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### A REVIEW OF TECHNIQUES OF LANDSLIDE SUSCEPTIBILITY MAPPING USING GIS

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#### ABSTRACT

Landslides are a big problem in the hilly areas. If the slopes along the roads are failed then these can create the jamming of traffic and also sometimes results in the fatal accidents. In the residential areas the landslides can result in disaster sometimes. The landslide susceptibility mapping of the landslide prone areas has been proved a very useful tool in planning and the mitigation of the problems in the field of landslides. Geographical Information System (GIS) has proved a very effective tool in the field of landslide mapping and risk assessment. There are different techniques i.e. quantitative approach, neural networks, fuzzy logic etc. which are used in landslide susceptibility mapping. Each of the techniques has its own advantages and disadvantages. The proposed study gives a review about the different techniques that are used in landslide susceptibility mapping and suggests the advantages and disadvantages of each technology. The present study basically compares the fuzzy logic, analytic hierarchy process and the statistical method. Fuzzy logic is found to be the most accurate method as compared to the other methods of susceptibility mapping, while the analytic hierarchy process depends upon the user perception.

**KEYWORDS:** GIS, Landslides, Fuzzy logic, AHP, Frequency ratio.

#### INTRODUCTION

A landslide may be defined as a mass movement or the failure of a soil mass, rock mass or a composite mass due to slope instability of the mass. Landslide is a very destructive process which can cause the destruction of the roads, bridges etc. A landslide event in the residential area can cause the destruction of the houses and also may result in the loss of life sometimes. The landslides can cause the jamming situation of the traffic and sometimes can result into the accidents. So, the landslide susceptibility mapping and the risk assessment of the landslide events is an important preliminary tool in the planning and the mitigation of the problem. Whenever the natural slope of the masses is disturbed during the construction process, the slopes become more susceptible to the landslides.

Landslide susceptibility mapping may be defined as quantitative prediction of spatial distribution of both deposits and slopes that are likely to be failure sites whose movement or reactivation will take place in a way and within a time period defined from information that is not directly incorporated in the analysis (Guzzetti et al., 1999). According to USGS, 2008, the principle used in landslide susceptibility mapping is 'the past is the key to future' i.e. the area where the landslides have occurred in the past will also be susceptible to the landslides to the landslides in

future. A landslide susceptibility map represents the probability of occurrence of landslide on a particular location and this spatial probability is represented in qualitative terms like high, low and very high.

There are different methods that are used for the purpose of landslide susceptibility mapping. Different approaches for the landslide susceptibility mapping include heuristics methods, landslide density approach, probabilistic approach and physically based models. A lot of methods are devised by various researchers for mapping the landslide susceptibility of different areas. Distribution analysis is used for preparing susceptibility map (Western 2001, Dahal et al. 2008, Bhoj Raj Pantha et al. 2008). Different probabilistic methods for predicting the occurrence of landslides are used by various researchers. Certainty Factor (CF) method is used to relate the probability of occurrence of landslides upon the different triggering factors responsible for occurrence of landslides (Lee et al. 2001, Lan et al. 2004, Coe et al. 2004, Tassetti et al., 2008). Frequency Ratio models are also probabilistic models that give accurate results in susceptibility mapping. Frequency ratio models are accurate upto 90 % ( Lee et al. 2001, Bathrellos et al; 2009, Avinash et. al.2010, Paretra et al. 2012). Statistical Models like Linear regression (LR) technique are proved useful in landslide mapping if the

statistical data about different parameters of landslides is available (Lei et. al.2006).

The heuristic approach depends upon the perception of the user and its accuracy also depends upon the perception of the user. The fuzzy logic and artificial neural network (ANN) methods are very accurate. The present study compares the three methods of the landslide mapping i.e. fuzzy logic, analytic hierarchy process (AHP) and the statistical methods. All these methods are used in GIS environment.

### USE OF GIS IN LANDSLIDE SUSCEPTIBILITY MAPPING

Mapping is used to present the information and its combination at different level of details. Geographical information system (GIS) can be used to manipulate, acquisition, store, retrieve and model the different spatial data (Megzugi et al.; 2012). The different techniques like remote sensing and global positioning system (GPS) can be combined in the GIS environment. GIS is helpful in making the precise map. In GIS, many techniques of landslide susceptibility mapping are attainable. The output results obtained in GIS environment can be improved by varying the input (Pantha et. al; 2008). The improvement of output by varying the input is very difficult in the conventional methods. In GIS the spatial and the temporal analysis are combined and hence the computational speed is increased (Baban and Sant; 2005).

GIS technique has also some disadvantages. The data entry process in GIS environment is very time consuming. If the data is not available in the digital form, then it has to be converted in the digital format. Also the results in the GIS technique depend upon the availability of relevant and accurate data. While there is a lot of techniques available, but unavailability of relevant data is a big problem.

### FUZZY LOGIC IN LANDSLIDE SUSCEPTIBILITY MAPPING

The concept of the fuzzy logic was introduced by Zadeh in 1965. Fuzzy logic models are successfully used for weighing the different layers in GIS for the purpose of the landslide susceptibility mapping. The fuzzy logic concept work upon the principle of partial truth. In the conventional set theory, 1 is taken as truth and 0 as false. There are no intermediate results except 1 and 0 in the conventional system (Scherthanner; 2014). . But in the fuzzy logic system, the thresholds are also allowed. In the fuzzy logic models, the possibility of occurrence of the occurrence of the landslide event is taken as the subset of the indicators

of the landslides (Marzanovic et. al; 2010). The values of the different indicators of the landslide are taken from 0 to 1. If an indicator shows that the occurrence of a landslide event in a particular grid is impossible, then the value assigned to that grid is zero. As the possibility of occurrence of a landslide event increases, the value assigned to the indicator also increases towards 1 (Miles and Keefer; 2008).

The different fuzzy operators like fuzzy OR, fuzzy AND, fuzzy algebraic sum, fuzzy gamma operator etc. are used in the fuzzy logic technique. Fuzzy logic models are also used for the earthquake induced landslides. The fuzzy logic models can give accuracy of upto 90%. Also the fuzzy logic models with artificial neural networks (ANN) have been proved highly precise (Kanungo et. al; 2006).

### STATISTICAL METHODS IN LANDSLIDE SUSCEPTIBILITY MAPPING

The statistical methods are widely used for the purpose of landslide susceptibility mapping. The methods used in the category of statistical methods are bivariate method, multivariate method and info value methods (Yan; 1988). If the available historical data for a large area is less, then the statistical methods can be used for the purpose of landslide susceptibility mapping. In the statistical methods, the mathematical relationship between the landslide distribution and the factors on which the occurrence of landslide event depends upon is used for the susceptibility mapping (Mezughi; 2012). The combination of landslide conditions at known landslide sites is analyzed statistically using a large amount of data and then landslide susceptibility is predicted for landslide free sites. The basic principle of statistical methods is that the occurrence of landslide in future will take place under same conditions as that of past in which it happened before (Pantha et al., 2008).

#### A. Multivariate Technique-

In the multivariate method, the probability of the occurrence of a landslide event is represented as an exponential function. The factors that affect the occurrence of landslide event are related linearly with a factor 'z' and the probability of occurrence of a landslide event is exponential related with the inverse of 'z' factor. Say, the occurrence of landslide event depends upon the factors i.e. A, B, C, D etc. then 'z' is given by the formula in equation.

$$z = Ax+By+Cz+..... \tag{1}$$

Here, x, y and z are the linear coefficients and A, B, C are the factors responsible for the occurrence of the landslide events. The probability of the occurrence of a landslide event is given by the equation (2).

$$P(z) = 1/e^{-z} \quad (2)$$

The accuracy of the multivariate method is generally upto 80% and the accuracy of the results can be improved by varying the different factors responsible for the landslide occurrence.

**B. Distribution Analysis-**

The distribution analysis technique was devised by Van Western in 2002. In the distribution analysis technique, the weights are calculated by the logarithmic expression of the landslide density. The landslide density is calculated in the terms of the number of the pixels (Van Western, 2002). The accuracy of this method is upto 70 %. This method is considered good at regional level (Soeters and Van Western; 1996, Guzzetti et. al; 1999).

**AHP APPROACH IN LANDSLIDE SUSCEPTIBILITY MAPPING**

Analytic hierarchy process (AHP) is a very useful method in landslide susceptibility mapping (Saaty; 1980). The method was devised by Saaty. AHP is based upon three principles i.e. decomposition of problem, comparative judgment and synthesis of relative importance or rankings. AHP works on the principle of breaking the problem in hierarchical order and then ranking the criterion according to their relative importance. The weights can be assigned by expert advice to the factors on which the occurrence of landslide event depends upon. These weights purely depend upon the user’s perception (Hong et. al; 2007). So, the accuracy of the expert driven approach depends upon the accuracy of the weights that are assigned to each factor. The factors on which the occurrence of landslide events depends upon are compared in the pairwise comparison matrix and the ranking of each factor is calculated according to their relative importance (Baban et. al; 2006). A numerical index called consistency ratio is also calculated to check the accuracy of the results (Saaty; 1980). If  $\lambda_{max}$  is the maximum value of the pairwise comparison matrix and ‘n’ is the number of the factors responsible for landslide occurrence, then consistency index is given by equation (3).

$$C.I. = (\lambda_{max} - 1) \div (n - 1) \quad (3)$$

The consistency ratio i.e. the ratio of consistency index and the randomness index. The randomness index is calculated by Saaty and is available in the literature. If the consistency index is less than 10%, then the weightages calculated are fairly accurate and can be used for deriving of susceptibility map. If the consistency index is more than 10 %, then the weightages are to be calculated again. The table for the randomness index is given. Analytic hierarchy process

is based upon the user perception. So, the pairwise comparison matrices will be different for the different study area. This method is good at regional level (Soeters et. al; 1996). In AHP the results are about 65 % accurate (Dai et. al; 2004).

**Table -1 Randomness Index**

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
R	0	0	0.5	0.9	1.1	1.2	1.3	1.4	1.4	1.5	1.5	1.5	1.5	1.5	1.5
I			8		2	4	2	1	5	9	1	3	6	7	9

**CONCLUSION**

The methods like fuzzy logic and neural network used by F.Sado et al in 2013 in landslide mapping are considered very accurate but in both the methods the data is to be converted into ASCII codes. The statistical methods as used by F.Mainici et al. in 2010, gives accuracy about 80%, but this method is based upon on the numerical calculation in which the user perception is not considered. The statistical methods require large amount of relevant data. If the data about the landslides is not available, then the statistical methods can not be applied. Analytic hierarchy process is based upon the user perception. So, the results may be erroneous if the perception of the user is wrong. But, this drawback of AHP method is overcome if data driven approach is used. It is found that AHP gives results with accuracy upto 65%.

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