EARTHQUAKE INDUCED LANDSLIDE SUSCEPTIBILITY ASSESSMENT OF DOLAKHA DISTRICT USING LOGISTIC REGRESSION MODEL

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***Abstract*— The Gorkha Earthquake – 2015 with a magnitude of Mw 7.8 seriously affected the thirty one districts of the country. The present study is focused on the earthquake induced landslide susceptibility mapping of the Dolakha district, one of the most affected district by the Gorkha Earthquake. The mapping is based on the statistical approach – logistic regression model. Statistical relationships for landslide susceptibility were developed using landslide and landslide causative factor databases. A total number of 1718 landslides were identified through the landslide inventory. 75% (1,288) of them were used for model development and the remaining 25% (430) were used for the validation purpose. The parameters used in this study are geological formation, landuse, slope, aspect, curvature, elevation and PGA values. The major objective of this study was to generate earthquake induced landslide susceptibility map using the ArcGIS and the logistic regression model.**

The landslide susceptibility map of the Dolakha district was prepared using the abovementioned seven parameters. The final susceptibility map was divided into four classes viz., low (less than 25%), moderate (25-50%), high (50-70%) and very high (> 70%). The study showed that 21% area of the district is under very high hazard of landslide and 47%, 25% and 7% under high, moderate and low hazard respectively. Further, the river corridors (inner valley) were found more susceptible to the earthquake induced landslides. The validation of the map was carried out by the success rate curve, which showed that the model is 76.5% accurate and further the model accuracy was predicted using the prediction curve which showed that the accuracy of model is 72.63%.

Keywords*— *Landslide, Susceptibility, Dolakha, Logistic Regression, Earthquake

I. Introduction

The 25 April 2015 earthquake, commonly known as the Gorkha Earthquake triggered more than 17,000 co-seismic and post-seismic landslides which are widely distributed in an area of about 20,500 sq. km [1].

Dolakha district, which lies in the eastern part of the country, is one of the most affected districts by the Gorkha earthquake, particularly by the major aftershock that occurred on May 12, 2015. Numerous co-seismic and the post-seismic landslides, rockslides, avalanches were occurred in the district. The landslide susceptibility map of the whole district is not found in the literature till date. Therefore, the landslide susceptibility map will provide the valuable information for disaster mitigation and sustainable project implementation.

Landslide susceptibility can be defined as the tendency for a landslide to be generated in a specific area in the future; this can be measured from the correlation between determining factors together with the spatial distribution of the movements [2]. Different methods are used to prepare the landslide susceptibility maps using Statistical tools and ArcGIS. Logistic regression, which is a multivariate analysis technique, predicts the presence or absence of a result based on values of a set of predictor variables. This model is suited when dependent variable (e.g. landslide event) is dichotomous [3].

This paper covers the earthquake-induced landslide susceptibility assessment of the Dolakha district and dividing area in to zones of different hazard level. The paper will help in the mitigation of future damages due to earthquake-triggered landslides by planning the settlements or development activities away from seismically vulnerable zones or by taking necessary remedial measures while dealing with such zones.

II. The Study Area

Dolakha district, one of the mostly affected district by the Gorkha Earthquake is chosen as the study area. The geographic location of the district is 27° 28’ to 28° 0’ N Latitude & 85°

50’ to 86° 32’ E longitude. This area is characterized by the elevated mountains and the deep river valleys. The altitude of the district varies from 732 amsl to 7,134 amsl. Geologically, Dolakha district lies in the Higher Himalyan Range in the north and extends to the midlands in the south. The majority of the district lies in the Higher Himalayan. The lithology is found different in different zones. Gniesses, schists, migmatites and marbles are found in the Higher Himalayan region whereas Gneisses, schists, phyllites and marbles are common in the fore Himalayan region of the altitude between 2000-5000 m. Lower part lies in the Lesser Himalayan Zone. Lesser and Higher Himalayan Zone are separated by the Main Central Thrust (MCT). The location map of the study area is given below in fig. 1.

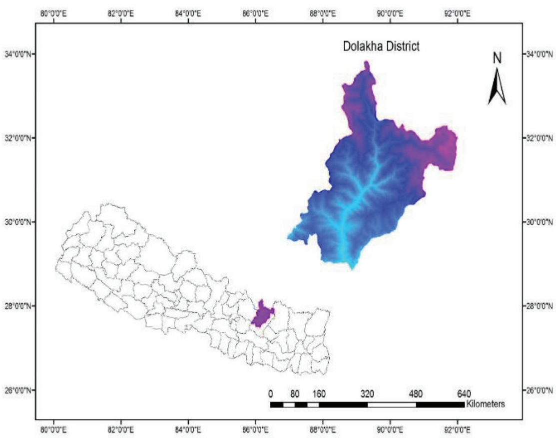


Fig. 1: Location map of the Dolakha district (the study area)

III. LANDSLIDE INVENTORY

An accurate landslide inventory is a pre-requisite for any kind of landslide hazard studies irrespective of models and methods. Landslide inventories are essentially factual in nature [4]. Preparation of landslide inventory map is the most important and initial step for landslide susceptibility analysis [5]. Since landslide occurrences in the past and present are keys to spatial prediction in future [6], a landslide inventory map is a prerequisite for such a study. Accurate detection of the location of landslides is very important for probabilistic landslide susceptibility analysis [7]. The landslides after Gorkha Earthquake were marked in the Google Earth and in total 1818 landslides were identified. The total area of these landslides were 1.873 km2 which is 0.086% of the study area. Out of 1818 landslides, 75% (1288) were randomly taken to prepare the model and remaining 25% (430) were used for the validation purpose. The landslide inventory map is shown in the fig. 2.

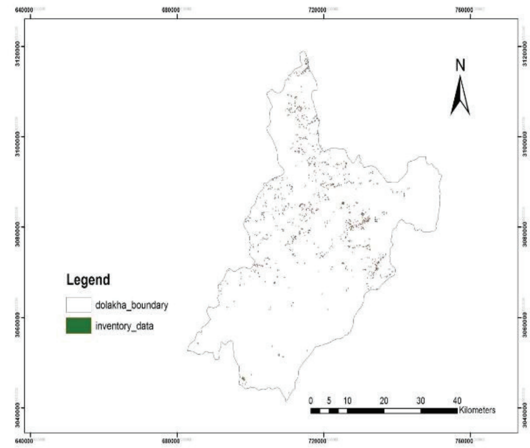


Fig. 2: Landslide Inventory map of the study area.

The landslides were verified from the field study and mostly shallow landslides were observed in the district. Among them, the concentration of the landslide was in the river corridor. (Fig. 3)

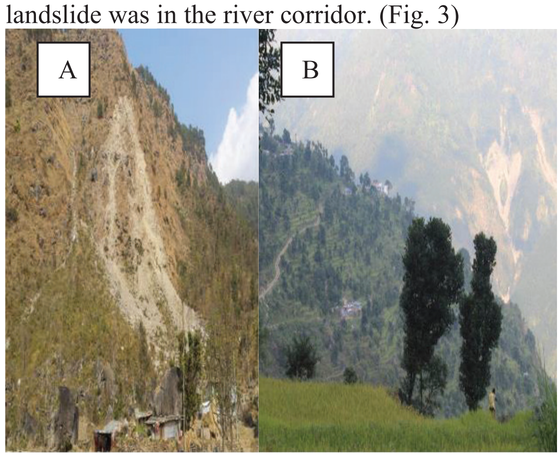
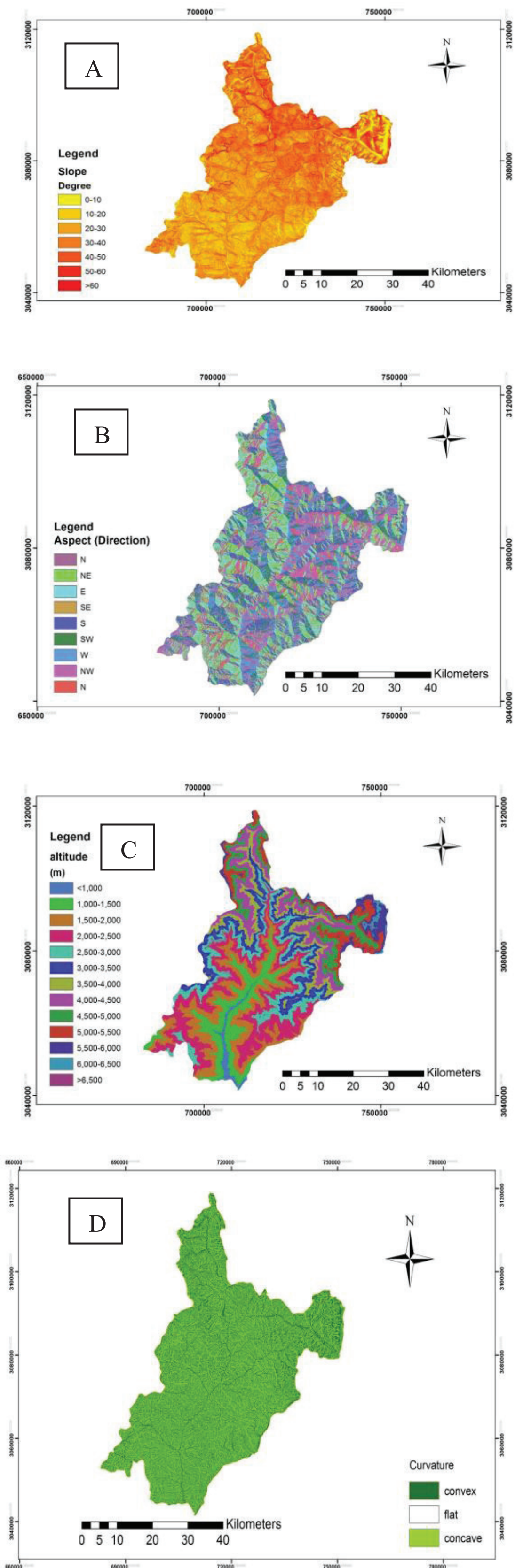


Fig. 3: Figure showing the landslides in the study area. (A) Rock Slide at Majhigaun, Tamakoshi RM-1, Dolakha,(B) Landslides at the river corridor in Bhimeshwar NP-1, Suspa Kshyamawati, Dolakha

IV. LANDSLIDE CAUSING FACTORS

The landslide causing factors that are considered in this study are slope gradient, aspect, plan curvature, altitude, geological formation, landuse and PGA values. The geomorphic factors like slope gradient, slope aspect, plan curvature, altitude were obtained from the Digital Elevation Model (DEM) produced by the topographic map provided by the Department of Survey, Nepal. The geological data was obtained by the digitization of the geological map produced by the Department of Mines and Geology and the PGA contour was obtained from the USGS website. Each of the thematic map was prepared in ArcGIS and were reclassified accordingly.



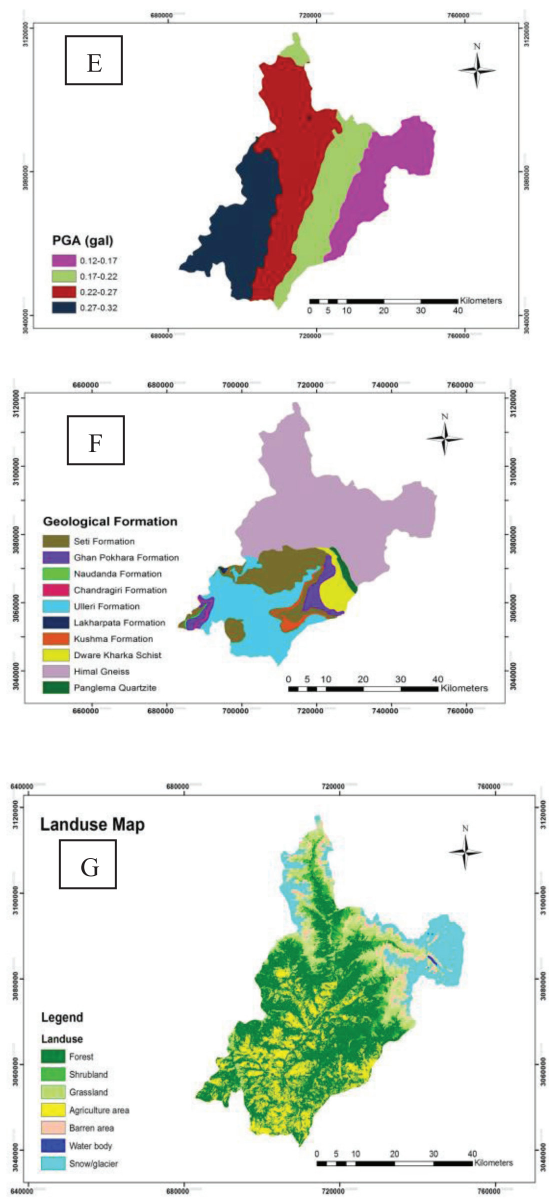


Fig. 4: Thematic maps used in the study, A. slope map (in degrees), B. aspect map, C. altitude map, D. curvature map, E. PGA map, F. Geological formation map, G. landuse map

V. MODELING APPROACH

A. Logistic Regression Model

Logistic regression (LR) allows forming a multivariate regression relation between a dependent variable and several independent variables [7]. In the present situation, the dependent variable is a binary variable representing the presence or absence of landslides. The logistic model can be expressed in its simplest form as:

$$P_r = \frac{e^z}{1+e^z} \quad \text{............(1)}$$

The logit Z is assumed to contain the independent variables on which landslide occurrence may depend. The LR analysis assumes the term Z to be a combination of the independent set of geographical variables X_i (i = 1,2,...,n) acting as potential causal factors of landslide phenomena. The term Z is expressed by the linear form

$$Z = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n \text{...........(2)}$$

Where, coefficients β_i(i = 1,2,...,n) are representative of the contribution of single independent variables X_i to the logit Z and β_0 is the intercept of the regression function. The logistic regression model involves fitting of Equation (2) to the data and then expressing the probability of the presence/absence of landslides in each mapping unit. The logistic regression analysis was performed using the Statistical Package for the Social Sciences (SPSS) statistical software.

The binary logistic regression model was used to calculate the weightage of each landslide causing factor. This research work contains seven independent variables and one dependent variable. The dependent variable is "Landslide Susceptibility" which is coded as 0 or 1. If there is landslide, it is coded as 1 and if there is not a landslide at all, it is coded as 0. The seven independent variables are slope, elevation, aspect, curvature, PGA, geology and land use. Among them the geological formation and land use are the categorical variables.

Finally, the binary logistic regression model was run in the SPSS and the resultant β coefficients for each independent variables are given in the table 1.

Table I: Coefficient of each independent variables used in logistic regression modelling

Factor	Class	β
PGA		2.124
curvature		.129
elevation		-.0004477
slope		.022
aspect		.001
Landuse Class	Agriculture	1.502
	Barren area	2.275
	Forest	1.945
	Grassland	1.706
	Shrubland	1.609
	Snow/glacier	2.254
	Water Body	0.000
Geological formation	Chandragiri Formation	-13.293
	Dware Kharka Schists	-2.117
	Ghan Pokhara Formation	-2.432
	Himal Gneiss	1.133
	Kushma Formation	-13.432
	Lakharpata Formation	-13.331
	Naudada Formation	-13.318
	Panglema Quartzite	-1.523
	Seti Formation	.592
	Ulleri Formation	0.000
Constant		-9.775

VI. RESULT AND DISCUSSION

A. Landslide Susceptibility Map of Dolakha District

The resultant beta (β) coefficients for each independent variable in the logistic regression equation are given in Table I. Based on the obtained result, Equation 2 can be rewritten as:

$$z = (2.124 \times pga) + (0.129 \times curvature) + (-0.0004477 \times elevation) + (0.022 \times slope) + (0.001 \times aspect) + landuse + geological\ formation - 9.775 \ldots.. (3)$$

Finally, landslide susceptibility map of the Dolakha district was obtained by running the above equation in the ArcGIS with the help of the raster calculator tool. The landuse map and geological formation map are already revised using the logistic regression coefficient in the ArcGIS. Therefore, the coefficient of those maps has been taken as one.

From the analysis of the logistic regression coefficients, it is seen that PGA value, curvature, aspect and the slope have the significant role in the landslide susceptibility of the Dolakha district, as they all have positive β values. Also, it is seen that PGA value has the highest β coefficient (2.124), followed by the curvature (0.129), slope (0.022) and the aspect (0.001) respectively. Elevation has the negative β coefficient, so it is considered less significant in the earthquake induced landslide susceptibility assessment. Considering to geological formation of the study area, it is seen that Himal Gneiss (β = 1.133) are most susceptible to sliding. Considering landuse, it is seen that barren area (β = 2.275) is the most prominent to cause the landslide as it has the highest β coefficient.

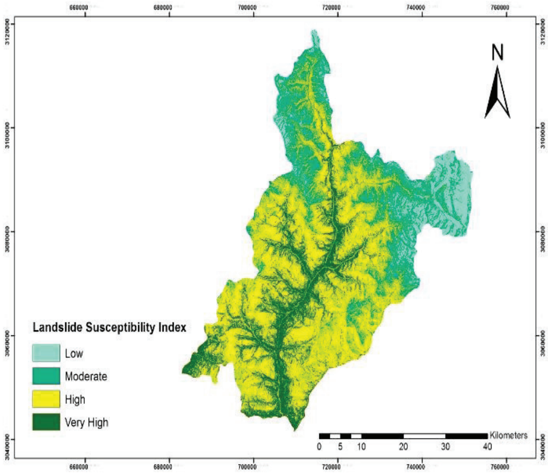


Fig. 5: Susceptibility Map of Dolakha district

The landslide susceptibility map was divided into four classes viz., low (less than 25%), moderate (25-50%), high (50-70%) and very high (> 70%). The area lying under the different susceptibility class was calculated in ArcGIS and it showed that 21% area of the district is under very high hazard of landslide and 47%, 25% and 7% under high, moderate and low hazard respectively.

Further, the river corridor is seen highly susceptible to the earthquake induced landslides. It is probably due to the reason that the river corridors (inner valleys) are geologically weak, and rivers continuously affect the side slope through bank cutting [8] and more vulnerable to the earthquake induced landslides. The inner valleys are subjected to the rapid incision by the current of the moving water and the loosen materials have been removed by the giant shaking of the earthquake.

B. Validation of Susceptibility Map

In total, 75% (1,288) of the landslides were used for the model building where remaining 25% (430) landslides were randomly selected for the model validation. The landslide susceptibility map prepared using the model building data was tested using the success rate curve. The Landslide Susceptibility Index map was reclassified into 100 equal intervals and it was crossed with the raster image of Landslide Inventory map. The landslides falling in each class was obtained and the success rate curve was drawn. The success rate curve was drawn on the basis of cumulative percentage of map area versus cumulative percentage of landslide occurrence. The success rate curve depicts that the area under the curve is 76.5% which shows that the model used is good for the analysis. Similar process was repeated for the prediction curve but using the remaining 25% landslides. The prediction curve showed that the prediction rate is 72.63% accurate.

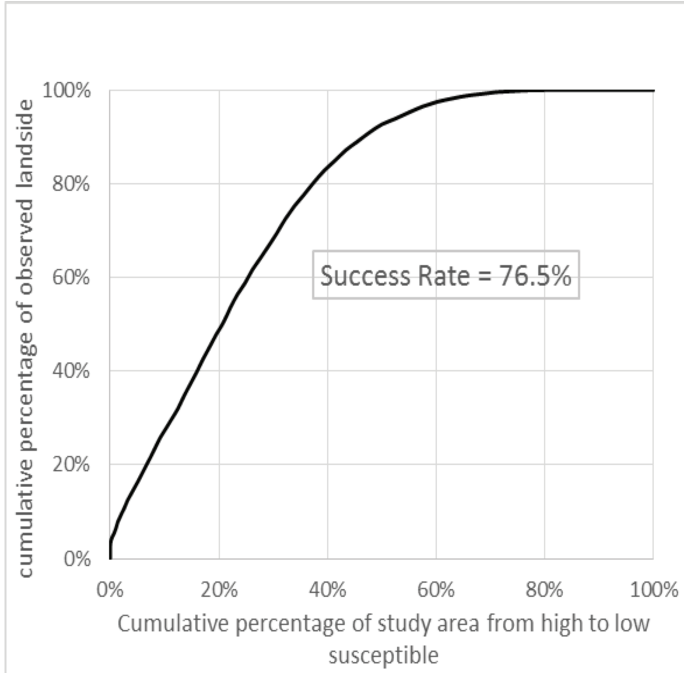


Fig. 6: Success rate curve of Susceptibility Map of Dolakha district

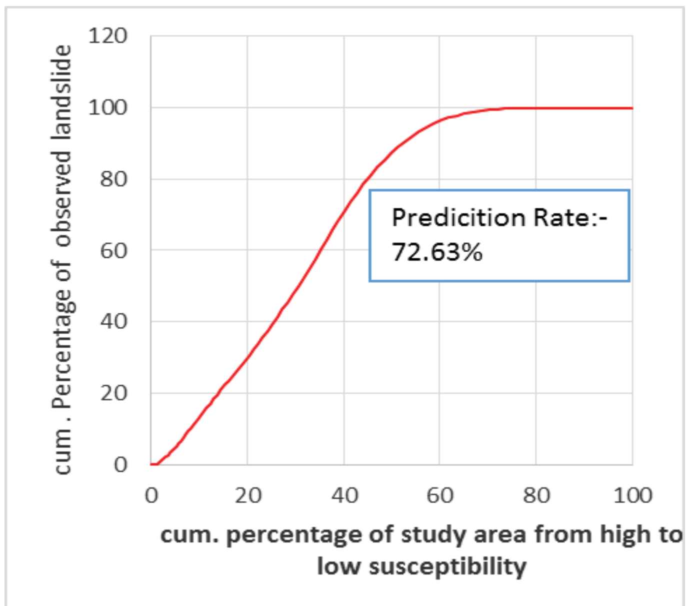


Fig. 7: Prediction rate curve of Susceptibility Map of Dolakha district

VII. CONCLUSION

The Gorkha Earthquake (2015) and its subsequent aftershocks have greatly affected the Dolakha district. Numerous landslides with rockfall have been observed in the field. This research was intended to qualitative susceptibility assessment of the earthquake induced landslides. For this purpose, logistic regression model was used for the landslide susceptibility assessment of the study area. For this study, only seven parameters (slope, curvature, aspect, elevation, PGA values, geological formation and landuse) were used for preparing the landslide susceptibility map due to the paucity of the data. A landslide inventory was prepared in Google Earth image and this inventory was verified with the field visit. 75% of the landslides were used for the model preparation and the remaining 25% data were used for model validation. The validity of the model was checked through the success rate curve and the success rate curve showed that the model is 76.5% valid and again the prediction rate curve was drawn using the remaining 25% landslides which showed that the prediction rate is 72.63% accurate. These values are taken as fairly good for landslide validation and prediction.

The landslide susceptibility assessment showed that 21% area of the district is under very high hazard of landslide and 47%, 25% and 7% under high, moderate and low hazard , from respectively. Further, from the study it has been seen that the river corridor is highly susceptibility and mostly the shallow disrupted landslides were observed which were later verified with the field study. The areas within high and very high landslide susceptibility categories identified in this study should require more detail engineering and geotechnical research by expert before commencing and planning projects on these zones. Proper mitigation measures should also be considered during the planning phase.

VIII. RECOMMENDATIONS

- For further research, the susceptibility assessment can be done using the other additional parameters like distance from fault, distance from drainage, topographic wetness index and the combined effect of those parameters may be observed.
- This study has incorporated the earthquake induced landslide susceptibility assessment using PGA values. Rainfall induced landslide susceptibility assessment may be done and the comparison of rainfall induced and earthquake induced maps may be another area of the research.

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REFERENCES

[1] Gnyawali, K. R., Maka, S., Adhikari, B. R., Chamlagain, D., Duwal, S., & Dhungana, A. R. (2016, April). Spatial implications of earthquake induced landslides triggered by the April 25 Gorkha earthquake Mw 7.8: preliminary analysis and findings. In International conference on earthquake engineering and post disastor reconstruction planning 24–26 April, 2016, Bhaktapur, Nepal (pp. 50-58).

[2] Brabb, E. E. 1984. `Innovative approaches to Landslide Hazard and Risk Mapping', IV International Symposium on Landslides, Toronto, Proceedings, Vol. 1, 307-324

[3] Wang, H. B., & Sassa, K. (2005). Comparative evaluation of landslide susceptibility in Minamata area, Japan. Environmental Geology, 47(7), 956-966.

[4] Fell, Robin, et al. "Guidelines for landslide susceptibility, hazard and risk zoning for land-use planning." Engineering Geology 102.3-4 (2008): 99-111

[5] Ayalew, L., & Yamagishi, H. (2005). The application of GIS-based logistic regression for landslide susceptibility mapping in the Kakuda-Yahiko Mountains, Central Japan. Geomorphology, 65(1-2), 15-31

[6] Guzzetti, F., Carrara, A., Cardinali, M., & Reichenbach, P. (1999). Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy. Geomorphology, 31(1), 181-216

[7] Devkota, K. C., Regmi, A. D., Pourghasemi, H. R., Yoshida, K., Pradhan, B., Ryu, I. C., ... & Althuwaynee, O. F. (2013). Landslide susceptibility mapping using certainty factor, index of entropy and logistic regression models in GIS and their comparison at Mugling–Narayanghat road section in Nepal Himalaya. Natural hazards, 65(1), 135-165

[8] Pokhrel, P., & Pathak, D. (2010). Landslide susceptibility mapping of southern part of Marsyangdi River basin, West Nepal using logistic regression method.