Landslide hazard zonation using GIS: A case study from Sindhupalchowk, Nepal

Article *in* International Journal of Applied Engineering Research · January 2015

2 authors:


Tri Dev Acharya
University of California, Davis


Intae Yang
Kangwon National University

International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 7 (2015) pp. 18385-18394

http://www.ripublication.com

Landslide Hazard Zonation using GIS: A Case Study from Sindhupalchowk, Nepal

Acharya, Tri Dev[1)] and Yang, In Tae[1)*]

1) Lab of GEO-Spatial Information Science, Department of Civil Engineering, Kangwon National University, Chuncehon, South Korea 200-701
**Corresponding Author: intae@kangwon.ac.kr (In Tae Yang)*

Abstract

Landslides are instant event of mass movement of earth surface down a slope, causing loss of life and property in hilly region of Nepal. Considering the recent massive landslide event, development of the landslide hazard map of Sindhupalchowk district was done using different weighted controlling factors i.e. slope, relative relief, distance to road & river network, landuse and soil maps. Landslide zone of low, moderate, high and very high hazards were derived and found that around 40% are in high hazard prone areas. Prior identification of hazard area could mitigate future loss events.

Keywords: Landslide, Hazard map, Weighted Multivariate Overlay, GIS, Sindhupalchowk, Nepal

1. Introduction

Landslides are natural phenomenon, defined as the movement of a mass of rock, debris or earth down a slope (Cruden, 1993). Globally, it is a disaster causing deaths and injuries of thousands of lives and destruction of billions of properties (Petley, 2012; Petley *et al.*, 2005). These damages can be reduced by understanding the mechanism of occurrence, prediction through hazard assessment, hazard zonation and early warning system (Dai *et al.*, 2002; Sassa and Canuti, 2008). In such case, preparation of landslide hazard maps can be an initial step towards mitigation and control. Hazard assessment can help authorities prevent and reduce damage through proper land use management for infrastructural development and environmental protection (Tien Bui *et al.*, 2013).

Landslide hazard zonation is division of the land surface into areas and the ranking of these areas according to degrees of actual or potential hazard from landslides or other mass movements on slopes (Varnes and IAEG, 1984). Even though landslide events are uncertain, with the advancement of Remote Sensing and GIS techniques, landslide hazard zonation studies have become more advanced and operative. Also, these techniques have made monitoring, evaluation and management of natural hazards better in terms of economy of results and cost. Several studies have been carried in different part of the world to understand landslide mechanism and process (Althuwaynee *et al.*, 2014; Nampak *et al.*, 2014; Devkota *et al.*, 2013; Tien Bui *et al.*, 2012; Pradhan and Lee, 2010; Nandi and Shakoor, 2010; Yilmaz, 2009).

Geographically, Nepal is a one of the most vulnerable countries in the world to landslide. Rugged topography, unstable geological structures, soft and fragile rocks, along with heavy and concentrated rainfalls during monsoon periods collectively cause severe land sliding problems and related phenomena in the mountainous part of Nepal (Dahal, 2012). In recent days, it has been raised by unmonitored expansion of rural transport networks in hilly regions, leading to terrain alteration and other negative impacts on environment (Petley *et al.*, 2007). In Nepal, a large number of human settlements are situated either on old landslide masses or on landslide-prone areas (Dahal, 2012). Apart from massive landslides in Nepal (Table 1), occurrences of many small-scale landslides in remote areas are seldom accounted unless they involve the loss of life. Also, the economic losses caused by small-scale landslides are no less than any other big event of natural disaster (Dahal, 2012).Various case studies have also been carried out in Nepal for different areas for landslide (Laban, 1979; Upreti and Dhital, 1996; Dhakal *et al.*, 2000; Neaupane and Achet, 2004; Acharya *et al.*, 2006; Petley *et al.*, 2007; Dahal *et al.*, 2008b; Dahal *et al.*, 2008a; Poudyal *et al.*, 2010; Ghimire, 2011; Dahal, 2012; Kayastha *et al.*, 2012; Devkota *et al.*, 2013; Bijukchhen *et al.*, 2013; Kayastha *et al.*, 2013a; Kayastha *et al.*, 2013b; Regmi *et al.*, 2014a; Regmi *et al.*, 2014b; Dahal, 2015; Kayastha, 2015). Besides these studies, there are many potential areas with large population density and infrastructures yet to be studied. Also, findings of these studies are not yet integrated in any local and national disaster management databases.

Table 1. Major Landslide dammed lakes in the past (Source: Newspaper and Internet)

Year	Place	Casualties
1926	DarbangBajar, Myagdi	more than 500 persons died
1967	Tarebhir, Budhigandaki	9 persons died
1968	Tarebhir, Budhigandaki	24 houses damaged
1982	Balefi, Sindhupalchowk	97 persons died and 15 houses destroyed
1987	Sunkoshi, Sindhupalchowk	98 persons died
1988	DarbangBajar, Myagdi	109 persons died and 94 houses damaged
1989	Tarukhola, Bajhang	16 persons died and 4 houses destroyed
1996	Larcha, Sindhupalchowk	54 persons died and 18 houses destroyed
2010	Madikhola, Kaski	5 persons died and 61 families affected
2014	Mankha, Sindhupalchok	156 person died and 436 people displaced

The purpose of the study is to develop landslide hazard maps of

Sindhupalchowk, Nepal based on weighted multivariate overlay approach. It could be used to identify suitable areas for future developmental activities and to undertake migration measures in critical zones.

2. Area of Study

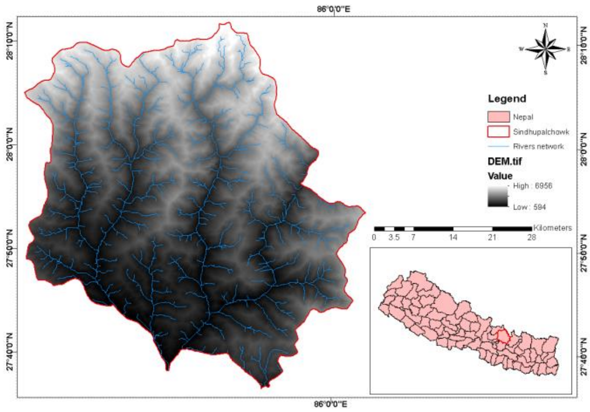

Fig. 1. Landslide location map of the study area with DEM and river network

The area of study, Sindhupalchowk district lies in Bagmati zone in the central region of Nepal (Fig. 1). It is 85km away to the north-east of Kathmandu valley and bordered by Nuwakot, Kathmandu, Kavre, Rasuwa, Dolakha and China. It covers an area of 2,542 km^2 and lies between 27’42” to 28’ 11”N latitude and 85’ 27” to 86’ 06”E longitude. The overall terrain of the study area is hilly ranging from 593-6959 meters with river passing through them. The climate is subtropical, temperate, and alpine. The temperature range is 28.5° to 4.0° C and rainfall is 3604.3 ml of which 80% fall in monsoon season (Nepal Tourism Board, 2008). Intense precipitation and dozer excavation for road are the main triggering factor of landslides. The district has a total population of 287,798 and density 110 persons per km^2 (Central Bureau of Statistics (CBS), 2012).

3. Materials and Methodology

In order to develop landslide hazard map, selection of controlling factors is very important. The slope of an area, its geomorphological feature, climate and anthropogenic activities play important roles in triggering the process. The study is based on data collected freely from data portals and webs. The main input data for the study are DEM, river and road network, landcover and soil maps.

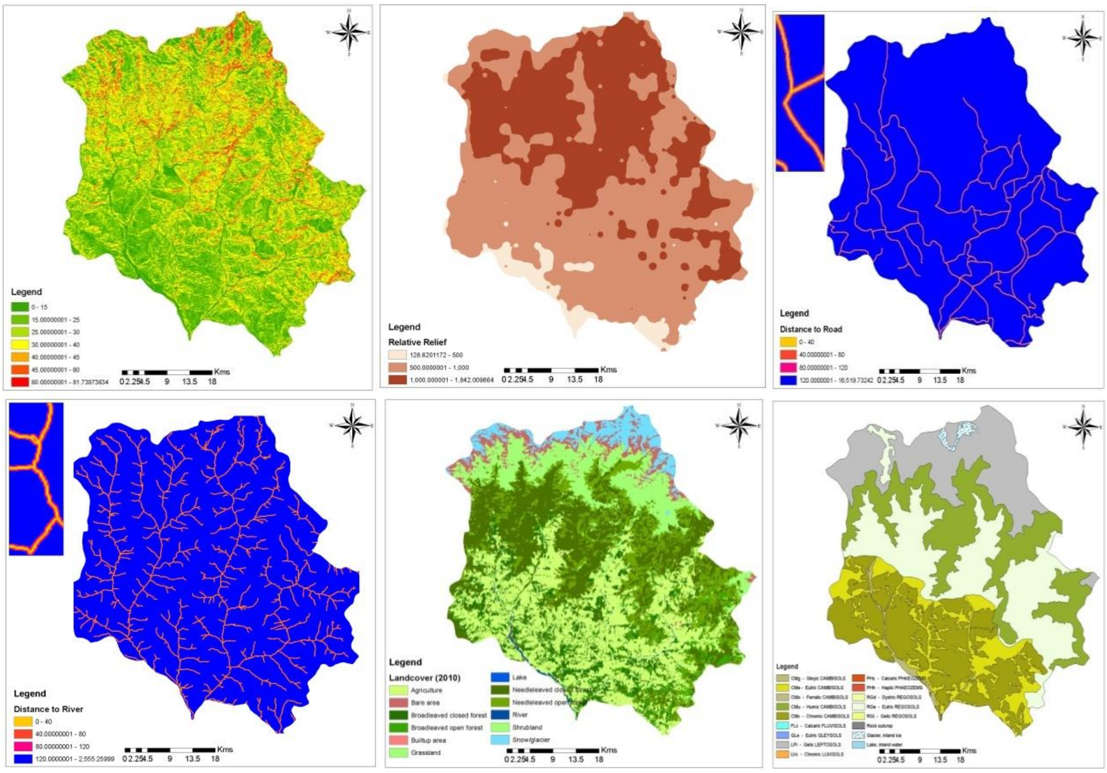

Fig. 2. Controlling factor maps: slope, relative relief, distance to road, distance to river, landcover and soil map (from top left to right bottom)

Digital elevation model (DEM):

DEM of the study area were clipped from freely available ASTER GDEM Worldwide Elevation data (1.5 arc second resolutions). Various derivatives were derived namely: slope and relative relief in ArcGIS 9.2. Increase in the slope gradient cause increase in the shear stress in soil, making it susceptible to failure (Saha *et al.*, 2002). Thus steeper slope has more chance of slope instability and leading to landslide (Oh and Lee, 2011; Sharma *et al.*, 2011). Relative relief refers to the difference between the highest and the lowest altitude in an area which plays a decisive role in the vulnerability of settlements, transport network and land (Lee *et al.*, 2004). The higher values indicate rapid rise in altitude and presence of faults, lower relief signifies mature topography.

Road and Stream network:

Both were clipped form data downloaded from Regional Database System (RDS) available at http://rds.icimod.org of International Centre for Integrated Mountain Development (ICIMOD). The distance from road and distance from stream were derived based on Euclidean distance from these features. The drainage patterns in the area are an outcome of long time interaction between the geological structures, topography and slope whereas roads are manmade artificial cuts and fills causing instability of the slope (Tien Bui *et al.*, 2011).

Landcover map:

Landcover map was clipped form Landcover data of 2010 available from RDS of ICIMOD. It is one of the important factors that control the occurrence of landslides and reflects relationships between land use, disaster risk and vulnerability to disaster events. It is an indirect indication of stability of hill slopes because it controls the rate of weathering and erosion of the underlying rock formations.

Soil map:

Soil map was clipped form the digital soil map of the world prepared by FAO. This digital soil map is available in shape format with geographic coordinate system. Various soil types are layered according to its maturity and their properties various bearing capacity of shear stress in soil.

The overall methodology of the project is shown in in fig. 3. Above mentioned controlling factors have been prepared using standard Remote Sensing and GIS techniques, and were utilized as parameters for giving weightage and for generating different landslide hazard classes. All these calculated and extracted controlling factors were categorized in range from 0 to 10 as shown in table 2 and converted to a 30m x 30m grid for further processing. The information collected from previous landslide studies were also incorporated to arrive at a more accurate weighted score for each factor and their respective classes. These weighted raster maps were overlaid using multivariate criteria analysis to prepare a landslide hazard map of Sindhupalchowk district.

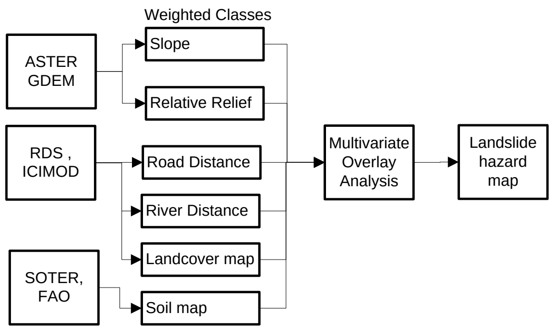

Fig. 3. Methodology of Landslide Hazard Zonation

Table 2. Weight for different class of controlling factors

Controlling factors	Class	Weight
Slope	0-15	2
	15-25	4
	25-30	6
	30-40	8
	40-45	5
	45-60	4

	>60	3
Relative Relief	0-500	2
	500-1000	3
	>1000	4
Distance to Road	0-40	2
	40-80	4
	80-120	3
	>120	2
Distance to River	0-40	2
	40-80	4
	80-120	3
	>120	2
Landuse	River, Lake, Broad and Needle leaves closed forest	2
	Snow/Glacier, Broad and Needle leaves open forest	3
	Shrubland, Grassland	4
	Builtup, Bare and Agriculture	6
Soil	Cambisols	4
	Regosols	3
	Leptosols	2
	Glacier,Iceland cap, Rock outcrop	2

4. Results and Discussion

In this study, combining all the factors, by giving different weightage value for various classes, the final landslide hazard map was prepared and classified into Low, Moderate, High and Very High hazard zones. The output map is generated on is shown in fig.4. It was found that around 0.6% of the area i.e. 16.44 km^2 is in very high risk whereas 40.65 % i.e. 1030.5 km^2 have high hazard to slope failure. These areas show either high relief or slope near river network or near to road and agricultural landcover. With influence of short intense rainfall, these areas could lead to landslide. The derived map was overlaid in Google Earth Pro and comparing with latest landslide events. One of the massive landslide cases in Sunkoshi River is shown in fig. 4.

Similarly, rest of the district shows moderate hazard and very few area shows lower hazard in the study area. As the area is mostly mountainous with terrace farming, there is always a moderate probability that intense and prolonged rainfall could lead to slope instability. The lower hazardous zones are mostly flat hilltops or the flat riversides. Agriculture area shows quite high hazard compared to open rock outcrops and forest covers. In order to see the effectiveness of the hazard map, a total of 50 landslides were collected from high resolution imagery of Google Earth Pro. More than 75% of the landslides fall under high and very high hazard zones.

Table 3. Landslide hazard zonation statistics

Landslide Hazard Code	Hazard Class	Area (km²)	Percentage
1	Low	153.22	6.05
2	Moderate	1334.63	52.65
3	High	1030.5	40.65
4	Very High	16.44	0.65

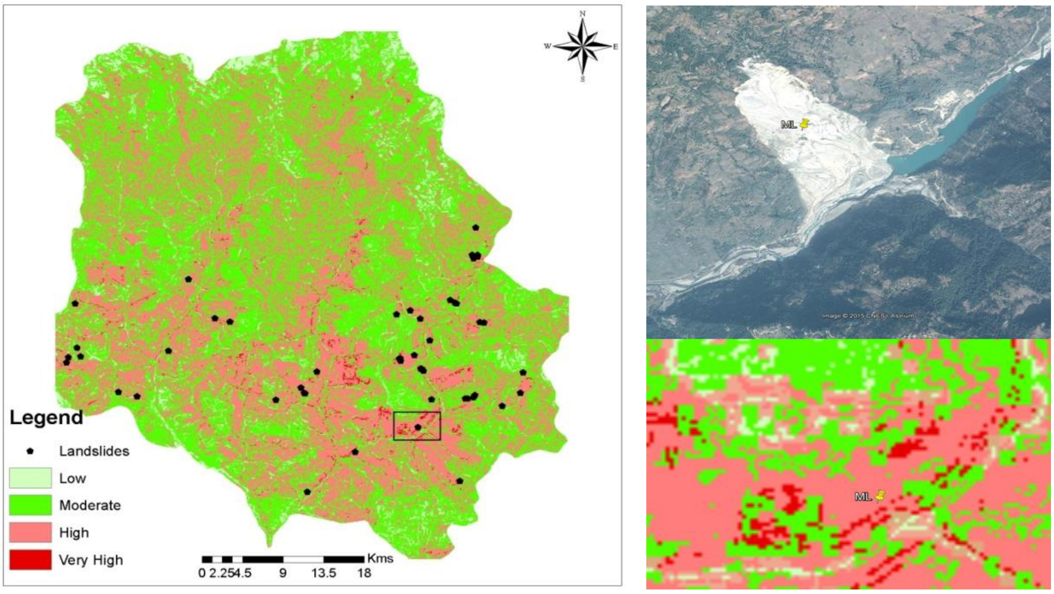

Fig. 4. Landslide Hazard map with Google Earth image of Sunkoshi Landslide event (ML represents massive landslide event)

6. Conclusion and Recommendation

Landslide is uncertain and instant event causing damage of life and property. The study shows application of multivariate overlay technique of GIS technology which used freely available data sources. Different controlling factors such as slope, relative relief, distance to road and river networks, landuse and soil types were used to derive the landslide hazard map. The study shows almost half the area is in high hazard of landslide in case of with or without intense rainfall. Identification and displacement of settlement in such areas need to be done immediately. And in future, using these landslides hazard maps in land use planning would be invaluable for the mitigation of loss as well as management of the environment at local level.

7. References

1. Acharya, G., De Smedt, F. and Long, N. (2006). "Assessing landslide hazard

in GIS: a case study from Rasuwa, Nepal." *Bull. Eng. Geol. Env.*, Vol. 65, No. 1, pp. 99-107.

2. Althuwaynee, O.F., Pradhan, B., Park, H. and Lee, J.H. (2014). "A novel ensemble bivariate statistical evidential belief function with knowledge-based analytical hierarchy process and multivariate statistical logistic regression for landslide susceptibility mapping." *Catena*, Vol. 114, No. 0, pp. 21-36.
3. Bijukchhen, S., Kayastha, P. and Dhital, M. (2013). "A comparative evaluation of heuristic and bivariate statistical modelling for landslide susceptibility mappings in Ghurmi-DhadKhola, east Nepal." *Arabian Journal of Geosciences*, Vol. 6, No. 8, pp. 2727-2743.
4. Central Bureau of Statistics (CBS) (2012). *National Populatio n and Housing Census 2011 (National Report)*, Government of Nepal, CBS.
5. Cruden, D.M. (1993). "The multilingual landslide glossary." *The International Geotechnical Societies UNESCO Working Party for World Landslide Inventory*, Vol. 5.
6. Dahal, R.K., Hasegawa, S., Nonomura, A., Yamanaka, M. and Dhakal, S. (2008a). "DEM-based deterministic landslide hazard analysis in the Lesser Himalaya of Nepal." *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards*, Vol. 2, No. 3, pp. 161-178.
7. Dahal, R.K. (2012). "Rainfall-induced Landslides in Nepal." *International Journal of Erosion Control Engineering*, Vol. 5, No. 1, pp. 1-8.
8. Dahal, R.K. (2015). *Understanding of Landslide Science in the Nepal Himalaya*, Springer International Publishing.
9. Dahal, R.K., Hasegawa, S., Nonomura, A., Yamanaka, M., Dhakal, S. and Paudyal, P. (2008b). "Predictive modelling of rainfall-induced landslide hazard in the Lesser Himalaya of Nepal based on weights-of-evidence." *Geomorphology*, Vol. 102, No. 3–4, pp. 496-510.
10. Dai, F.C., Lee, C.F. and Ngai, Y.Y. (2002). "Landslide risk assessment and management: an overview." *Eng. Geol.*, Vol. 64, No. 1, pp. 65-87.
11. Devkota, K., Regmi, A., Pourghasemi, H., Yoshida, K., Pradhan, B., Ryu, I., Dhital, M. and Althuwaynee, O. (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." *Nat. Hazards*, Vol. 65, No. 1, pp. 135-165.
12. Dhakal, A.S., Amada, T. and Aniya, M. (2000). "Landslide hazard mapping and its evaluation using GIS: an investigation of sampling schemes for a grid-cell based quantitative method." *Photogramm. Eng. Remote Sensing*, Vol. 66, No. 8, pp. 981-989.
13. Ghimire, M. (2011). "Landslide occurrence and its relation with terrain factors in the Siwalik Hills, Nepal: case study of susceptibility assessment in three basins." *Nat. Hazards*, Vol. 56, No. 1, pp. 299-320.
14. Kayastha, P., Dhital, M.R. and De Smedt, F. (2013a). "Application of the analytical hierarchy process (AHP) for landslide susceptibility mapping: A case study from the Tinau watershed, west Nepal." *Comput. Geosci.*, Vol. 52, No. 0, pp. 398-408.

15. Kayastha, P. (2015). "Landslide susceptibility mapping and factor effect analysis using frequency ratio in a catchment scale: a case study from Garuwa sub-basin, East Nepal." *Arabian Journal of Geosciences*, pp. 1-13.
16. Kayastha, P., Dhital, M. and De Smedt, F. (2012). "Landslide susceptibility mapping using the weight of evidence method in the Tinau watershed, Nepal." *Nat. Hazards*, Vol. 63, No. 2, pp. 479-498.
17. Kayastha, P., Dhital, M. and De Smedt, F. (2013b). "Evaluation and comparison of GIS based landslide susceptibility mapping procedures in Kulekhani watershed, Nepal." *Journal of the Geological Society of India*, Vol. 81, No. 2, pp. 219-231.
18. Laban, P. (1979). *Landslide occurrence in Nepal*, Ministry of Forest, Department of Soil and Water Conservation, Integrated Watershed Management, Torrent Control, and Land Use Development Project.
19. Lee, S., Choi, J. and Min, K. (2004). "Probabilistic landslide hazard mapping using GIS and remote sensing data at Boun, Korea." *Int. J. Remote Sens.*, Vol. 25, No. 11, pp. 2037-2052.
20. Nampak, H., Pradhan, B. and Manap, M.A. (2014). "Application of GIS based data driven evidential belief function model to predict groundwater potential zonation." *Journal of Hydrology*, Vol. 513, No. 0, pp. 283-300.
21. Nandi, A. and Shakoor, A. (2010). "A GIS-based landslide susceptibility evaluation using bivariate and multivariate statistical analyses." *Eng. Geol.*, Vol. 110, No. 1–2, pp. 11-20.
22. Neaupane, K.M. and Achet, S.H. (2004). "Use of backpropagation neural network for landslide monitoring: a case study in the higher Himalaya." *Eng. Geol.*, Vol. 74, No. 3–4, pp. 213-226.
23. Nepal Tourism Board (2008). "Tourism Procucts of Nepal." .
24. Oh, H. and Lee, S. (2011). "Cross-application used to validate landslide susceptibility maps using a probabilistic model from Korea." *Environmental Earth Sciences*, Vol. 64, No. 2, pp. 395-409.
25. Petley, D., Dunning, S. and Rosser, N. (2005). "The analysis of global landslide risk through the creation of a database of worldwide landslide fatalities." *Landslide risk management.Balkema, Amsterdam*, pp. 367-374.
26. Petley, D. (2012). "Global patterns of loss of life from landslides." *Geology*, Vol. 40, No. 10, pp. 927-930.
27. Petley, D., Hearn, G., Hart, A., Rosser, N., Dunning, S., Oven, K. and Mitchell, W. (2007). "Trends in landslide occurrence in Nepal." *Nat. Hazards*, Vol. 43, No. 1, pp. 23-44.
28. Poudyal, C., Chang, C., Oh, H. and Lee, S. (2010). "Landslide susceptibility maps comparing frequency ratio and artificial neural networks: a case study from the Nepal Himalaya." *Environmental Earth Sciences*, Vol. 61, No. 5, pp. 1049-1064.
29. Pradhan, B. and Lee, S. (2010). "Landslide susceptibility assessment and factor effect analysis: backpropagation artificial neural networks and their comparison with frequency ratio and bivariate logistic regression modelling."

Environmental Modelling & Software, Vol. 25, No. 6, pp. 747-759.

30. Regmi, A.D., Devkota, K.C., Yoshida, K., Pradhan, B., Pourghasemi, H., Kumamoto, T. and Akgun, A. (2014a). "Application of frequency ratio, statistical index, and weights-of-evidence models and their comparison in landslide susceptibility mapping in Central Nepal Himalaya." *Arabian Journal of Geosciences*, Vol. 7, No. 2, pp. 725-742.
31. Regmi, A.D., Yoshida, K., Nagata, H. and Pradhan, B. (2014b). "Rock toppling assessment at Mugling–Narayanghat road section: 'A case study from Mauri Khola landslide', Nepal." *Catena*, Vol. 114, No. 0, pp. 67-77.
32. Saha, A.K., Gupta, R.P. and Arora, M.K. (2002). "GIS-based Landslide Hazard Zonation in the Bhagirathi (Ganga) Valley, Himalayas." *Int. J. Remote Sens.*, Vol. 23, No. 2, pp. 357-369.
33. Sassa, K. and Canuti, P. (2008). *Landslides-Disaster Risk Reduction: Disaster Risk Reduction*, Springer Science & Business Media.
34. Sharma, A., Joshi, V. and Kumar, K. (2011). "Landslide hazard zonation of Gangtok area, Sikkim Himalaya using remote sensing and GIS techniques." *Journal of Geomatics*, Vol. 5, No. 2, pp. 87-88.
35. Tien Bui, D., Pradhan, B., Lofman, O., Revhaug, I. and Dick, Ø (2013). "Regional prediction of landslide hazard using probability analysis of intense rainfall in the Hoa Binh province, Vietnam." *Nat. Hazards*, Vol. 66, No. 2, pp. 707-730.
36. Tien Bui, D., Lofman, O., Revhaug, I. and Dick, O. (2011). "Landslide susceptibility analysis in the Hoa Binh province of Vietnam using statistical index and logistic regression." *Nat. Hazards*, Vol. 59, No. 3, pp. 1413-1444.
37. Tien Bui, D., Pradhan, B., Lofman, O. and Revhaug, I. (2012). "Landslide Susceptibility Assessment in Vietnam Using Support Vector Machines, Decision Tree, and Naïve Bayes Models." *Mathematical Problems in Engineering*, Vol. 2012, pp. 26.
38. Upreti, B.N. and Dhital, M. (1996). "Landslide studies and management in Nepal." ICIMOD, Kathmandu, Nepal.
39. Varnes, D.J. and IAEG (1984). *Landslide hazard zonation: a review of principles and practice*, United Nations Scientific and Cultural Organization, Paris, France.
40. Yilmaz, I. (2009). "Landslide susceptibility mapping using frequency ratio, logistic regression, artificial neural networks and their comparison: A case study from Kat landslides (Tokat—Turkey)." *Comput. Geosci.*, Vol. 35, No. 6, pp. 1125-1138.