Remote Sensing GIS Based Statistical Modelling for the Prediction of Natural Hazards

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Abstract

Disaster due to snow avalanche that interacts directly with man and material has become an issue of great concern in North-West Himalayas. That required spatial and temporal multi-layered information to assess the natural hazard susceptibility in the mountainous regions. The manual method of data integration as well as marking boundaries for targeting potential zones susceptible to these hazards in a rugged mountainous terrain is expensive and time-consuming. Hence an attempt has been made to develop an automatic technique for identification of avalanche hazard area and their severity index in conjunctions with topographic parameters, derived from Digital Elevation Model (DEM) and high-resolution Linear Imaging Self-Scanning Sensor-IV (LISS-IV) of IRS-P6 with Geographic Information System (GIS). These topographic parameters used as an input to Multi-Criteria Evaluation (MCE) which assigns the Suitability and Severity Index (SI) of each pixel in an image to meet particular conditions for delineating the potential hazard zones. This shows the degree of suitability and severity for avalanche release and hazard zone in Pir-Pangal range of Himalayas. A good correlation observed with the registered avalanche sites which have been mapped by carrying out numerous summer/winter ground as well as aerial reconnaissances and severity index has also verified with the occurrences of individual avalanche.

Keywords: *Topographic parameters, MCE, SI, DEM, GIS, LISS-IV*

1. Introduction

Himachal Pradesh is a state in Northern India. It is spread over 55673 km², located between 30"22' and 30"12' north latitude and between 75"47' and 79"4' east longitude. It is a mountainous state with altitudes ranging from 350 to 7000 meters above the sea level. Himalayas in Himachal extends almost 2,500 Km from North-West to South-East and width of Himalayas is between 250 to 300 Km. These Himalayan ranges have vast natural resources, most of which have not been explored due to its geologic, climatic and disastrous geo-environment. Despite of their severity, the Himalayas have always attracted humans because of their social and economical aspirations, adventures, abundant natural resources and other strategic reasons. If these resources are to be utilized there needs a construction of man-made structures, roads and communication setup in these areas with proper planning and execution against natural disaster, specially snow avalanches, which cut off these areas for 3-6 months during winters. The snowy regions of other parts of country like Jammu & Kashmir - Kashmir valley, Kargil & Laddakh regions; West Uttar Pradesh - Parts of Tehri Garhwal and Chamoli districts in North India where especially Indian Army troops deployed throughout the season, which are remain under grave danger of snow avalanches. Snow avalanches are sudden falling masses of snow that may contain soil and rocks which destroy property, disrupt transportation networks and recreational facilities [1]. It is life threatening natural hazard and killing more people due to continuous exposure to this hazard. The previous research has focused on the weather conditions associated with avalanching in different country [2] [3] and western Himalaya [4] but none of these studies examined a panoptic range of avalanche sites to study the spatial extent and severity of the avalanche cycles in Himalayas. These are mainly dependent on the topography of region [5] [6]. The aim of the study is to develop an object oriented automatic technique and operational working methodology wherein topographic parameters such as slope, aspect, elevation, drainage, spur/ridges, formation zone area, ground cover and curvature (convex, flat and concave) are analyzed to develop models for mapping avalanche prone areas and its severity index using remotely sensed data and GIS to arrive at the overall Hazard Zonation Map (HZM) of the area which can be used as a guide by the deviser to avoid the avalanche prone areas and opt a safer camp as well as path or install the essential safety measures initially itself. This technique has been applied for Manali-South Portal (MSP) of proposed Rohtang tunnel (13044ft) and Manali-Rohtang axis, a small area (1147.9 Km^2) [7] situated in Pir-Panjal range of Himalayas.

Investigation suggests that this automatic technique and working methodology is a useful for identification of avalanche hazard area and avalanche severity in lower Himalayan snow climatic zone [8].

2. Study area

The area lies between 32.10^0 N to 32.25^0 N latitude and 77.00^0 E to 77.20^0 E longitude in Kullu district of Himachal Pradesh (India) as shown in Figure 1, commonly known as Beas catchment area which has been selected to study the overall proficiency of the proposed technique.

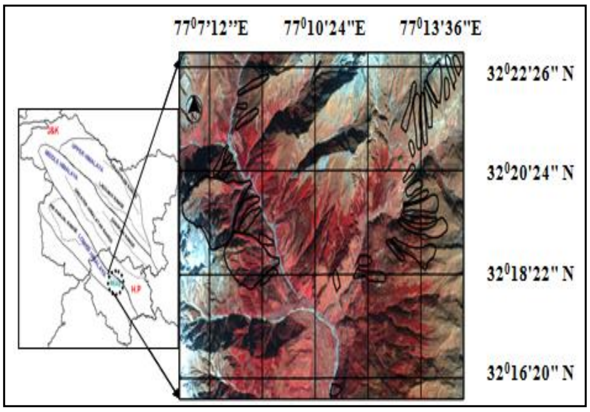


Figure 1. Study Area on India Map and Satellite Image (Manali-MSP-Rothang)

An elevation of the area varies from 1100 m to 5000 m and the slope inclination varies up to 55^0. The area is densely forested up to an altitude of 3000 m. In this study area, there are 12 registered avalanche sites [9] (MSP_2 to MSP_{13}) along Manali-South Portal (MSP) axis (link road to proposed Rohtang tunnel) and 22 registered avalanche sites (A_0 to A_{19}) along existing Manali-Rohtang axis. The area has three SASE's permanent field observatories located at varying altitudes i.e. Bahang (2003 m) and Solang (2440m) and Dhundi (3080 m).Generally area receives moderate to heavy snowfall above 2400 m and daily mean minimum temperature ranges between -15°C to 0°C in January and mean maximums ranges between 20°C to 30°C in June [7]

3. Data used

The satellite data LISS-IV has been used in the present study which has a 23.9 km (MX mode) and 70.3 km (PAN mode) wide swath, acquiring data in 3 spectral bands including Green (520-590 nm), Red (620-680 nm) and NIR (770-860 nm). Its spatial resolution is 5.8m at Nadir and its radiometric resolution is 7 bit. This high resolution data is used to extract detailed information in rugged Himalayan terrain about avalanche boundary, forested & non-forested area and other relevant information with very good accuracy. The survey of India (SoI) mapsheet of 1:50,000 scale having 40 m contour interval has also been used for generation of DEM. Ground validation has been carried out using registered avalanche site and reported avalanche occurrences along both axis.

4. Methodology

For any investigation in a rugged mountainous terrain of the Himalayas using satellite data and DEM, it requires properly geometrically corrected images and DEM with very good accuracy to extract detailed information about avalanche prone areas.

4.1. Methods of investigation

High resolution satellite images LISS-IV were geo-referenced up to sub pixel accuracy and DEM of study area has been generated from precise geo-referenced topographic digital data using ERDAS Imagine ver.9.1 image processing software. The slope, aspect and terrain configurations are derived from DEM [10] and further 3D view of Digital terrain model (DTM) has been generated. It gives a realistic view of the area and make easy to understand the deviser nature of the area as well as different terrain features e.g. hills, valleys, gorges and configuration can be identified with ease. The data sources of each factor are illustrated in Table 1.

4.2. Generation of cartographic model

In the present work, the development of conceptual framework is required to explain the cartographic processes. These processes are arranged as cartographic model- geospatial data manipulation (analytical study, projection, generalization, transformation and quality), geospatial data processing (digital mapping) and geospatial visualization (conventional and alternatives) with appropriate contents. These contents for cartographic model generation and analytical methodology have been illustrated in Figure 2.

4.3. Ground cover estimation

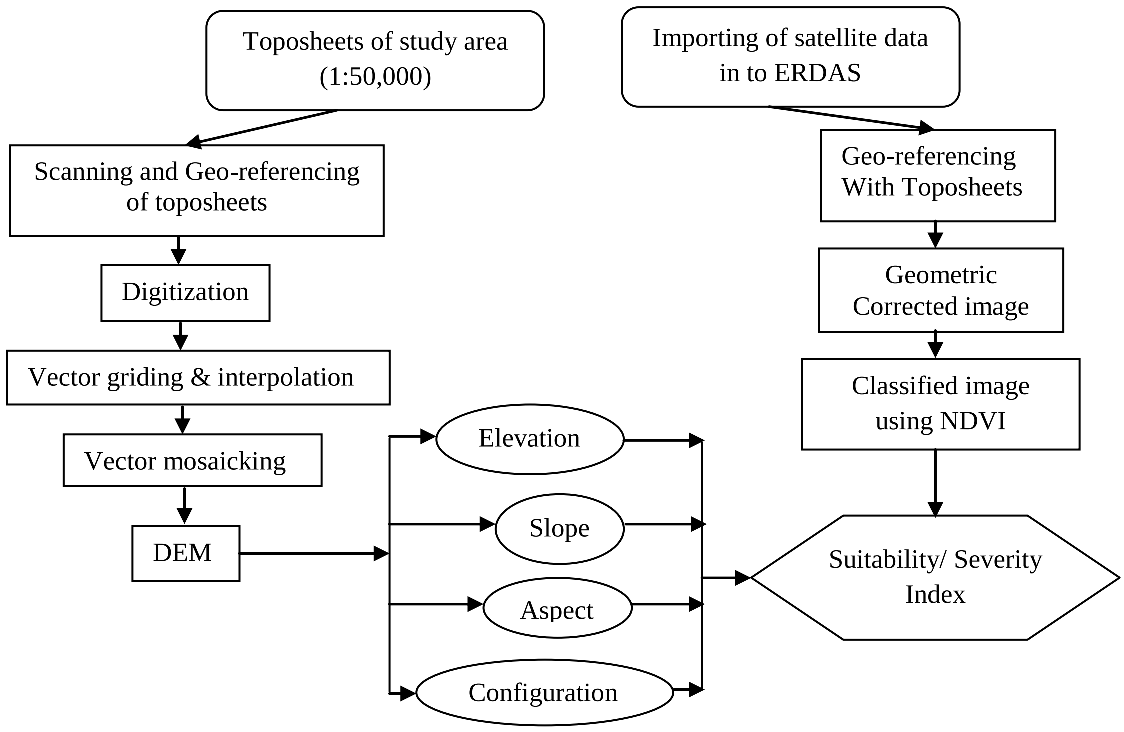


Figure 2. Flow chart summarizing the methodology followed in the study

The ground cover parameters have been derived from the appropriate data selected after the detailed analysis of LISS-IV satellite data using image processing techniques. In order to map forested and non-forested area from remote sensing data, Normalized Difference Vegetation Index (NDVI) method [11] has been used. NDVI is defined as the difference of reflectance observed in a near infrared (NIR) band and visible band divided by sum of the two reflectance. The equation is given below:

$$\text{NDVI} = \frac{(\text{NIR Reflectance} - \text{Red Reflectance})}{(\text{NIR Reflectance} + \text{Red Reflectance})}$$

NDVI is useful for describing temporal and spatial dynamics of vegetation [12], classifying land cover and monitoring forest. Higher the NDVI value, better be the photosynthesis activity and the greater the vegetation cover which standardize the NDVI values distribution from -1 to +1.

4.4. Avalanching factor estimation

The terrain parameters such as slope, elevation, aspect, groundcover, formation zone area and curvature are the major factors responsible for avalanche release because variation in snow stability depends upon small slopes [13]. The second order derivative of the Digital terrain model (DTM) grid (i.e the first derivative of the slope) gives the curvature of the DTM. The curvature describes the convex, concave or plane nature of the surface [14]. Most avalanches tend to start on a convex slope [5] where the weight of snow on the steeper part of the curve sets up stresses in the snow pack which reflect the maximum category of weight factor. Avalanche incidents show a distinct distribution pattern across all slopes - orientations. Mostly avalanche incidents occur on southeastern facing slopes [15]. Avalanches are also greatly affected by groundcover type either forested or non-forested. Densely forests covered within formation zone offers the best protection against avalanche initiation [16]. Areas above the timber line are more exposed to the effect of wind on snow distribution which affects the stability of the overlying snow pack. This conception assign maximum weight factor for non-forested and higher elevation.

Thematic map as in Figure 3 with colour coding as in Table 2 to 7 of each terrain parameter based on criteria function has been generated using DEM and satellite data.

4.5. Multi-Criteria Evaluation

MCE is a set of procedures designed to facilitate decision making approach in GIS to elucidate a group of weights for the evaluation criteria [17].

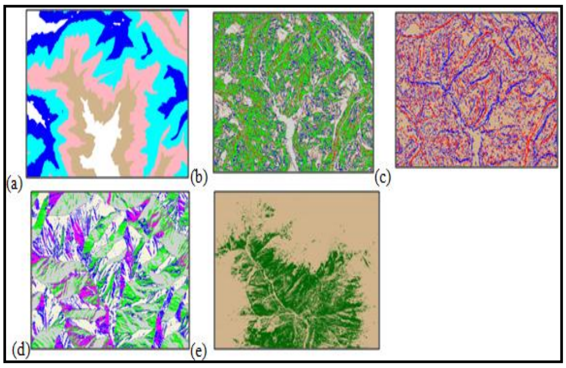


Figure 3. Thematic maps of terrain parameters (a) Elevation Zone (b) Slope (c) Curvature (d) Aspect (e) Ground cover

Table 2. Weight Factor for Elevation

Elevation (m)	Weight Factor
2000<= 2600	1
>2600 <= 3200	2
>3200<= 3800	3
>3800<= 4400	4
>4400<= 5000	5

Table 3. Weight Factor for Slope

Slope (Degree)	Weight Factor
0<= 15	1
>15 <= 25	2
>25<= 30	3
>30<=45	5
>45<= 55	4

Table 4. Weight Factor for Curvature

Curvature	Weight Factor
0 < - 0.2	1
>-0.2 <= 0.2	3
>0.2	5

Table 5. Weight Factor for Aspect

Aspect w.r.t Sun (Degree)	Weight Factor
NW-N-NE (315-360-45)	1
NE-ENE (45-67.5)	2
ENE-ESE (67.5-112.5)	3
ESE-SE (112.5-135)	4
SE-SW (135-225)	5
SW-WSW (225-247.5)	4
WSW-WNW (247.5-292.5)	2
WNW-NW (292.5-315)	1

Table 6. Weight Factor for Ground Cover

Curvature	Weight Factor
Forested	1
Non-Forested	5

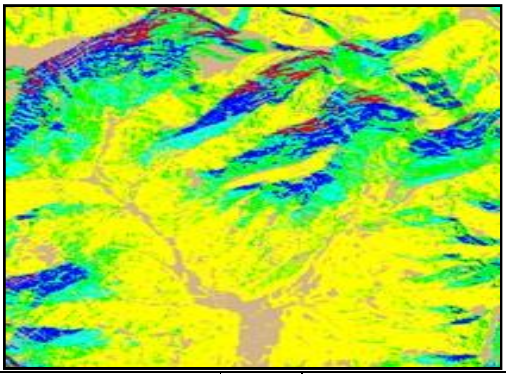
Table 7. Weight Factor for Formation Zone

Formation Zone Area (ha)	Weight Factor
<= 3	1
>3 <= 12	3
>12	5

To assign the suitability of each pixel in an image to meet a particular condition, weight factors 1 to 5 have been assigned for terrain parameters as shown in Table 2 to 7. A weighted linear combination [18] is a usual technique for MCE procedures. Information from several criteria is used in MCE analysis as represented by below equation to form a single index.

$$MCE= (Pslp) * (Pele) * (Pasp) * (Pgcvr) * (Pcur) * (P\ fzone)$$

In the MCE analysis, six factors- slope, elevation, aspect, ground cover, curvature and formation zone area represent the decision variables for suitability as well as severity index for an avalanche. Each factor is layer geographic information, normally in raster format that is weighted and reclassified in order to evaluate suitable avalanche release areas Figure 4.

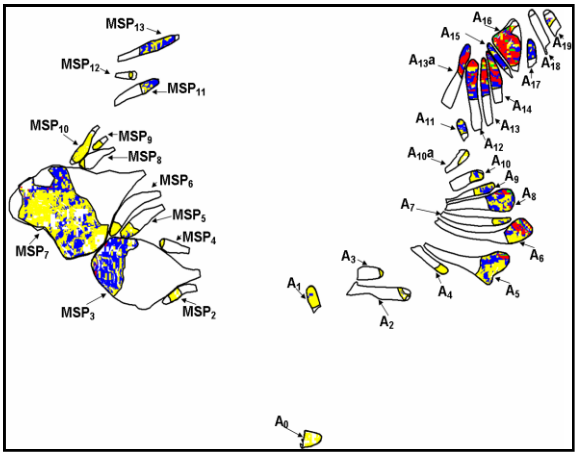


MCE Value Range	Re-class	Suitability Index
0<= 125	1	Not suitable
>125 <=250	2	Least suitable
>250<= 375	3	Moderate suitable
>375<=500	4	Most suitable
>500<= 625	5	Extreme suitable

Figure 4. Suitability Index Map for Avalanche Hazard Area

5. Results

Topographic influence based on MCE for study area in Pir Panjal range finds the possibilities of suitability as well as severity index (SI) Figure 4 and Figure 5(a) of avalanche occurrence. The study indicates that in selected area the majority of the area is not suitable for avalanche release which is having MCE value between 0-125 lies in SI value 1, comes under the condition of not severe. This is forested area lies at lower elevation in valley, except some area at higher elevation near to ridges/spurs, where the slopes are less than 15°. Whereas level (low, medium, high and extreme) of avalanche harshness increases as MCE values increases from 125 to 500 as in Figure 6. Topography analysis of avalanche sites shows that the sites A_5, A_6, A_8, A_{12}, A_{13}, A_{13}a, A_{14}, A_{16}, MSP_3, and MSP_7, having lager formation zone Fig.6. Out of these the possibilities of trigging and avalanche disasters in sites A_8, A_{13}, A_{14} and A_{16}, MSP_3, MSP_7 are more as compared to other sites. These results have been compared with the avalanche occurrence report of the past eight years as shown in Table 8 but for MSP_3 and MSP_7 ground data not available. Detected avalanche sites and their severity have been correlated with SoI topographical maps, high resolution satellite data as in Figure 7 and ground data which collected during reconnaissance surveys carried out earlier [9]. The proposed technique and methodology also identify 31 avalanche sites out of 34 registered [9] avalanche sites which show 91% accuracy.



MCE Value Range	Re-class	Suitability Index
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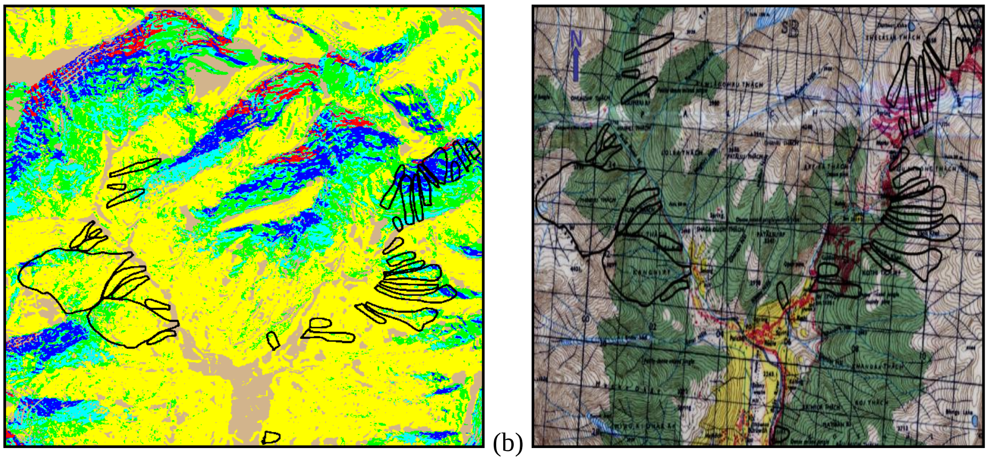
Figure 6. Correlation of severity index map with registered avalanche hazard area.


(a) (b)

MCE Value Range	Reclass	Suitability Index	Area (Km^2)
0<= 125	1	Not suitable	94.65
>125 <=250	2	Least suitable	35.18
>250<= 375	3	Moderate suitable	18.55
>375<=500	4	Most suitable	14.24
>500<= 625	5	Extreme suitable	3.35
Total Area			165.97

Figure 5. (a) Correlation of suitability index map with registered avalanche hazard area (b) Avalanche site shown in SoI map sheet ($52H_3$)

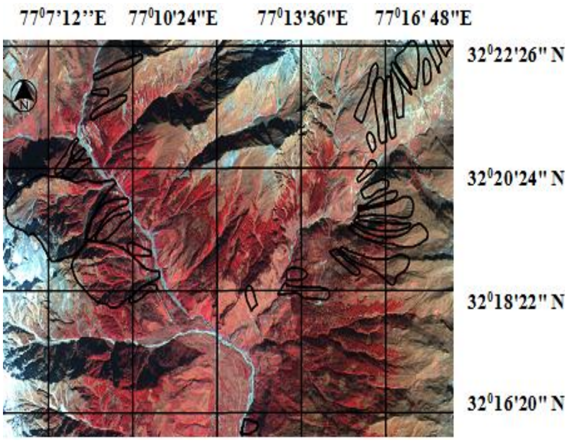


Figure 7. Avalanche site shown in high resolution satellite data IRS-P6_ LISS-IV.

areas. It is expected, based on results that this technique is user-interactive and offers better visual interpretation that are lacking in conventional techniques, which use the SoI topographical maps as a source of information. This methodology can be used for the rapid generation and updating of avalanche hazard maps of remote areas. This will definitely reduce the impact of the avalanche disaster in future. Furthermore, this provides an efficient way to warn and educate people about avalanche prone areas. It can also be used by land use planners and decision-makers for sustainable growth in snow bound regions.

Table 8. Available past history of avalanche occurrences [9]

Avalanche No.	Year and frequency of avalanche occurrences							
	1971-72	1972-73	1983-84	1985-86	1985-86	1986-87	1987-88	1988-89
A_0	-	-	1	-	-	-	-	1
A_1	-	2	1	2	-	-	-	-
A_2	-	-	-	1	1	-	-	-
A_3	-	1	1	-	-	-	-	-
A_4	2	-	-		-	-	2	-
A_5	3	2	-	3	1	2	2	-
A_6	2	3	-	3	2	-	-	-
A_7	2	3	-	2	-	1	1	1
A_8	2	3	-	2	1	1	1	1
A_9	2	3	-	1	-	1	1	1
A_{10}	2	3	-	-	-	-	-	1
A_{10}a	2	3	-	3	2	2	2	3
A_{11}	1	3	-	1	-	-	-	-
A_{12}	1	-	-	-	-	-	-	1
A_{13}	2	2	-	2	1	1	1	2
A_{13}a	-	-	-	2	-	-	-	-
A_{14}	2	3	-	3	1	1	1	2
A_{15}	3	2	-	3	1	3	1	2
A_{16}	3	2	-	3	1	3	1	2
A_{17}	2	3	-	2	-	-	-	1
A_{18}	3	2	-	1	-	-	-	1
A_{19}	1	2	1	2	-	-	-	1

(Source: SASE, DRDO)

6. Conclusion

The mapping of avalanche release areas, using DEM, Satellite imagery and GIS, is potentially a valuable means of initial assessment of avalanche prone areas over large mountainous region. Suitability mapping of avalanche prone areas may be used as a base map for plotting avalanche incidents and can be used for defining potentially hazardous areas, in the regions with no avalanche occurrence data. This can be also used as a component of an avalanche risk analysis for assessing avalanche safety over large geographic

Acknowledgement

The authors are highly thankful to Sh Ashwagosha Ganju, Director, Snow & Avalanche Study establishment (SASE) for providing necessary facilities and encouragement. Our profound sense of gratitude also to all SASE's persons who helped in collecting the ground data.

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