We are IntechOpen, the world’s leading publisher of Open Access books
Built by scientists, for scientists

6,600
Open access books available

177,000
International authors and editors

195M
Downloads

154
Countries delivered to

TOP 1%
Our authors are among the most cited scientists

12.2%
Contributors from top 500 universities

WEB OF SCIENCE™
Selection of our books indexed in the Book Citation Index in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com
Chapter

Comparative Evaluation of Various Statistical Models and Its Accuracy for Landslide Risk Mapping: A Case Study on Part of Himalayan Region, India

C. Prakash, Aravinth R., Varinder S. Kanwar and B. Nagarajan

Abstract

Among other natural hazards, Landslides are the most prominent and frequently occurring natural disaster in the state of Himachal Pradesh with higher socio-economical losses. About 0.42 million sq.kms of area are prone to landslide activities in our country that is excluding the snow covered areas. The current research focuses on estimating the landslide risk zones of the Shimla Tehsil, Himachal Pradesh using various statistical models. Landslide contributing factors as such Landuse Landcover, Elevation, Slope, Lithology, Soil, Geology and Geomorphology has been used to assess the Landslide risk factors. Data obtained from LANDSAT 8 OLI sensors, SRTM DEM, Soil and Land Use Survey of India and SOI Toposheets have been used as sources. Weighted Overlay, Fuzzy logic and Analytical Hierarchical Process models will be used to categorize the Vulnerability and risk Zones of the study area. The causative factors were analyzed and processed in GIS environment. These values will be then being integrated using various studied models to produce individual landslide vulnerability and risk zones. The results reveal that most of the study area falls under Very Low risk category with a total coverage of 67.34%. Low and Moderate area covers about 23% and 9.13% of the study area. Higher risk areas only account for about 0.46%. Higher percent of the study area is mostly covered by settlements. National highways, Metal roads, Slopes and Denser settlements are located along the Moderate and low risk areas. The results retrieved from the WOM model reveals a total of 55% of the area comes under very low category. Low and Moderate category covers about 31.4% and 10.6% of the study area. High and Very High category cover a total of 1.9% together.

Keywords: weighted overlay, fuzzy logic, risk mapping, Shimla tehsil, landslide inventory
1. Introduction

“Landslides are simply defined as down slope movement of rock, debris and/or earth under the influence of gravity. This sudden movement of material causes extensive damage to life, economy and environment” [1, 2]. Landslide occurrence in mountainous regions can be due to both natural and Man-made causes such as Roadway and Settlement construction etc. (Figure 1). These causes include cloud-burst, thunderstorm, construction for various activities etc. [3]. The most sensitive areas are the Himalayan belt, Western and Eastern Ghats. Among other ecosystems Mountain ecosystem is one of the most fragile ecosystem in the world, when these ecosystems are disturbed either due to natural process or Anthropogenic process or the combined effect of both results in Geohazard and environmental problems such as landslides, soil erosion, reservoir siltation and land degradation [4–7]. Among other various problems that affect hill ecosystem, landslides have observed as fast spreading epidemic due to its multivariate morphodynamic process and also due to improper interaction of human being on nature, especially terrain ecosystem [8–10]. Not only in India but countries located along the borders of Himalayan region experience frequent landslide occurrences. These areas include the North Western and North Eastern Himalayas and the Western & Eastern Ghats [3]. Statistics on world landslides and its impacts is given in Table 1. Landslides of Various types, Pose severe hazards in the Himalayan mountains. Some of the worst disasters in the world have been caused by landslides [11–14]. Every year the damage cause by caused landslide amounts 1 billion$ says a us study and an average of 200 deaths in a year which is 30% of the such losses around the world [15, 16]. Map derived from the world bank data [17] indicates that most of the landslide hotspots are located along the mountainous region and active tectonics region (Figure 2) [18].

Surya Prakash [19] has compiled a list of landslides that have socio-economic impacts in India (Table 2). In his research he reported that the Western and North Western Himalayas account for about 51% high prone landslides.

Over the years' various scientist and researchers have addressed the landslide problems using various qualitative, Quantitative, Statistical and Numerical

![Figure 1: Landslide causative factors.](image-url)
methods. Every methodology used has its own merits and demerits. The type of
landslide involved depends upon varying condition such as slope, geology, geomor-
phology, nature of landslide, type of causative factor etc [16, 20, 21]. Based on the
literature it can be concluded that no methodology is global for landslide studies.
The accuracy of estimating landslide risk zones varies for each method [22–28]. It
is imperative reliable methodology should be used for the analysis of regional scale
landslide risk mapping. Addressing the nature and causative factor of individual
landslide is as important as preparing landslide risk maps. Most of the literature
address the mapping risk zones or slope stability analysis, it is imperative that all

| Continents | Events | Killed | Injured | Homeless | Affected | Total affected |
|------------|--------|--------|---------|----------|----------|----------------|
| Africa     | 23     | 745    | 56      | 7936     | 13,748   | 21,740         |
| Avg. Per event | 32  | 2      | 345     | 568      | 945      |
| America    | 145    | 20,684 | 4809    | 1,86,752 | 44,85,037| 46,76,598      |
| Avg. Per event | 143 | 33     | 1288    | 30,931   | 32,252   |
| Asia       | 255    | 18,299 | 3776    | 38,25,311| 16,47,683| 54,76,770      |
| Avg. Per event | 72  | 15     | 15,001  | 6462     | 21,478   |
| Europe     | 72     | 16,758 | 523     | 8625     | 39,376   | 48,524         |
| Avg. Per event | 23  | 7      | 120     | 547      | 674      |
| Oceania    | 16     | 542    | 52      | 18,000   | 2963     | 21,015         |
| Avg. Per event | 34  | 3      | 1125    | 185      | 1313     |

Table 1.
World statistics on landslides (1900–2010).

Figure 2.
Global landslide hotspots (2017), source (World Bank).
these problems should be addressed together. The current research is focused on analyzing the accuracy of weighted Overlay model and Fuzzy logic model to estimate the landslide risk mapping along the Rampur tehsil, Himachal Pradesh, India.

2. Study area

The study area extends from “76°58’19” to 77°19’21” longitude and 30°59’3” to 31°14’10” h latitude” with a total area of 368 Sq.km hectares (Figure 3). According to 2011 census the Shimla has a total of 576 villages. The total population of Shimla as of 2011 census is 1,71,640 people among which 1,69,578 reside in “Shimla Municipal Corporation” and the rest in Shimla Rural and Jutogh cantonment board.

| Sl.no | Year       | No. of socio economically significant events | Persons killed | No. of fatal events |
|-------|------------|---------------------------------------------|---------------|--------------------|
| 1     | 2018–2019  | 1                                           | 0             | 0                  |
| 2     | 2007–2017  | 893 (Nasa Catalog)                          | 6614          | 893                |
| 3     | 2011       | 26                                          | 74            | 19                 |
| 4     | 2010       | 85                                          | 368           | 53                 |
| 5     | 2009       | 47                                          | 270           | 46                 |
| 6     | 2008       | 36                                          | 220           | 30                 |
| 7     | 2007       | 54                                          | 409           | 39                 |
| 8     | 2000–2007  | 123                                         | 2630          | 61                 |

Table 2. Socio-economic significant landslides (1800–2011).

Figure 3. Study area.
Sutlej, Giri and Pabbar are the three major rivers that drain through Shimla. The economic activities are majorly dependent upon agriculture, horticulture and tourist activities in these areas. Cereals, off-season vegetables and stone fruits are most suitable to grow in the high altitude areas. Most of the agriculture is rainfall dependent. The soil varies from Sandy loam to Loamy skeletal in the valley and mountain regions. Geologically, Lithology was interpreted from the maps retrieved from the Soil and Landuse Survey of India (SLUSI). Major rock types present in these are Granite, Phyllite, Dolomite, Limestone and Shale. Geomorphologically the area is mostly Undifferentiated hillside and mountain side slope. An average of 999.4 mm of rainfall is recorded where most of the rainfall is received during monsoon period. “The temperature can go as low as 0°C during winter times and as much as 40°C during summer times”.

3. Dataset and research method

The base map of the study area was digitized from Survey of India Toposheets. One cloud free satellite data LANDSAT 8 OLI (26/01/2020) was downloaded from the earth explorer website. Soil data covering the study area was received from “Soil and Landuse Survey of India (SLUSI)”. In addition, a 30 mts ASTERGDEM data was downloaded from USGS website for topographical analysis. Rainfall data has been acquired from Indian Meteorological Department, Shimla. The types of data used is given in (Table 3).

Weighted Overlay and Fuzzy logic models are the two type statistical methods used in the research. In the recent years many researchers and scientist have used the methodology to derive landslide risk mapping with higher accuracies [29–36]. “Barrile Vincenzo et.al, 2016 used Fuzzy logic method for mapping landslide susceptibilities. The province of Reggio Calabria, Italy chosen as study area. Parameters such as Elevation Slope, Lithology, Rainfall and Landuse were assigned values and processed in GIS environment. The output subdivides into five categories ranging from Very low to Very high. The results indicate that 22%, 36% and 20% of the area comes under Very high, High and Moderate risk zones”. “Leonardi Geovani et.al, 2016 used a Fuzzy approach to analyze landslide susceptibility for Reggio Province, Calabria, Italy. Rainfall, Elevation, Slope, Landuse and Lithology were used as landslide influencing parameters. The output signifies that 22% and 36% of the area

| Sl. No | Data        | Source                          | Date       | Resolution |
|-------|-------------|---------------------------------|------------|------------|
| 1     | Toposheets  | SOI                             | 1987       | 1:50,000   |
| 2     | Rainfall    | IMD                             | 2000-2017  | —          |
| 3     | Soil        | “Soil and landuse survey of India” | —          | 1:50,000   |
| 4     | Geology     | “Soil and landuse survey of India” | —          | 1:50,000   |
| 5     | Geomorphology | “Soil and landuse survey of India” | —          | 1:50,000   |
| 6     | LULC        | Landsat 8 OLI USGS              | 26/01/2020 | 30 mts     |
| 7     | ASTERGDEM   | USGS                            | 2009       | 30 mts     |
| 8     | Landslide Inventory | Google Earth                  | 2017       | 0.4 mts    |

Table 3. Data used.
comes under high and very high risk areas. The results were validated with accuracy of 80% with the data. The fuzzy logic method uses a value of 0 to 1 to evaluate the relation between landslide occurrences with its respective causative factors. Then the causative factors are analyzed and integrated in the GIS environment to create landslide risk maps and landslide inventory data collected from the field is used to establish the degree of association with each causative factor. “Weighted Overlay Model (WOM)” uses numerical based rating method to classify the parameters ranging from very low to very high based on its degree of importance for landslide initiation and each sub factor is classified into sub categories at a scale of 1 to 5 where 1 indicating the very low risk and 5 indicates very high risk.

4. Result and discussion

4.1 Landuse and landcover

Landuse and Landcover is one of the important causative factor for landslide risk and initiation. Urbanization along hilly areas and unstable constructions lead to slope instability causing slope failure. The LULC has interpreted from LANDSAT OLI imagery for the year 2020. Supervised classification method has been used to map Land cover of the study area. Shimla Tehsil has been classified into four classes namely Forest, Agriculture, Slopes and Settlement (Table 4). The classification was based NRSC Level I classification system of Landuse.

Among the various land covers forest is comprised of 63.4% of the total area. Agriculture and barren land together makes 26.7% of the study area. Settlement account for only about 9.7% of the study area (Figure 4). The occurrences of mass movements of landslides are minimal along forest due to its soil binding capacity. Tree root bind the soil to the ground avoiding soil erosion due to torrential and monsoon rainfall. In places such as slopes and settlements soils are exposed without vegetation cover and hence prone to a large No. of landslides during monsoon season in the study area.

4.2 Soil

Soil plays an active role a landslide control factor especially in rugged terrains such as Himalayas. In the study area the soil class area differentiated into coarse loamy, fine loamy and loamy skeletal (Table 5). Fine loamy soils in these areas make up about 95.6% of the study area. The rest of the soils coarse loamy and loamy skeletal makes up about 4.2% of the area. Fine soil loamy soil has as clay content of between 18 to 35% and the reminder covered by sand and silt (Figure 5). Fine loamy

| Sl. no | Class      | Area (ha) | Percent (%) | Weighted overlay model | Fuzzy logic |
|-------|------------|-----------|-------------|------------------------|-------------|
| 1     | Agriculture| 5225.31   | 14.19%      | 2                      | 0.3         |
| 2     | Forest     | 23,354.53 | 63.42%      | 1                      | 0.1         |
| 3     | Build-up   | 3605.37   | 9.79%       | 4                      | 0.7         |
| 4     | Slope      | 4639.24   | 12.60%      | 5                      | 0.8         |
|       | Total      | 36,824    | 100.00%     |                        |             |

Table 4. LULC with WOM and fuzzy overlay values.
soils are moderately prone to landslides due to their high clay content. These types of soils are prone to mass movements when the water stress in the soil particle exceeds the effective stress of the soil. Coarse loamy and loamy skeletal soil have less clay content between 10 to 18% which are considerably more prone to landslides than fine loamy soil. These soil particles without any vegetation cover are more susceptible to mass movements when the deformation rate in the ground is high.

### 4.3 Geomorphology

The geomorphology has been differentiated into Habitation, Undifferentiated Hillside and Mountainside slopes (Table 6). Undifferentiated mountainside slopes cover about 97.83% and the hillside slopes and habitation covers only minor quantities about 0.5% and 1.6% in the study area (Figure 6). Geomorphologically Shimla Tehsil is moderately prone to landslides while the settlement areas are highly prone to mass movement.
4.4 Geology

Geology plays a key role in groundwater recharge as the types rocks present in an area could hugely affect the amount of water entering into the groundwater table. The study area is covered three major classes namely Schist, Slate and Habitation (Figure 7) in which mainly dominated by two types of rock formation namely Slate and Schist that comprises 95.9% and 2.1% (Table 7) of the study area. These rocks vary from Moderate to strong in nature in the GSI index. Waters can percolate through the cracks within the rocks or even between them. Fractures and joints formed along the rock surface act as perfect carriers for Rainwater into the groundwater table. Habitation accounts for only 1.90% and these areas mostly comprised of settlements they are placed in the high risk factor for mass movements initiation.

4.5 DEM

Elevation is a secondary factor often used in landslide risk mapping. The risk mapping in DEM model depends upon the no of landslides occurring within a particular...
elevation height. In the current study area most of the landslide occurs between 1400 to 2100 mts (Table 8) above the mean sea level compared to other elevation heights. Hence these particular elevations are assigned higher risk values (Figure 8).

Figure 6.
Geomorphology.

Figure 7.
Geology.
Slope Engineering

4.6 Slope

Slope aspect plays a crucial role in highly dissected mountainous regions for landslide movements. The steeper the angle of the slopes, the higher the possibility of the mass movements. In the research, SRTM DEM data has been used for deriving slope parameters (Figure 9). The slopes have been classified into five ranging from very gentle to very steep (Table 9) in nature.
4.7 Landslide risk mapping

4.7.1 Fuzzy logic model

For the current study two statistical models were employed “Fuzzy logic and Weighted Overlay model (WOM)” for landslide risk mapping. Factor including LULC, Geology, Geomorphology, Soil, slope (Table 10) were used as factoring parameters for risk mapping. Each causative factors were assigned a value of 0 to 1 based on it degree of association between causative factors. The factors are then processed in the GIS environment to derive fuzzy logic based landslide risk mapping.

Based on the results it can be concluded that most of the study area falls under very low risk with a total coverage of 67.34%. Low and Moderate area covers about 23% and 9.13% of the study area. Higher risk areas only account for about 0.46%. Higher percent of the study area is mostly covered by settlements. National highways, Metal roads, Slopes and Denser settlements are located along the Moderate and low risk areas (Figure 10).
4.7.2 Weighted overlay model

Weighted Overlay Model (WOM) was used as a second statistical method for Landslide Risk mapping. Weighted overlay model uses the ranking method to classify each causative factors based on its degree of importance for landslide initiation and each sub factor is classified into sub categories at a scale of 1 to 5 where 1 indicating the very low risk and 5 indicates very high risk. Six causative factors namely LULC, Geology, Geomorphology, Soil (Table 11) etc. was used. The factors are then processed in the GIS environment to derive fuzzy logic based landslide risk mapping (Figure 11).

The results retrieved from the WOM model reveals 55% of the Tehsil comes under very low category. Low and Moderate category covers about 31.4% and 10.6% of the study area. High and Very High category cover a total of 1.9% together. Most of the low category indicators are located along the Forest and Agricultural areas that include plantations. Slope and settlements covers a major part of Moderate to Very High vulnerable areas.

### Table 10.
Fuzzy logic landslide risk categories.

| Sl. no | Landslide risk class | Area (sq.km) | Percent coverage (%) |
|--------|----------------------|--------------|----------------------|
| 1      | Very low             | 247.8        | 67.34%               |
| 2      | Low                  | 84.9         | 23.07%               |
| 3      | Moderate             | 33.6         | 9.13%                |
| 4      | High                 | 1.7          | 0.46%                |

368 100.00%

Figure 10.
Fuzzy logic based landslide risk assessment.

4.7.2 Weighted overlay model

Weighted Overlay Model (WOM) was used as a second statistical method for Landslide Risk mapping. Weighted overlay model uses the ranking method to classify each causative factors based on its degree of importance for landslide initiation and each sub factor is classified into sub categories at a scale of 1 to 5 where 1 indicating the very low risk and 5 indicates very high risk. Six causative factors namely LULC, Geology, Geomorphology, Soil (Table 11) etc. was used. The factors are then processed in the GIS environment to derive fuzzy logic based landslide risk mapping (Figure 11).

The results retrieved from the WOM model reveals 55% of the Tehsil comes under very low category. Low and Moderate category covers about 31.4% and 10.6% of the study area. High and Very High category cover a total of 1.9% together. Most of the low category indicators are located along the Forest and Agricultural areas that include plantations. Slope and settlements covers a major part of Moderate to Very High vulnerable areas.
5. Conclusion

The research reveals the landslide risk mapping of the study area through Weighted Overlay and Fuzzy logic models. Fuzzy model classified a total of 9.1% and 0.4% of the area under moderate and high risk categories whereas Weighted Overlay model classified a total of 10% and 2% area under moderate and high to very high risk categories. Both the statistical model covers Forest and Agricultural areas under Very Low to Low Risk factor. Areas located along barren lands, Settlements and Roadways are classified under moderate to Very High risk areas for mass movements.

Acknowledgements

“The research work done is a part of NRDMS-DST funded research project. We would like to express our sincerest gratitude to NRDMS-DST, GOI, New Delhi, India for funding this research project.”
“We would like to thank CSIR, New Delhi, GOI for the SRF – Direct, scholarship for pursing Research Work”.

Author details

C. Prakasam*, Aravinth R.¹, Varinder S. Kanwar¹ and B. Nagarajan²

1 Department of Civil Engineering, Chitkara University, Himachal Pradesh, India

2 National Centre for Geodesy, Indian Institute of Technology Kanpur, Uttar Pradesh, India

*Address all correspondence to: cprakasam@gmail.com

© 2020 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
References

[1] Varnes DJ. Landslide types and processes. Landslides and engineering practice. 1958;24:20-47.

[2] Varnes DJ. Slope movement types and processes. Special report. 1978;176:11-3

[3] Introduction to Indian Landslides and Statistics. Available from: https://www.gsi.gov.in/webcenter/portal/OCBIS/pageGeoInfo/pageLANDSLIDEHAZRD?

[4] Mondal S, Mandal S. RS & GIS-based landslide susceptibility mapping of the Balason River basin, Darjeeling Himalaya, using logistic regression (LR) model. Georisk [Internet]. 2018;12(1):29-44. Available from: doi:10.1080/17499518.2017.1347949

[5] Kumar A, Asthana AKL, Priyanka RS, Jayangondaperumal R, Gupta AK, Bhakuni SS. Assessment of landslide hazards induced by extreme rainfall event in Jammu and Kashmir Himalaya, northwest India. Geomorphology [Internet]. 2017;284:72-87. Available from: doi:10.1016/j.geomorph.2017.01.003

[6] Ashutosh PKS, Panthee KS. Rockfall analysis along transportation corridors in high hill slopes. Environ Earth Sci. 2016;1-11.

[7] Society IM. Landslides and Erosion in the Catchment of the Gaula River, Kumaun Lesser Himalaya, India Author (s): S. K. Bartarya and K. S. Valdiya Published by: International Mountain Society Stable URL : http://wwwjstor.org/stable/3673588REFERENCES Linked references are available on JSTOR for this article : You may need to log in to JSTOR to access the linked references. LANDSLIDES AND EROSION IN THE CATCHMENT OF THE GAULA RIVER, KUMAUN LESSER HIMALAYA, INDIA. 2016;9(4):405-19.

[8] Sarkar S, Roy AK, Raha P. Deterministic approach for susceptibility assessment of shallow debris slide in the Darjeeling Himalayas, India. Catena [Internet]. 2016;142:36-46. Available from: doi:10.1016/j.catena.2016.02.009

[9] Metha RL, Koli SR, Koli VR. Landslide Hazard Zonation Using Remote Sensing and GIS Technology : A Case Study of Landslide Prone Area near Mahabaleshwar, Maharashtra,. 2015;3(4):6-16.

[10] Sharma G, Sanjeevi S. Landslide Hazard Zonation using Remote Sensing, Ground Penetrating Radar surveys and Geographical Information System in Katteri. Int J Curr Eng Technol. 2015;5(2):1160-9.

[11] Ghosh S, Carranza EJM, van Westen CJ, Jetten VG, Bhattacharya DN. Selecting and weighting spatial predictors for empirical modeling of landslide susceptibility in the darjeeling himalayas (india). Geomorphology [Internet]. 2011;131(1-2):35-56. Available from: doi:10.1016/j.geomorph.2011.04.019

[12] Kanungo DP, Sarkar S, Sharma S. Combining neural network with fuzzy, certainty factor and likelihood ratio concepts for spatial prediction of landslides. Nat Hazards. 2011;59(3):1491-512.

[13] Sharma LP, Patel N, Ghose MK, Debnath P. Landslide vulnerability assessment and zonation through ranking of causative parameters based on landslide density-derived statistical indicators. Geocarto Int. 2011;26(6):491-504.
[14] Martha TR, Kerle N, van Westen CJ, Jetten V, Vinod Kumar K. Object-oriented analysis of multi-temporal panchromatic images for creation of historical landslide inventories. ISPRS J Photogramm Remote Sens [Internet]. 2012;67(1):105-19. Available from: doi:10.1016/j.isprsjprs.2011.11.004

[15] Bilham R, Bali BS. A ninth century earthquake-induced landslide and flood in the Kashmir Valley, and earthquake damage to Kashmir’s Medieval temples. Bull Earthq Eng. 2014;12(1):79-109.

[16] Pareek N, Pal S, Sharma ML, Arora MK. Study of effect of seismic displacements on landslide susceptibility zonation (LSZ) in Garhwal Himalayan region of India using GIS and remote sensing techniques. Comput Geosci [Internet]. 2013;61:50-63. Available from: doi:10.1016/j.cageo.2013.07.018

[17] Global landslide hotspots (2017). Available from: https://datacatalog.worldbank.org/dataset/global-landslide-hazard-map

[18] Naithani AK. The Himalayan landslides. Employment News. 1999;23(47):20-26

[19] Prakash S. Historical Records of Socio-Economically Significant Landslides in India. Journal of South Asia Disaster Studies. 2011;4(2):177-204

[20] Martha TR, van Westen CJ, Kerle N, Jetten V, Vinod Kumar K. Landslide hazard and risk assessment using semi-automatically created landslide inventories. Geomorphology [Internet]. 2013;184:139-50. Available from: doi:10.1016/j.geomorph.2012.12.001

[21] Singh R, Umroa RK, Singh TN. Probabilistic analysis of slope in Amiyan landslide area, Uttarakhand. Geomatics, Nat Hazards Risk. 2013;4(1):13-29.

[22] Chauhan S, Sharma M, Arora MK, Gupta NK. Landslide susceptibility zonation through ratings derived from artificial neural network. Int J Appl Earth Obs Geoinf [Internet]. 2010;12(5):340-50. Available from: doi:10.1016/j.jag.2010.04.006

[23] Martha TR, Kerle N, Jetten V, van Westen CJ, Kumar KV. Characterising spectral, spatial and morphometric properties of landslides for semi-automatic detection using object-oriented methods. Geomorphology [Internet]. 2010;116(1-2):24-36. Available from: doi:10.1016/j.geomorph.2009.10.004

[24] Das I, Sahoo S, van Westen C, Stein A, Hack R. Landslide susceptibility assessment using logistic regression and its comparison with a rock mass classification system, along a road section in the northern Himalayas (India). Geomorphology [Internet]. 2010;114(4):627-37. Available from: doi:10.1016/j.geomorph.2009.09.023

[25] Mathew J, Jha VK, Rawat GS. Weights of evidence modelling for landslide hazard zonation mapping in part of Bhagirathi valley, Uttarakhand. Curr Sci. 2007;92(5):628-38.

[26] Ray PKC, Dimri S, Lakhera RC, Sati S. Fuzzy-based method for landslide hazard assessment in active seismic zone of Himalaya. Landslides. 2007;4(2):101-11.

[27] Gupta RP, Kanungo DP, Arora MK, Sarkar S. Approaches for comparative evaluation of raster GIS-based landslide susceptibility zonation maps. Int J Appl Earth Obs Geoinf. 2008;10(3):330-41.

[28] Kanungo DP, Arora MK, Sarkar S, Gupta RP. A comparative study of conventional, ANN black box, fuzzy and combined neural and fuzzy weighting procedures for landslide susceptibility zonation in Darjeeling Himalayas. Eng Geol. 2006;85(3-4):347-66.
[29] Feizizadeh B, Shadman Roodposhti M, Jankowski P, Blaschke T. A GIS-based extended fuzzy multi-criteria evaluation for landslide susceptibility mapping. Comput Geosci [Internet]. 2014;73:208-21. Available from: doi:10.1016/j.cageo.2014.08.001

[30] Kayastha P, Dhital MR, De Smedt F. Application of the analytical hierarchy process (AHP) for landslide susceptibility mapping: A case study from the Tinau watershed, west Nepal. Comput Geosci [Internet]. 2013;52:398-408. Available from: doi:10.1016/j.cageo.2012.11.003

[31] Alimohammadlou Y, Najafi A, Yalcin A. Landslide process and impacts: A proposed classification method. Catena. 2013;104:219-32.

[32] Raghuvanshi TK, Negassa L, Kala PM. GIS based Grid overlay method versus modeling approach - A comparative study for landslide hazard zonation (LHZ) in Meta Robi District of West Showa Zone in Ethiopia. Egypt J Remote Sens Sp Sci [Internet]. 2015;18(2):235-50. Available from: doi:10.1016/j.ejrs.2015.08.001

[33] Guzzetti F, Cesare A, Cardinali M, Fiorucci F, Santangelo M, Chang K. Earth-Science Reviews Landslide inventory maps : New tools for an old problem. Earth Sci Rev [Internet]. 2012;112(1-2):42-66. Available from: doi:10.1016/j.earscirev.2012.02.001

[34] Feizizadeh B, Blaschke T, Tiede D, Moghaddam MHR. Evaluating fuzzy operators of an object-based image analysis for detecting landslides and their changes. Geomorphology [Internet]. 2017;293(June):240-54. Available from: doi:10.1016/j.geomorph.2017.06.002

[35] Catani F, Tofani V, Lagomarsino D. Spatial patterns of landslide dimension: A tool for magnitude mapping.