recommended terrain hazard zonation map for landslide risk reduction. In fact, Malaysia is one of the signatory nations who committed it to reducing the land slide risk by taking structural measures approaches. From the literature survey, it can

be determined that no single method may be termed as the most suited best to landslide susceptible mapping.

A future direction collected from the authors

Actions towards acquiring high temporal resolution with high degree of confidence, the Evidential Belief Functional model can provide planners with a quick yet comprehensive assessment of future failure and- a guide for future zoning issues (Althuwaynee *et al.,* 2012). More landslide data are needed and more case studies should be conducted for covering the whole areas (Oh and Pradhan, 2011). In order to obtain higher prediction accuracy, it is recommended to use a suitable set of landslide data (Pradhan and Lee, 2010). Itis necessary to investigate the landslide causative parameters and their direct relationship with the triggering factors of future landslides (Pradhan *et al.,* 2010). An assessment of available factors relevant to the vulnerability of buildings and other property would result in a valuable risk analysis (Pradhan and Buchroithner, 2010). Every used model should be verified in different geological and environmental settings (Pradhan and Lee, 2010). It would be ideal to develop hybrid model which model will accumulate the beneficial side of each and try to overcome the limitations by it.

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CONFLICTS OF INTEREST:

The authors declared no possible conflicts of the interest with respect to the research, authorship and publication of this article.

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