Chapter 6
Vulnerability Assessment of Avalanches in Upper Satluj Basin, District Kinnaur, Himachal Pradesh, India: A Geographic Information System (GIS)-Based Approach

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Abstract The satellite images interpretation and its analysis through the geographic information system (GIS) is one of the technical and scientific methods to analyze the avalanches. The selected parameters such as slope, slope aspect, slope profile, relative relief and land use, land cover and their subclasses are major base triggering factors for the impacts and its vulnerability analysis. All base factors indicate the threat of avalanches and its vulnerabilities depend on the impact value of the parameters classes. The overlay analysis reveals that the about 6% region of basin has very high vulnerability of avalanches. Out of which 0.9% area has high vulnerability and the remaining portion 99.1% of basin area has low vulnerability and not recorded incidences of avalanches. The average vulnerability (0.41) and impact score (0.54) indicates low vulnerability of avalanches.

Keywords Geographic information system (GIS) · Avalanches · Vulnerability

6.1 Introduction

The down slope movement of snow masses under the impact of gravity and consist of rocks, soil, debris, uproot tree and rocks is known as avalanches (Colbeck et al. 1990). The avalanches occurrences are triggered by some factors such as high relative relief, a high degree of slope, slope aspect, slope profile, the volume of snow and land use and land cover (Fohn 1993). The high relative relief (>3000 m) and a high degree of slope (>30°–40°) provides acceleration to avalanches. Sometime avalanches are generated due to the high intensity of earthquakes (Dunning et al. 2007). The avalanches are

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also generated due the excessive snowfall in a short period. Even human induced avalanches are also generated because of blasting activities (Bocchiola et al. 2008). In Kinnaur district the blasting activities are common due to hydro power construction (Lata et al. 2017). If we see the frequency and magnitude of snow avalanches it shows that Himachal Pradesh are less disastrous and effected very limited spatial extent. The incidences of avalanches are most prevalent in the districts of Lahul and Spiti, Kinnaur, Kullu and Chamba, before the 1971 the information regarding the incidences of avalanches are very limited (Chandel 2015). The Lahul and Spiti district is the most vulnerable district which has highest number of avalanches and Kinnaur (36.59%) is the second leading district. In district Kinnaur about 15 people were died because of avalanches (GHP 2006). Snow avalanches are a disastrous type of hazard in mountainous terrain. The potential vulnerability of avalanches and their assessment can be done during the time of planning of new settlements. It could be helpful to mitigate the potential damage of avalanches. Vulnerability and the degree of loss to a given element or set of elements within the area affected by avalanche(s); it is expressed on a scale of 0 (no loss) to 1 (total loss); for property, the loss could be the value of the property, probability of particular life loss (the element at risk) of given the person(s) affected by the avalanche (IUGS 1997; IPCC 2012).

6.2   Study Area

The River Sutlej Basin in Himachal Pradesh forms a part of the Northwestern Himalaya which is topographically fragile and ecologically delicate. The Sutlej catchment in Himachal Pradesh extends approximately 30° 50′ N to 32° 50′ N latitudes and 76° 50′ E to 79° 09′ E longitudes, occupying an area from the Shiwalik to Greater Himalayan region (Fig. 6.1). The Sutlej basin rises from beyond the Indian borders in the Southern slope of the Kailash mountain near the Mansarovar lake of the Rakastal lake. Being the largest river of Himachal Pradesh, it enters into Himachal Pradesh from Shipki La Pass at an altitude 6608 m and flow in the south-westerly direction through Kinnaur, Shimla, Solan, Mandi, Kullu, and Bilaspur districts. In Himachal Pradesh, the Sutlej Basin covers an area of about 21,457 km^2. Geologically and geomorphologically, the basin is considered to be the youngest mountain chain in the world and is still in the building process. The relative relief of the basin varies from 452 to 6735 m as ml. The study area of the upper Sutlej basin in district Kinnaur extended from approximately 31° 19′ 4″ N to 32° 05′ 59″ N latitudes and 77° 82′ 01″ E to 78° 83′ 05″ E longitudes, climate of whole of the Satluj valley is generally temperate. But due to a large variation in the altitude (455–6735 m), there is also a wide range of climatic variations (Sharma et al. 2008). Climate varies from the sub-tropical, sub-mountainous at the bottom of the Sutlej valley to the alpine in the upper reaches, parts of which remain perpetually under snow. In this region, the temperature generally starts rising from the beginning of March till June, which is the hottest month of the year. The mean minimum and maximum temperatures were observed to be around 15.6 °C and 24 °C respectively. The month of January
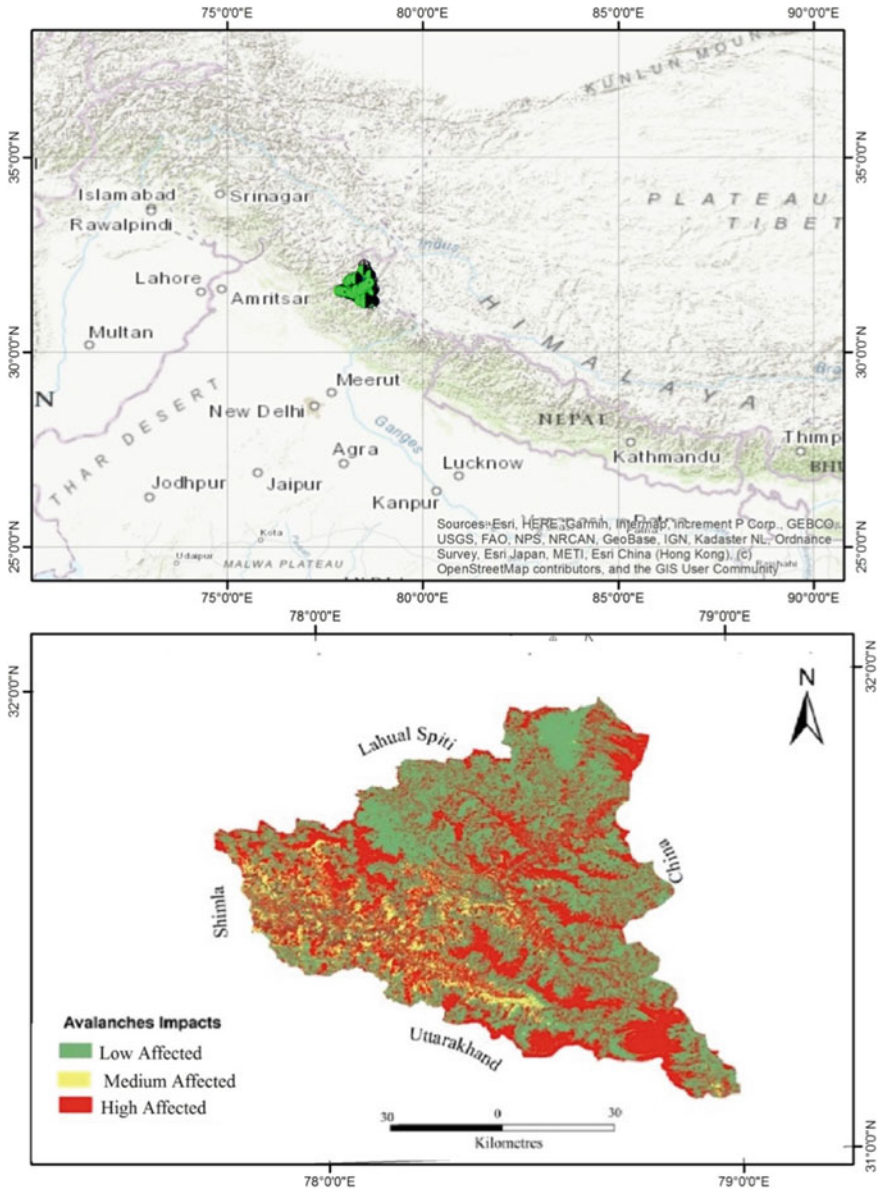
Fig. 6.1 Study area

is the coldest month with the mean maximum and minimum temperatures of around 8.9 °C and 1.7 °C respectively. During winters, under the influence of the western disturbances, the temperature falls considerably and it may go even below 0°. The climate of the Sutlej valley shows a gradual alteration from the heavy monsoon of the outer Himalayas to the arid Tibetan type with a winter snowfall practically there is no summer rains. The total annual rainfall is observed to be 766 mm in Kinnaur. The abundance rainfall is received between the month of January and March all over the year.

6.3   Methodology

Avalanches monitoring and observation are based on field survey and satellite images interpretation. The field survey has done along the river Satluj and points (Location coordinates) are taken (GPS) of near to the actual incidences sites. A total of 25 points are taken in surrounding villages of sites. These points are taken and export in the kml format and visually interpreted. The avalanches are identified and area is calculated through the kml files as in polygon format. Then polygon kml files are exported in arc GIS for calculation of area. The Land use land cover (LULC) map is prepared on the basis of digital glove image (DGI) at the resolution of 5 m. The Slope and relative relief maps are prepared on the basis of Digital Elevation Model (DEM) at 30 m resolution (USGS 2004). Local survey is conducted in the study region to understand the geophysical setting of the region. Relative relief, land use lands cover (LULC) are measured and using surface analysis tool in Arc GIS 10.3 (Moges and Bhole 2015).

Some important or selected parameter is exported in GIS environment and the incidences locations are overlaid and then the degraded and vulnerable area is identified. Then identified area is cross checked and validated with field survey (Stoffel et al. 1998). The highest affected area is scored with the highest number from the total number of subclasses. The values are normalized from 0 to 1 to check the impacts on parameter classes. The formula is used to normalized as PN (parameters normalized) = Ps (Parameters Score)/Np(Total number of parameters). The degraded areas are identified on every selected parameter. The weighted score is based on parameter classification (Fig. 6.2).

6.4   Result and Discussion (Parameters–Based Analysis)

6.4.1   Relative Relief

High relative relief had high vulnerability as a hazard point of view, high soil erosion, high surface runoff (Clung and Schaefer 1993). DEM (Digital Elevation Model) is
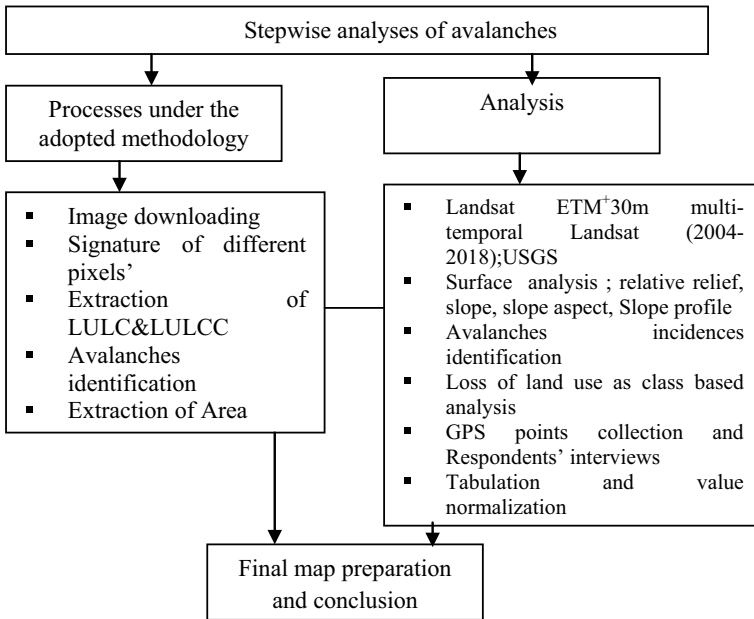
Fig. 6.2 Stepwise analyses of avalanches

used widely for landscape analysis not only in geo-morphometric, but also in other geosciences-based studies, such as geomorphology, hydrology, meteorology, soil sciences and vegetation studies. The relative relief of the basin has a high value of 1244–6755 m. The dissection index value 0.64–0.87 has high risk as an avalanches point of view. In the basin, the area falls under the altitudes 3000–6755 m is falls under the high risk (Singh 2004). The unstable layers of snow easily moved downward on high relative relief (>3000 m). More the 50% area of the upper basin is fallen under the snow-covered and avalanches risk. If we see the history of incidences impacts about 129 people died from 1970 to 2015. The relative relief area of 1244–3000 m is less affected by incidences and impact and risk point of view scored as 1 and relative area 3000–6755 m area are scored as 0.5 (Table 6.1).

6.4.2   *Slope*

The slope is one of the trigging factors which accelerates or slows the incidences of avalanches. The high degree of slope greater than the >35° has high vulnerability and risk of snow avalanches (Jurg and Martina 2001). The study region of the different slopes is classified as gentle slope 8%, moderate slope 13%, moderately steep slope 17%, steep slope 18% and very steep slope 30%. The highest affected area (1.5 km^2) of the basin is recorded under the high vertical slope (45°–90°) which is scored

Table 6.1 Parameters-based analysis, identification and status of avalanches

Parameters	Classification	Affected area in terms of land degradation Identification and	Weight score (Score/Total No. of Parameters $= P_s/N_p$)	Vulnerability	Avalanches incidences impacts
1. Slope $P_1 = P_s/N_p$	Gentle slope	0	0	0	Snow avalanches region, where slope greater than $>35^0$ more vulnerable to landscape loss. In this region the avalanches incidences are very high
	Moderate slope (5°–10°)	0.31	0.8	0	
	Moderate Steep slope (10°–18°)	0.39	0.6	0	
	Steep slope (18°–30°)	1.42	0.5	0	
	Very steep slope (30°–45°)	1.45	0.3	1	
	Vertical slope (45°–90°)	1.5	1	1	
2. Slope Profile ($p_4 = P_s/N_p$)	Summital convexity	1.1	0.7	1	The summital convexity had high degree of losses and adversely affected (Jamwal et al. 2019)
	Rectilinear section	0.3	0.5	0	
	Free face	0.11	0.2	0	
	Basal concavity	1.17	1	1	
3. Relative relief ($p_4 = P_s/N_p$)	R_R 1244–3000 RR > 3000 m	0.9.3	0.5 1	0 1	The higher relative relief and avalanches both have positive correlation
4. Land use land cover (LULC) ($p_4 = P_s/N_p$)	Settlements	0.15	0.2	0	The land use type barren/wasteland, scrub land providing more acceleration to avalanches (Salm 1978)
	Agricultural land	0.6	0.3	0	
	Forest cover	0.8	0.5	1	
	Barren/wasteland	1.40	1	1	
	Grass/grazing	1.30	0.8	1	
	Scrubland	1.05	0.6	0	
	Water bodies	1.17	0.7	0	
	Snow and glacier	0.10	0.1	0	
5. Slope aspect (p_5) $P_5 = P_s/N_p$	Flat	0.01	0.1	0	North and south facing slopes are more vulnerable because of their direction during the time of winter and summer (Kuniyal et al. 2019)
	North	2.10	1	1	
	North East	0.71	0.4	0	
	East	0.24	0.3	0	
	South East	1.05	0.7	1	

(continued)

Table 6.1 (continued)

Parameters	Classification	Affected area in terms of land degradation Identification and	Weight score (Score/Total No. of Parameters = P_s/N_p)	Vulnerability	Avalanches incidences impacts
	South	1.10	0.8	1	
	South West	0.91	0.5	0	
	West	0.22	0.2	0	
	North West	0.97	0.6	1	
	Average = Total cells value/no. of cells	0.80	0.54	0.41	

as 1, slope of very steep slope (30°–45°) with affected area (1.45 km^2) is scored as 0.3, steep slope (18°–30°) is scored as 0.5, moderate steep slope scored as 0.6, moderate slope (0.39 km^2) is scored 0.8 and gentle slope is not affected with the avalanches and scored as 0. Tangling, Apka, Lippa, Asrang, Chakra, Spillo, Poo, Khab and Nakko village's area has a very steep slope which has poor soil texture, less vegetation-covered, high gully rills erosion, dry climate condition. Gentle slope to moderate slope found in the region of Chaura, Burang and Wangtu above the region (YashangDhar, PunagKhas, Urni, Cooling, MeruKhas, Rurag, Kibla, Karcham, Rali) has moderate steep to the steep slope (Fig. 6.3). Here forest-covered is moderate sparse and snow impact is high above the RaliRanrang, Shongtong, Barang and Tangling. Kalpa, Pangi, Khadura, Akpa, Khab areas have a very steep slope with sparse vegetation and with indicated the high risk of avalanches (Table 6.1).

Fig. 6.3 Avalanches incidences in Spillo, Poo, Khab and Nakko village's of Satluj River upper basin

6.4.3 Slope Aspect

In the northern hemisphere of temperate latitudes, the north direction slope is mostly affected during the winter. The settlement on the North Slope aspect has high vulnerability and risk north-facing (shady) slopes usually produce more avalanches and more persistent avalanche hazard in mid-winter. The south-facing slope is produced more wet avalanches during the summer season (Fohn et al. 1998). The slope aspects of North (2.10 km^2), South (1.10 km^2), Southeast (1.05 km^2) are highly affected areas with high risk and North scored as 1, South scored as 0.8, southeast scored as 0.7, respectively. And other aspects of the basin are scored such has 0.6 North West (0.71 km^2), 0.5 Southwest (0.91 km^2), 0.4 northeast (0.71 km^2), 0.3 East (0.24 km^2) and West (0.22 km^2) aspect is scored as 0.2 (Table 6.1).

6.4.4 Slope Profile

The distinctive segments such as profile are called slope elements or slope segments. A slope profile study is done on the basis of field surveys. Different types of slopes profile such as summits convexity, basal concavity, rectilinear section and free face of slope profiles are commonly found in the Satluj valley Concave elements of slopes are very commonly found in the lower portion of the Satluj valley (Fig. 6.4). The free face, rectilinear section, and summital convexity are affected with avalanches impacts (Perla 1977). The basal concavity is highly affected (1.17 km^2) and scored as 1, rectilinear section (0.30 km^2) is scored as 0.5, free face (0.11 km^2) is scored as 0.2 and semimetal convexity (1.1 km^2) is scored as 0.7 (Table 6.1). The Basal concavity area is highly affected by avalanches. The basal concavities are also affected because this section received high pressure of snow mass and leads to incidences of avalanches.
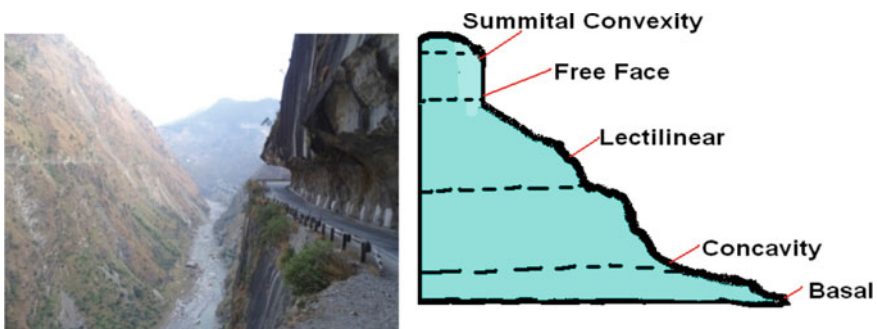

Fig. 6.4 Free face segments of hill slope has also found in upper (near to Khab) and in the areas of Powari, Shongtong and Karcham Wangtu

6.4.5 Land Use Land Cover (LULC)

LULC is also considered to be the major factor in influencing the movement of the avalanche. The heterogeneous structure of the mountain forest appears to play a significant role in stopping avalanches. Significant snow-mass detrainment behind tree stands appears to be the key process to stop small avalanches on steep slopes (Clung and Schaerer 1993). Barren and sparsely vegetated areas are more prone to weathering, erosion and slope instability and more susceptible to avalanches. Kinnaur district has maximum area is found under the categories of Snow-covered 2490 km^2 (39%) and wasteland 2030.63 km^2 (31%) types of land use. However, water bodies (5.3 km^2), Built-up (1.54 km^2) and agriculture (52.8 km^2) has a very low area. Other categories forest-covered 484.63 km^2 (8%) area and Grassland covered is only 1383.1 (20.58%). It is made clear from the field survey that the area of Karchamwagtu, Powari, Tangling, Kalpa, Bokta, Pangi, RarangKhas, Akpa, Rispa, Jangi, Spillo, Nako has heavy snowfall incidences during the winter season. The soil compactness is reduced during the snowfall and incidences of avalanches increased (Table 6.1; Figs. 6.5 and 6.6).
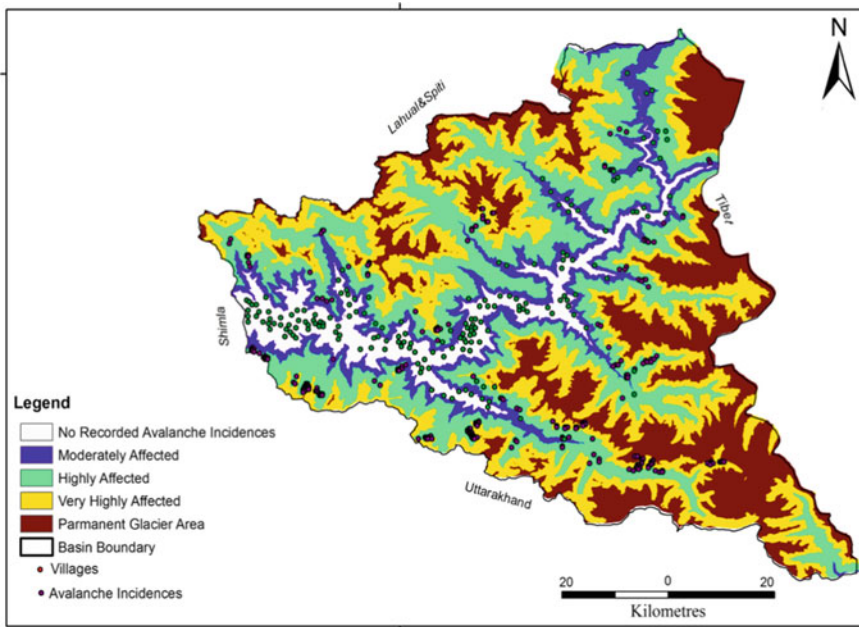

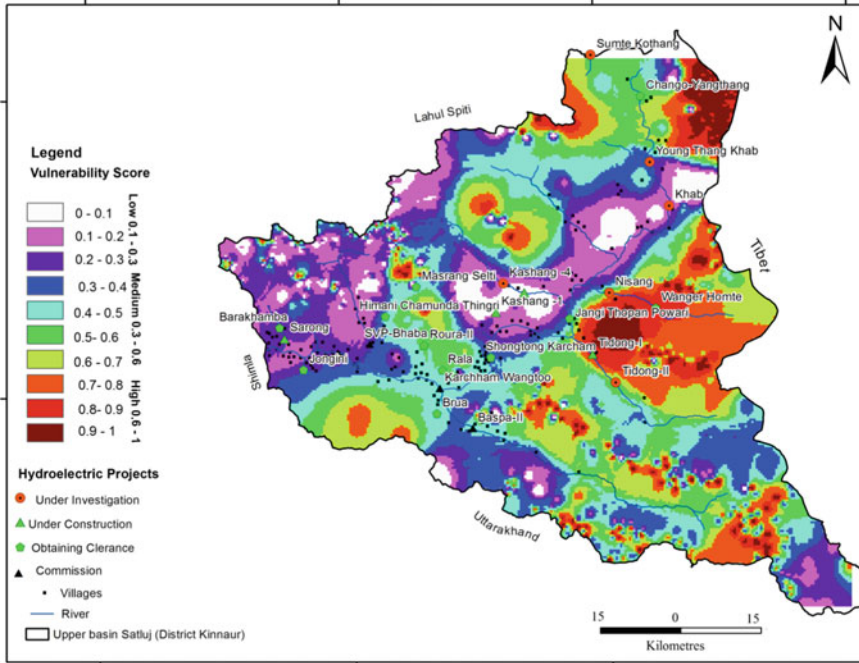**Fig. 6.5** Avalanches affected area in upper basin of River Satluj

Fig. 6.6 Avalanches vulnerability in upper Satluj basin of Himachal Pradesh

6.5 Conclusion

The avalanches incidences are noticed in the upper region of the basin. The losses are highly counted on the selective trigging factors such as very steep slope, basal concavity slope profile, high relative relief >3000 m and region of sparse vegetation and wasteland is highly affected. The slope aspect of north, south, and southeast is highly affected. However, human causality and property losses are very rarely recorded. Geographic information system made clear that about 100 km^2 areas are highly damaged because of snow avalanches. Because of avalanches, forest lands are highly affected. The maximum incidences of avalanches are recorded above the 3500 m in district Kinnaur. More than 75% area of the upper basin falls under the high altitude. The 5458 km^2 (80%) area of the study region has under the high degree of slope >35°. The maximum incidences of avalanches were noticed under the slope types of higher degree. The concave slope more prone to avalanches incidences during the time of high precipitation. The physical degradation has high on the slope aspects of the north, east, southeast and south and west. The region has more barren areas (62%) then the region has more vulnerability as an avalanches point of view.

The overlay analysis reveals that the about 6% region has very high vulnerability of avalanches. Out of which 0.9% (61.7 km^2) area has high vulnerability and 5.5% (362.2 km^2) region has medium vulnerability. The remaining portion 93% (6137

km^2) of basin has low vulnerability and not recorded incidences of avalanches. All avalanches parameters analyzed average vulnerability score (0.41) indicated the low vulnerability.

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