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Study on Advance Technique and Recent Trends for Landslide Hazard Assessment

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ABSTRACT

Landslides are the most far-flung natural hazards, causing loss of thousands of lives and billions of dollars annually worldwide. Particularly in the hilly regions has led to the necessity of in-depth study and research in the field of landslide hazard zonation. Despite many technical papers being considered in this area of study, there is no particular standard method available for evaluating and predicting the pattern of landslides. Different researchers come up with different methods for landslide hazard assessment, due to complexity involved in the landslide triggering mechanisms. As the triggering factors of the landslides are not uniform and the nature of the earth is not same, it is very often confusing to identify appropriate method to apply. This paper deals with the compilation of various landslide hazard assessment methods with adequate contextual information. A critical review is presented on each of these methods, highlighting their limitations and suitability of application.

***Keywords:** Landslide; Landslide Triggering Mechanism.*

1.0 Introduction

Landslide is an important geological hazard that causes damage to natural and social environment. The concept of landslide is has investigate by many authors differently. Varnes and IAEG [1] defined landslides as „almost all varieties of mass movements on slope including some such as rock falls, topples and debris flow that involve little or no true sliding‟. It introduced by Brusden [2] landslides of a unique form of mass transport which do not require a transportation medium such as water, air or ice. It has been revealed by Crozier [3] landslides as „the outward and downward gravitational movement of the earth material without the aid of running water as a transporting agent‟.

According to Hutchinson [4] „A landslide in its strict sense is a relatively rapid mass wasting process that causes the down slope movement of mass of rock, debris or earth triggered by variety of external stimulus‟. It‟s define by Courture R [5] simply states that „landslide is a movement of mass of soil (earth or debris) or rock down a slope‟. This concept of landslide is more broaden with respect to the type of material that moves down slope.

Landslide causes loss of around 1000 lives and property worth billions annually [6]. According to the database created by the Centre for Research on Epidemiology of Disasters, landslides and related processes have killed over 61,000 people world over in the period between A.D. 1900 and A.D. [7]

According to Brabb [8] at least 90% of landslide losses can be avoided if we can predetermine the landslide event. Hence, there is need of research at different scale. The available literature needs to be reviewed to identify to reveal the development of methodologies for landslides hazard zonation over globe.

The present article reviews recent advances in landslide hazard assessment. The main purpose of this paper is to discuss recent developments in landslide hazard zonation mapping methods, consideration of essential and triggering variables for mapping and application of Remote Sensing and Geographical Information System in the same. Most of recent research articles from referred journals viz. Geomorphology, Landslides, Engineering Geology, Natural Hazards and Earth Syst. Sci. and International Journal of Remote Sensing have been reviewed and compared on the

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basis of type of hazard zonation method adopted and variables considered for hazard zonation.

2.0 Landslide Hazard Zonation Methods

Landslides are natural events, but may turn into hazard and cause loss of lives and damage to man-made and natural structures. The term landslide hazard is defined by many authors differently, among them definition given by Burton et al. [9] Rezig et al. [10] Varnes and IAEG [11] Cardinali et al. [12] are important.

Though there are numerous approaches to define landslide hazards, many of the researchers have largely adopted or modified the definition given by Varnes and IAEG [13].

3.0 Quantative Approach

This method has been developed to rectify high level of subjectivity in connection with better expert judgments evaluation. The evaluation involves the determination of various combinations of variables and these variables were main reason of earlier instability after that these methods are performed for stable slope and region where similar condition exist.

3.1 Field analysis

In field a direct method known as geomorphological mapping of landslide hazard zonation is used that depend on efficiency of investigator to estimate the actual and potential failure of slope based on his earlier experience. This method depends on how much researcher understands and knows geomorphological processes acting upon the area. Results are highly varying person to person and instability factors are weighted and ranked according to their expected or assumed importance in causing slope failure

3.1.1 Statically methods

A statically model of slope instability in hazard is assessed through correlation of past landslides with several influential factors. The general linear model assumes the form as:

$$y = \alpha_0 + \alpha_1 X_1 + \alpha_2 X_2 + \alpha_3 X_3 + ...+ \alpha_n X_n + \xi \quad (1)$$

Here y is the presence or absence of landslide in each mapping unit. The Xn „s areinput predictor variable (or instability factors) measured for each mapping unit. The αn„s are coefficients estimated from the data through technics, which are dependent on the statically tool selected and ξ represents the residual error of the model.

3.1.2 Slope stability methods

This method focuses stability of a particular site or a slope. The input data for this method is obtained from laboratory tests and can be used to determine safety factor for particular considered slope. In this method the accuracy is high accuracy and this accuracy is depending on provided input data and the methods utilized for analysis. This method usually ignores causative factor like climate and human induced factors, drainage and vegetation which are cause to landslides.

This method only provides the stability of a slope that means factor of safety at the particular time of data collection. It does not account other factor that is mainly responsible for the changes of causes of landslides.

4.0 Frequency Ratio Approach

Frequency ratio is one of the bi-variate statistical approaches of landslide susceptibility assessment which is based on observed relationships between landslide distribution and each causative factor related to landslides.

This method can be used to establish spatial correlation between landslide location and landslide explanatory factors [14]. Frequency ratio for each sub-class of individual causative factor is calculated based on their relationship with landslide occurrence. Landslide Susceptibility Index (LSI) is computed by summing of frequency ratio values of each factor.

Lee [14] applied this model to landslide susceptibility in Penang region of Malaysia. He compared landslide susceptibility maps produced by Frequency Ratio Model and Logistic Regression model.

Goswami et al. [15] used frequency area statistics to assess spatial distribution of landslides in south west Calabria, Italy.

5.0 Information Value Method

Information Value Model (IVM) is a bi-variate statistical method for spatial prediction of landslides based on relationships between landslide occurrence and related parameters [16].

The information values are determined for each subclass of landslide related parameter on the basis of presence of landslide in a given mapping unit. Several studies have applied this method for LHZ mapping.

The study revealed that anthropogenic activities play significant role in landslide occurrence and magnitude of landslides depends largely upon typology of landslides. It also has compared landslide susceptibility maps for Minamata area of Japan produced by Logistic Regression and Information Value Model in GIS environment. Sarkar [16] presented a GIS based spatial data analysis for landslide hazard mapping in Sikkim Himalayas.

They performed Information Value Model to integrate thematic data layers and subsequently numerical weights were assigned. Sharma [17] carried out GIS based landslide susceptibility zonation for Sikkim Himalayas using IVM.

The accuracy assessment of landslide susceptibility map confirmed the model with highest degree of accuracy for high susceptibility class. Akbar and Ha [18] developed an integrated model for landslide susceptibility zonation using Global Positioning System (GPS), Geographical Information System and Remotely Sensed data.

A modified form of pixel based information value model was applied to map landslide susceptibility. The study revealed that factors such as land use, rainfall intensity, distance from road and river influenced landslides more than that of other factors.

IVM to evaluate the role of different combinations of landslide predisposing factors in the occurrence of shallow landslides in parts of Northern Portugal [19].

IVM based 120 landslide susceptibility maps were produced and compared to determine „best fit model‟ to landslide susceptibility in the study area. Recently, this method has applied for landslide hazard zonation mapping in Giri valley of Himachal Pradesh using high resolution satellite data [20].

6.0 BIS Based LHEF Method

Bureau of Indian Standards [21] has given guidelines for macro level landslide hazard zonation (BIS - IS 14496, Part 2) in India. BIS based Landslide Hazard Evaluation Factor (LHEF) rating scheme for landslide susceptibility zonation is a heuristic approach to landslide hazard assessment. Anbalagan et al. [22] applied this method to map landslide susceptibility at meso-scale in Nainital, Kumaun Himalayas. The slope facet map was considered as base map to prepare thematic data layers. Few attempts have been made to apply this method in several parts of India [23] [24] [25] [26].

BIS based LHEF rating scheme is a very simple and cost effective method of landslide hazard mapping. However, subjectivity in weight assignment procedure exists in this method which can affect the level of accuracy of hazard zonation map. Moreover, this method does not consider landslide distribution and therefore very difficult to test its validity. Evaluation of effectiveness for the existing BIS method in Darjeeling Himalayas by adopting WofE model. They proposed a modified BIS model based on relationships of landslide causative factors with landslide distribution and found it more effective method for LHZ method [27].

7.0 Fuzzy Logic Method

Fuzzy Logic method of landslide hazard zonation is based on bi-variate analysis wherein each landslide explanatory variable is represented by a value between 0 and 1 based on the degree of association of these parameters with landslide occurrence [28]. These membership values are then integrated using Fuzzy algebraic Sum to produce landslide hazard zonation map. Champatiray et al. [29] applied this method to landslide susceptibility assessment in Garhwal Himalayas. Bi-variate statistical approach for LHZ mapping considers the relationship of landslide explanatory variables with landslide distribution. However, assigning weightage to the causative factors on the basis of this relationship may not always be appropriate as interrelationships among the causative factors also determine the degree of landslide hazard. Moreover, landslide events are outcome of several explanatory variables at a time.

Therefore, it calls for application of multivariate statistical methods for more accurate LHZ mapping.

8.0 Multi-Varient Statical Analysis

Multi-variate statistical analysis for landslide hazard zonation considers relative contribution of each thematic data layer to the total landslide susceptibility [30]. These methods calculate percentage of landslide area for each pixel and landslide absence - presence data layer is produced followed by the application of multivariate statistical method for reclassification of hazard for the given area. Logistic regression model, Discriminant analysis, Multiple regression models, conditional analysis, Artificial Neural Networks (ANN) are commonly used methods for LHZ mapping.

9.0 Logistic Regression (LR) Analysis

The Logistic Regression is useful for predicting the presence or absence of a characteristic or outcome based on values of a set of predictor variables. This model is suited when dependent variable (e.g. landslide event) is dichotomous [31]. Logistic Regression can be of two type viz. Binary Logistic (when dependent variable is dichotomous and independent variable is of any type) and Multinomial Logistic Regression (dependent variable with more than two classes). In case of landslide susceptibility mapping, the LR model find the best fitting model to describe the relationship between presence and absence of landslides and the set of independent variables such as slope angle, slope aspect, lithology and land use [32]. It generates the model statistics and coefficient of formulae useful in defining susceptibility. If coefficient is positive, the landslide event is likely to occur. LR is a statistical model of slope instability built on the assumption that factor which caused slope failure in a region are the same as those which will generate landslides in future [33]. This method to model used landslide susceptibility for Umbria region in central Italy. Rowbotham and Dudycha [34] applied LR model to landslide susceptibility zonation for Hong Kong. They classified the region in terrain units based on Digital Elevation Model in GIS environment. Tolga et al. carried out landslide susceptibility assessment in Black Sea region of Turkey using LR model. They used Unique Condition Unit as a mapping unit for susceptibility classification.

10.0 Atificial Neural Network

Landslides are governed by several preparatory and triggering factors which are complexly interrelated. The interrelationships between these factors and landslides are nonlinear in nature. To get accurate landslide susceptibility assessment more accurate methods are needed. ANN is a system based on the capability to learn a particular phenomenon similar to human being. ANN has over three layers of neurons which are connected by weights.

This model use „Back propagation learning algorithm‟ which define rules for assignment of weights. Weight of each variable is then adjusted to minimize errors. Artificial Neural Network (ANN) is a non-linear model and proved to be more effective in landslide hazard assessment [35] [36] [37] [38][39].

Ercanglu produced landslide susceptibility map using „Back Propagation ANN model‟ in NeuralNet module of Idrisi Kilimanjaro for west Black Sea, Turkey. He considered six parameters (slope gradient, aspect, topographical elevation, topographical shape, Wetness Index (WI) and Normalized Differential Vegetation Index (NDVI) for determination of weights in training phase of ANN model.

The outcome of the model after validation indicated 82.5% correct results. Catani et al. [40] applied ANN model to landslide susceptibility zonation in Arno river basin of central Italy. Landslide preparatory factor layers were overlaid to define Unique Condition Units (UCU).

The final susceptibility map showed over 85% correctly recognized areas susceptible to landslides.

Chang and Liu [41] performed ANN model for landslide susceptibility zonation in central Taiwan using high resolution satellite data. They argued that ANN method is better than Maximum Likelihood statistical method. Pradhan and Lee found 72-81%

Good quality aerial photographs help in accurate landslide detection and mapping. However, aerial accurate results for landslide susceptibility in five training sites of Penang island, Malaysia. They applied ANN model in GIS environment. This method applied for landslide susceptibility assessment in Malaysia. Bui et al. performed LHZ mapping in Malaysia using Bayesian Regularization Neural Networks and Levenberg Marquardt Neural Networks and found accuracy up to 90.3% and 86.1% respectively. Hence, ANN model can effectively be implemented in landslide hazard assessment in GIS environment to improve landslide prediction capability. Arora et al. [42] proposed ANN black box approach for landslide hazard zonation mapping. This approach determines weights which remain hidden during training stage. After training and testing of different neural network archives, the best one is selected based on the accuracy. They applied this model in Bhagirathi (Ganga) valley, India.

11.0 Rainfall Thershold Model

Rainfall threshold for landsliding refers to minimum intensity or duration of rainfall necessary to cause landslide [43] Cumulative rainfall, antecedent rainfall, rainfall intensity and rainfall duration are most commonly used parameters to design rainfall threshold. The critical rainfall threshold model (Qcr) is based on soil properties, slope angle, upslope drainage, wet soil bulk density and density of water. Several studies on landslide susceptibility assessment have used rainfall threshold model to predict landslide. The rainfall threshold decreases with increasing seasonal accumulation and become constant at 11 mm/day [44] Chelboard et al. [45] applied cumulative rainfall threshold (CT) for prediction of landslides in Seattle, Washington, USA. The model was compared with historical records of rainfall and landslide events. The results indicated that CT captured over 90% of the historical landslide events. They argued that both CT and exceedance rainfall intensity duration threshold must be used together for landslide prediction. Chang and Chiang [46] proposed an integrated model for landslide susceptibility combining deterministic, statistical and rainfall threshold model for typhoon induced landslides in Taiwan.

12.0 Application of RS and GIS in LHZ

The review of few studies on landslide hazard assessment using RS data indicate that aerial photographs are widely used in landslide detection and mapping [46] [47] [48] [49] [50] [51] [52] [53]. photographs may not be used in continuous landslide monitoring, since it does not prove repetitive coverage of the same area. Geographical Information System is widely used in landslide hazard assessment especially for generation of thematic data layers, computation of different indices, assignment of weights, data integration and generation of LSZ maps. Several LSZ methods such as ANN, Decision Tree model, Weighted Overlay, AHP, MCDA, IVM and physically based landslide hazard models are GIS based models to predict landslide probability [54][55][56].

13.0 Conclusion

Landslide hazard zonation is a critical task in landslide management process. Landslides are influenced by several preparatory and triggering factors which vary significantly from region to region. It is therefore difficult to determine weights for given parameter. The assignment weights based on relative importance of landslide causative factors is determined by several LHZ methods differently. Heuristic and semi quantitative techniques involve subjectivity in assigning of weights therefore validity of these maps cannot be assessed. Quantitative methods on the other hand, provide objective methods for determining weights for a given parameter based on their relationships with landslide occurrence. Multi criteria decision approach provides tools to determine weights based on pair wise comparison. Application of Remote Sensing and Geographical Information System is of immense importance for effective landslide hazard assessment. High resolution satellite data combined with powerful GIS techniques have improved the level of accuracy of LHZ maps in recent times.

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