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Landslide Hazard Zonation Methods: A Critical Review

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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. Urbanization 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 dealt 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: Component; Landslides ; hazard zonation ; qualatative methods; quantative methods.

1. Introduction

Landslides are the most occurring geological hazards in the world, these causes injuries, loss of life, damage to the property as well as infrastructures and affect large number of resources. There are many factors that cause the instability of slopes, but the main controlling factors rainfalls, seismic activities and human activities. Due to scarcity of plane area, they do not have other option than to establish their houses in hill regions. For construction of all facilities in hilly regions they are not considering factors like deforestation, erosion hill face disturbance, drainage pattern, water resources disturbance, rainfall, weather and seismic activities that are crucial for design of houses, road and other life line facilities.

In general the LHZ map divides the landslide prone hilly terrain into different zones according to the relative degree of susceptibility to land-slides. This requires the identification of those areas that are, or could be affected by landslides, and the assessment of the probability of such landslides occurring within a specific period of time. Commenting on the time domain of landslide occurrence through Zonation mapping is a difficult task. Due to operational and conceptual limitations, landslide hazard Zonation is conceptually stated as Landslide Susceptibility Zonation (LSZ). The LHZ maps do not incorporate directly the magnitude and time of landslide occurrences. Since LSZ is conceptually accepted as LHZ, it is popularly referred to as LHZ in south Asia. LHZ mapping serves as one of the many components in landslide risk assessment. The methodology to develop landslide hazard map depends upon several factors like nature of terrain, parameters to be considered, available data on geology, soil, slope, rainfall, seismicity etc. For the simplicity, we can discuss available methods in five groups.

Applying restrictive zoning codes for development or codes for excavation, construction, or grading, designed to reduce damages due to landslides, in areas not prone to landslides is itself costly. Delimiting landslide slide susceptible areas in which to apply loss reduction strategies requires a sound scientific basis. Landslide hazard zonation is a safe and very quick mitigation measures for strategic planning and to identify the most vulnerable areas and channelizing most of the protective measures and techniques to a more focused area. Number of different methods for landslide hazard assessment is proposed by various researchers, 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.

2. Landslide Hazard Zonation Methods

Classification of landslide hazard methodologies is subjective. These methods are broadly classified as quantitative and qualitative.

2.1 Qualitative Methods

Qualitative methods of landslide hazard assessment are used with expert knowledge and experience. It is simplest method of landslide hazard zonation; it can be used directly in the field by geomorphologists or geologist. This method was mostly used during 1970 to 1980 (Aleotti et.al, 1999). Landslide hazard zonation is based on this geological and geomorphological attributes are more popular particularly for regional scale. These methods can be widely classified into two types: Field analysis and Use of index maps or parameter maps with or without weights.

2.1.1 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.

2.1.2 Use of index or parameter maps

Analytical Hierarchy Process (AHP) was developed by Saaty in 1980. It is useful for the formalization of our non-rational understanding of a complex or composit problem using a hierarchical structure (Yoon & Hwang, 1995). AHP method was used for identifying areas which are susceptible to landslides, here it assigns values to each causative factor of landslide susceptible areas that have been observed in aerial photographs and evaluate the total susceptibility of landslide using that score provided to each causative factor. AHP method uses the subjective judgment and their experience of researcher into a layer structure, and expresses the process quantitatively. Here, the landslide susceptibility means the possibility of another landslide in the region where landslides have been occurred in the earlier in the past. AHP method uses initial subjectivity the following procedure given in table.

Table 1: Relative importance scale (Saaty, 1980).

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8 Reciprocals	Intermediate values between adjacent scale values	When compromise is needed

Drawbacks: In AHP, even though the factors at lower level have impacts on upper level, factors at the same hierarchical level are independent with each other. However in the actual process of landslide mass wasting, many factors are interrelated, and they have the influence with each other. Because of these reasons, the regular AHP method frequently fails to speculate the essential link.

Salient features of ANP are only briefly discussed here, while detailed procedures on the ANP model can be found in Saaty (2003. the fundamentals are summarized here. The ANP model controls hierarchies, elements, clusters, inter relationship between elements, and interrelationship between clusters. The modeling of ANP can be divided into four simple steps for the simple understanding which are as follows steps: (1) Pairwise comparison and relative weight idea. (2) Formation of initial super matrix. (3) Formation of weighted super matrix. (4) Calculation of global priority vectors and weight.

2.2 Quantitative Methods

This method has been developed to rectify high level of subjectivity in connection with better expert judgments evaluation. This evaluation involve the determination of various combination of variables and these variables was main reason of earlier instability after that these methods are performed for stable slope and region where similar condition exist (Dai and Lee, 2001)

2.2.1 Statically Methods

The statically methods are based on relationships that have been observed between every factors that have contributed to present and past landslide distribution. All possible causative terrain parameters are weighted and integrated using GIS for landslide susceptibility analysis. The reliability and capacity of functional method is depends on quantity and reliability of collected data. Bivariate, multivariate statistic and favorability functions are used to analyze the parameters of instability (Carrare et al., 1991)

Multivariate statistical model were developed for landslide hazard zonation by Carrara et al. (1991). In their application, the grids or morphometric units are reclassified into landslide hazard classes. This method is based on determination of absence or presence of landslides. The resulting matrix is analyzed by multiple regression 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:

$$y = \beta 0 + \beta 1X1 + \beta 2X2 + \beta 3X3 + \text{------} \beta nXn + \xi \quad (1)$$

Here y is the presence or absence of landslide in each mapping unit. The X_n ‘s are input predictor variable (or instability factors) measured for each mapping unit. The β_n‘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.

Although multivariate techniques can be applied to different scales landslide zonation, their use becomes quite bounded at the regional scale, where exact input map of landslide occurrences may not be available and most of the causative factors cannot be collected with satisfactory accuracy. At macro scales, different factors will have to be used (such as ground water depth, soil sequences and thickness, ground water depth). These data are very difficult to found even for relatively small areas. Therefore, the medium scale is believed most appropriate for multivariate analysis.

Bivariate statistical models, the role of individual factors or combinations related to slope failure is evaluated. In each individual class, the weight or contribution of a causative factor to the landslide hazard is determined on the basis of landslide density. The GIS procedure for bivariate analysis usually are: (1) the division of each parameter map into no of relevant classes; (2) the determination of landslide density and weighting the value of each parameter map; (2) the overlaying of the landslide map with each parameter map; (3) the determination of landslide density and weighting the value of each parameter class; (4) the assignment of weighting values to the various parameters maps; (5) the final overlay mapping using a decision rule and determination of susceptibility threshold values; and (6) the classification of the resulting score in a landslide classes

The main drawback of bivariate statistical method is, independency between different parameter maps with respect to probability to landslide occurrence, due the assumption of conditional independence. This assumption is generally invalid. The problem can be solved by developing the combined dependent maps from the data and then preparing a new parameter map (Van Westen et al.,1997).

2.2.2Geotechnical or physically based models (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 depend 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, the temporal and spatial frequencies of the landslides, and the magnitudes of the landslides.

3. Conclusion

There are different methods available for landslide zonation, every method has its own advantages and disadvantages. It has been observed that no single method is able to describe long term detailed landslide zonation. This paper presents a critical review of different landslide zonation methods with their respective advantages and disadvantages. For short term and small region geotechnical method (Slope stability analysis) is more appropriate but for long term this method does not consider causative factors like vegetations, weathering, aspect and drainage which influence long term stability of slope. For long term and larger region qualitative and quantitative methods are appropriate. Qualitative methods consider initial subjectivity so this method would be suitable for experienced designer whereas in quantitative methods interdependencies are not properly considered and very frequent in use.

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