# Preparation of
# Hazard, Vulnerability & Risk Analysis atlas and report for the state of Himachal Pradesh

## Avalanche Hazard Risk Assessment

Composite Final Draft Report

(T6)

Prepared for

Disaster Management Cell, Department of Revenue
Government of Himachal Pradesh, Shimla

Prepared by

TARU

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# VOLUME GUIDE

This series of reports present detailed technical and methodological documentation of the study entitled “Preparation of Hazard, Vulnerability & Risk Analysis Atlas and Report for the State of Himachal Pradesh” for DM Cell, Revenue Department, Himachal Pradesh.

Volume
**1**

## Hazard Risk

This volume contains Technical papers on hazard risk assessment due to natural and man-made hazards within Himachal Pradesh as presented below.

1. **Avalanche Hazard Risk**
2. Climate Change & Flood Hazard Risk
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## Vulnerability and Risk

This volume contains Technical papers on the Vulnerability and Risks to key elements at risk within Himachal Pradesh as presented below.

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# Hazard Risk

# Avalanche Hazard Risk Assessment

## Composite Final Draft Report

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# Abbreviations

| | |
|---|---|
| ASTER | Advanced Spaceborne Thermal Emission and Reflection Radiometer |
| DEM | Digital Elevation Model |
| GE | Google Earth |
| GIS | Geographical Information Systems |
| GLC | Global Land Cover |
| QGis | Quantam Geographical Information System |
| SPOT | Système Pour l'Observation de la Terre |
| SRTM | Shuttle Radar Topography Mission |
| WMS | Web Map Service |
| WRS | Worldwide Reference System |

# Executive Summary

Snow avalanches in the Higher Himachal Himalaya are common high- frequency low magnitude process where slope, aspect, relief and surface gradient are conducive for initiation of failure. Shallow avalanches are common during winter months (snow precipitation related to the mid-latitude westerlies) in higher altitudes, feeding to glacier mass balance. Depending on the length of run-out distance and catchment area, these avalanches may be catastrophic.

A single snowfall event contributing over 2-3 feet of snow accumulation in the high probability snow avalanche area are more at risk, given the existing investments in infrastructures. Based on our analysis the high probability area comprise of only 1.2% of the total geographical area within the state leading to limited possible impact on built infrastructure and population. Moderately probable avalanches occurs in about 15% of the geographical area; which are mainly confined to higher altitudes that feed glaciers sustenance and mass balance. Even though the extent of area is large the low population density around these areas do minimize the extent of the risk.

Nevertheless, the extent of developmental activities including roads and bridges around the avalanche prone areas have increased in the recent past which might lead to increased economic vulnerability. Therefore there is a need to develop a mechanism to artificially trigger avalanches in the event of single snowfall spell in excess of 2 feet or more to avoid large scale damage. Since the regional government is in the process of infrastructural investments by constructing all weather roads dedicated action-force may be constituted to artificially trigger avalanches in avalanche risk prone areas.

# Chapter 1: Introduction

Avalanches occur when weight of accumulated snow on slopes exceeds forces within snowpack or between snowpack and ground. Such imbalance can take place when there is an increased snowfall or internal changes occur within existing snow cover or caused due to anthropogenic activities such as skiing. This relatively marginal force required to start the snow sliding is called an avalanche trigger.

There are two types of snow avalanches; avalanches which originate in cohesion-less snow and starts from one point and gathers more snow as it descends (so called snow-balling effect) are called the loose-snow avalanche; and avalanches which start when large area of cohesive snow begins to slide at the same time are called slab avalanches. Both types occur in wet and dry snow (Cox and Fulsaas, 2003).

## 1.1 Factor Influencing Snow Avalanche Formation

Snow avalanches are confined to areas that receive sufficient snowfall, and have high relief with gradient greater than 300. Since the period of snowfall largely transpires only during winter months, the avalanches are mainly confined to winter season (i.e. between December to March). A sudden temperature rise after winter snowfall may create isothermal avalanches, by abrupt dislodgement of snow pack causing disastrous avalanche down-slope.

However, there may be freak snowfall events in summer months but these events are less likely to translate in to avalanching due to high ambient temperatures. Activities that trigger avalanches around likely areas include sound and vibrations either caused by human activity or natural events such as earthquakes.

### 1.1.1 Altitude/Elevation

There is a strong relationship between altitude and snowfall/temperature. The higher the terrain, the colder it is and therefore more likely to find thicker snow cover.

### 1.1.2 Slope

Avalanches are likely in slopes between 20° and 60° but extreme avalanches occur on slopes between 30° and 45°. Some avalanches have been known to occur on slopes as low as 15° and some above 60° but occurrence of such events are rare due to relative loss in translational motion and limited snow accumulation respectively.

### 1.1.3 Aspect

It represents a crucial role in a number of morphological, hydrological and ecological processes. It is defined as the compass direction to which a slope faces, measured in degrees from North in a clockwise direction and ranging from 0° to 360° The aspect of slope provides information on windward and leeward sides and also the sun facing slopes.

### 1.1.4 Sliding Surface/Roughness

Land cover of a terrain can act to create either a sliding surface or a cohesive layer trapping snow on the slope. Bare soil, grass and mountain vegetation which have low density cover act as an ideal sliding surfaces. Trees, and to a lesser extent shrubs, aid in packing snow onto the slope.

## 1.2 Data Base

### 1.2.1 Primary data

The primary data for this study were collected through field visits. Some of the regions which were covered included Beas, Chandrabhaga, Ravi, Yunam and Spiti Basins. In addition to field photographs, information collected from these visits included data on avalanche deposits and cones that survived through winter failures, terrain information and records of type of infrastructure/ settlements.

### 1.2.2 Secondary Data

Data on the type, snow characteristics, weather elements and historical avalanches locations are currently limited for the snow-fed Himalayas. Further, there is limited availability of cloud free satellite imageries especially for the winter seasons. In the absence of necessary base data, proxy methods were incorporated.

1. In order to overcome this imageries from different years but from same months and location were collated to create composites to estimate and analyze. Cloud free Image Mosaic (Through WMS services of ArcGIS, QGis and GE):
    - i. Quick bird Imageries (Ranging from 2003-2010 at 0.6m resolution)
    - ii. SPOT 4 and 5, Panchromatic (of 2011 and 2012 at 10m resolution)
2. Topographical sheet, 1:50,000, Survey of India.
3. Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER), 16 bit, version 2, (30 m resolution)
4. Shuttle Radar Terrain Mapper (SRTM, 2000) for elevation data (90 m resolution).
5. GLC-2000, processed from the SPOT Vegetation sensor.

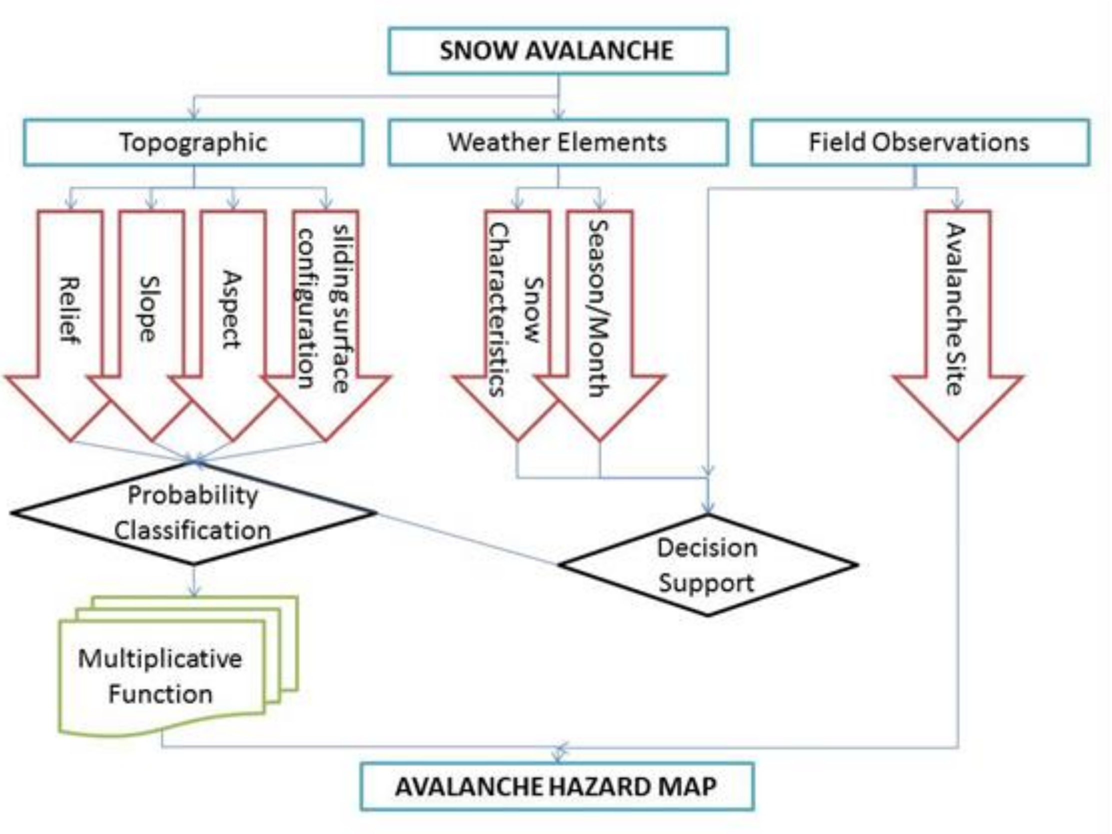
# Chapter 2: Methodology

Avalanche hazard risk mapping presented within this study was based on geographical factors that initiate snow-avalanches. In analyzing risk zones, the regional climatic factors were given equal importance. The methodology adopted within this study were coupled with the field-occurrence evidences of avalanche around the same time.

While precise assessment was not possible in this case due to the lack of required time series data an effort was made to collate information from secondary sources to identify risk prone regions. The methodology is therefore appropriate for regional scale analysis, with an error margin of ± 5 percent. A detailed flow chart indicating the methodology is presented in Figure 1.

Following methodology was adopted to obtain/achieve the final results.

**Figure 1: Himachal Pradesh: Avalanche Methodology**



Source: TARU 2013

## 2.1 Role of Aspect

Keeping in consideration the orientation of mountain ranges in the state probability values/categories were assigned to varied aspects and sun angle based on their damaging potential. The isothermal condition for triggering snowfall depends on sunshine especially in high relief areas within the state.

The highest probability was assigned to Northeast and Eastern aspect within the state. Since these areas tend to warn early with respect to others thereby initiating early failures post heavy snowfall.

**Table 1: Role of Aspect**

| Aspect and Angle in Degrees (Clockwise) | Probability Category | Area (Sq. km) | Expected Time of Failure | Remarks |
|---|---|---|---|---|
| North<br>(337.5-22.5) | 3 | 4,153 | Variable | Aspect is insignificant in such cases, Steep gradient is the cause of failure |
| Northeast<br>(22.5-67.5) | 3 | 4,241 | 8.30am-9.30am | Damaging for infrastructure and life |
| East<br>(67.5-112.5) | 3 | 4,360 | 8.30am-9.30am | Damaging for infrastructure and life |
| Southeast<br>(112.5-157.5) | 2 | 4,515 | 9.30am-10.30am | Damaging for infrastructure and life |
| South<br>(157.5-202.5) | 2 | 4,466 | 9.30am-10.30am | Damaging for infrastructure and life |
| Southwest<br>(202.5-247.5) | 1 | 4,950 | 11.00am-1.00pm | - |
| West<br>(247.5-292.5) | 1 | 4,620 | 11.00am - 1.00pm | - |
| Northwest<br>(292.5-337.5) | 1 | 4,415 | Variable | - |
| Almost Flat | 0 | 1 | - | Nil Probability |

*Probability (for aspect only): 3 (High), 2 (Medium), 1 (Low)*
*Note: Values calculated above 2,000 meters. Due to tolerance Limit, variations in total area are ±0.01 percent.*

## 2.2 Role of Slope

Snow avalanches occur more frequently on the slopes between 45º to 60º during winter months in Himachal Pradesh. Rest of the areas (major portion of the state) where either there occurs less snow precipitation or their slope gradient below 25º, have less probability for an avalanche to occur. In the areas where gradient is greater than 60º and are above 4,000 meters above mean sea level, the likelihood of shallow avalanches increases. The event of shallow avalanches are more frequent during winter months. With less population density around these regions, the risk to infrastructure and human lives are low. On the other hand these shallow avalanches contributes to glacier mass balance and their existence.

Figure 2 highlights the slope and probability of avalanche risk which was considered for this study along with their respective area.

**Table 2: Role of Slope**

| Slope (Degrees) | Probability Category | Area (sq. km) | Remarks |
|---|---|---|---|
| < 20 | 0 | 8,220 | Nil Probability |
| 20 - 30 | 1 | 9,308 | Low Probability |
| 30 - 45 | 2 | 13,801 | Moderate |
| 45 - 60 | 3 | 4,139 | High Probability |
| > 60 | 1 | 253 | Low because snow cannot attain depth |
| *Probability (for slope only): 3 (High), 2 (Medium), 1 (Low)*<br>*Note: Values calculated above 2000 meters.*<br>*Due to tolerance Limit, variations in total area is ±0.01 percent* | | | |

## 2.3 Role of Sliding Surface/Roughness

Land cover and surface configuration has an important role to determine the type of sliding surface where snow avalanches are triggered. A steep slope strewn with boulders and shattered rocks provide a rough surface, thus inhibiting the possible sliding. On the other hand, natural or planted tree cover, cultivated field with terraces and water body act as slope-breaks, thus reducing the chances of avalanche failures. However, bare smooth-slopes with small herbaceous cover are idle sliding surfaces in the event of snowfall; and rest of the areas comes under moderate probability category.

**Table 3: Role of Sliding Surface/Roughness**

| Land Cover | Probability Category | Area (sq. km) | Remarks |
|---|---|---|---|
| Tree Cover, broadleaved, evergreen LCCS >15% tree cover, tree height >3m closed > 40% tree cove; open 15-40% tree cover) | 1 | 10 | Low Probability |
| Tree Cover, broadleaved, deciduous, closed | 1 | 281 | Low Probability |
| Tree Cover, needle-leaved, evergreen | 1 | 9,266 | Low Probability |
| Shrub Cover, closed-open, deciduous | 2 | 10 | Moderate |
| Herbaceous Cover, closed-open | 2 | 12,409 | Moderate |
| Sparse Herbaceous or sparse Shrub Cover | 3 | 164 | High Probability |
| Cultivated and managed areas | 1 | 2,601 | Low Probability |
| Mosaic: Cropland / Shrub or Grass Cover | 1 | 22 | Low Probability |
| Bare Areas | 3 | 690 | High Probability |
| Water Bodies (natural & artificial) | 1 | 15 | Low Probability |
| Snow and Ice | 3 | 10,130 | High Probability |
| *Probability (for Land cover only): 3 (High), 2 (Medium), 1 (Low)*<br>*Note: Values calculated above 2000 meters.*<br>*Due to tolerance Limit, variations in total area is ±0.36 percent* | | | |

## 2.4 Snow Avalanche Probability Classification for field records

The snow avalanche probability categories in the Table 4 are based on its frequency of occurrence, damaging capability, and amount of solid precipitation in a single event.

Probability 3 is assigned to the sites where failures are frequent, highly vulnerable for infrastructure that exists, and snow fall is more than 3 feet in a single event. Rest of the failure sites are categorized as moderate and low probability classes where man-made infrastructure is absent.

**Table 4: Snow Avalanche Probability Classification for Field Records**

| Probability | Explanation |
|---|---|
| 1 | Least Damaging and less frequent;<br>Snowfall is 1-2 feet or more in a single event |
| 2 | Moderately Damaging but more frequent;<br>Snowfall is 2-3 feet or more in a single event |
| 3 | Highly damaging and very frequent;<br>Snowfall in excess of 3-5 feet in a single event |
| *Note: Sunshine after snow fall spell is very important in triggering avalanches* | |

### 2.4.1 Avalanche Site Analysis based on Field Records

The probability classification presented in Table 5 is based on the parameters given in Table 4, which relies on frequency of occurrence and damages to resources. The coordinates are only of the accessible points of the run out zones, collected from the avalanche cones that had survived through the season and were recorded during the field visits. These are the field evidences; where no technical analysis is possible for type, frequency and magnitude of avalanches in the absence of geo-technical data on snow characteristics and weather parameters.

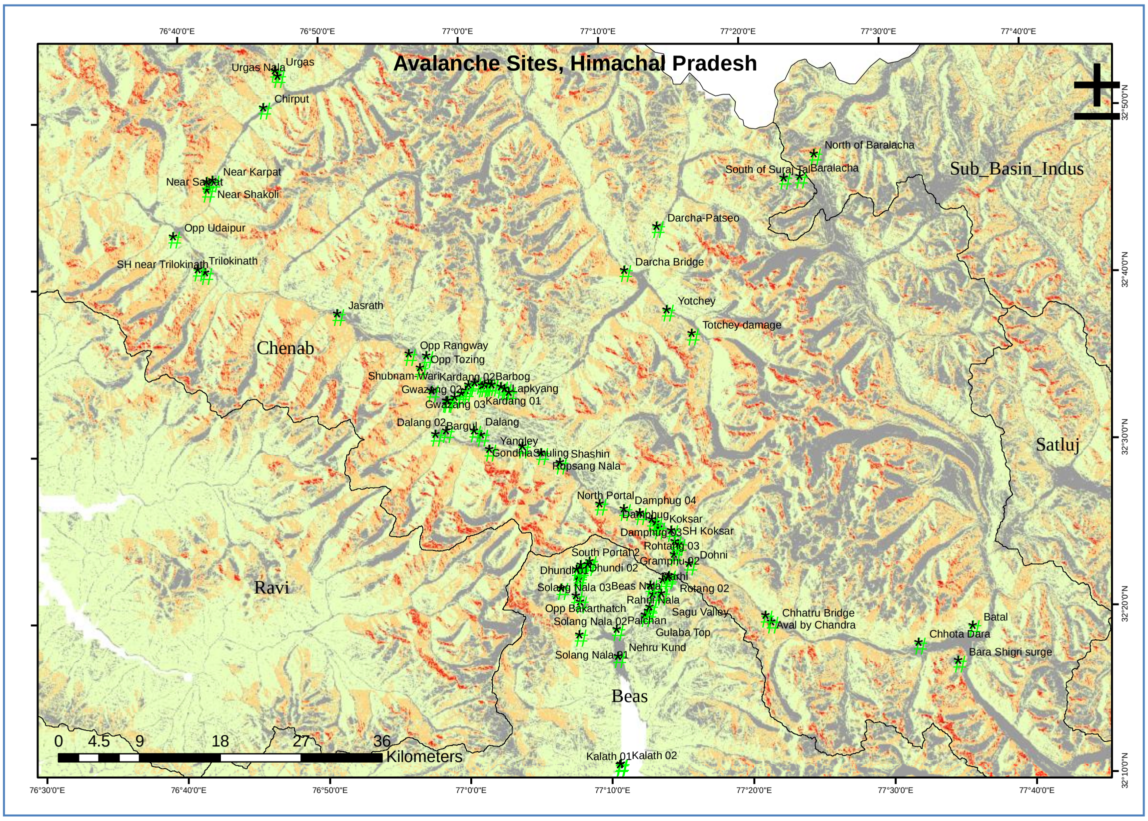
**Table 5: Avalanche Site Analysis Based on Field Records**

| Sl. No. | Name | Latitude | Longitude | Probability |
|---|---|---|---|---|
| 1 | Kalath 01 | 32.179091 | 77.179807 | 1 |
| 2 | Kalath 02 | 32.180048 | 77.180843 | 1 |
| 3 | Nehru Kund | 32.287766 | 77.180148 | 1 |
| 4 | Solang Nala 01 | 32.309942 | 77.135091 | 3 |
| 5 | Solang Nala 02 | 32.342966 | 77.136434 | 3 |
| 6 | Dhundi 01 | 32.365539 | 77.135019 | 2 |
| 7 | Dhundi 02 | 32.368079 | 77.135035 | 2 |
| 8 | South Portal 01 | 32.375420 | 77.137952 | 3 |
| 9 | South Portal 2 | 32.383237 | 77.148403 | 3 |
| 10 | South Portal 03 | 32.379542 | 77.138135 | 3 |
| 11 | South Portal 04 | 32.375397 | 77.132836 | 3 |
| 12 | South Portal 05 | 32.380479 | 77.146585 | 2 |
| 13 | Opp Bakarthatch | 32.356766 | 77.114708 | 3 |
| 14 | Palchan | 32.314870 | 77.178909 | 2 |
| 15 | Gulaba Top | 32.328530 | 77.212712 | 3 |
| 16 | Rahla Fall | 32.332673 | 77.216623 | 3 |
| 17 | Seven Sisters | 32.336572 | 77.218386 | 3 |
| 18 | Beas Nala | 32.348881 | 77.222444 | 3 |
| 19 | Sagu Valley | 32.349671 | 77.232245 | 3 |

| Sl. No. | Name | Latitude | Longitude | Probability |
|---|---|---|---|---|
| 20 | Rahni Nala | 32.363067 | 77.234526 | 3 |
| 21 | Marhi | 32.358162 | 77.219798 | 3 |
| 22 | Rohtang 01 | 32.365298 | 77.240799 | 3 |
| 23 | Rotang 02 | 32.367083 | 77.242102 | 3 |
| 24 | Rohtang 03 | 32.388372 | 77.248735 | 3 |
| 25 | Dohni | 32.378849 | 77.265901 | 3 |
| 26 | Gramphu Waterfall | 32.398264 | 77.254057 | 3 |
| 27 | Gramphu 02 | 32.401573 | 77.249900 | 3 |
| 28 | Koksar | 32.415375 | 77.230517 | 3 |
| 29 | Damphug | 32.420177 | 77.227318 | 3 |
| 30 | Damphug 02 | 32.423693 | 77.223160 | 2 |
| 31 | Damphug 03 | 32.430395 | 77.208991 | 2 |
| 32 | Damphug 04 | 32.434583 | 77.190257 | 3 |
| 33 | North Portal | 32.440474 | 77.161822 | 3 |
| 34 | Shashin | 32.482482 | 77.115788 | 2 |
| 35 | Ropsang Nala | 32.492375 | 77.093937 | 2 |
| 36 | Shuling | 32.499060 | 77.071677 | 1 |
| 37 | Gondhla | 32.511476 | 77.023293 | 2 |
| 38 | Dalang | 32.515928 | 77.015091 | 1 |
| 39 | Yangley | 32.496877 | 77.032767 | 1 |
| 40 | Dalang 02 | 32.516200 | 76.982193 | 1 |
| 41 | Guru Ghantal 01 | 32.546492 | 76.982564 | 2 |
| 42 | Guru Ghantal 02 | 32.546037 | 76.984380 | 2 |
| 43 | Zero Point 01 | 32.549563 | 76.992830 | 2 |
| 44 | Gwazang 01 | 32.553516 | 77.000923 | 2 |
| 45 | Gwazang 02 | 32.556499 | 77.005764 | 2 |
| 46 | Gwazang 03 | 32.561850 | 77.009520 | 2 |
| 47 | Kardang 01 | 32.563622 | 77.016962 | 1 |
| 48 | Kardang 02 | 32.560532 | 77.025623 | 1 |
| 49 | Barbog | 32.561258 | 77.028519 | 1 |
| 50 | Pasprang 01 | 32.562315 | 77.033528 | 2 |
| 51 | Pasprang 02 | 32.561577 | 77.036828 | 2 |
| 52 | Lapkyang | 32.559364 | 77.047801 | 2 |
| 53 | Chhelling 01 | 32.557016 | 77.051878 | 2 |
| 54 | Chhelling 02 | 32.553662 | 77.057028 | 1 |
| 55 | Solang Nala 03 | 32.348902 | 77.131627 | 1 |
| 56 | Batal | 32.310802 | 77.599389 | 2 |
| 57 | Chhatru Bridge | 32.319033 | 77.361795 | 3 |
| 58 | Chhota Dara | 32.294722 | 77.534901 | 1 |
| 59 | Ghushal Fields | 32.556485 | 76.965492 | 1 |

| Sl. No. | Name | Latitude | Longitude | Probability |
|---|---|---|---|---|
| 60 | Darcha Bridge | 32.672986 | 77.196698 | 3 |
| 61 | Yotchey | 32.632560 | 77.246077 | 1 |
| 62 | Baralacha | 32.762819 | 77.407179 | 2 |
| 63 | North of Baralacha | 32.785120 | 77.424557 | 1 |
| 64 | Yotchey damage | 32.608304 | 77.274960 | 1 |
| 65 | Bara Shigri surge | 32.276052 | 77.581413 | 3 |
| 66 | Bargul | 32.512910 | 76.969101 | 1 |
| 67 | Darcha-Patseo | 32.716055 | 77.236066 | 1 |
| 68 | SH Koksar | 32.412640 | 77.245888 | 2 |
| 69 | Shubnam-Wari | 32.591181 | 76.960125 | 1 |
| 70 | Opp Rangway | 32.593520 | 76.939553 | 1 |
| 71 | Aval by Chandra | 32.325482 | 77.355317 | 1 |
| 72 | Opp Tozing | 32.579351 | 76.952141 | 1 |
| 73 | Jasrath | 32.634930 | 76.855665 | 1 |
| 74 | SH near Trilokinath | 32.678087 | 76.699873 | 2 |
| 75 | Trilokinath | 32.681395 | 76.691138 | 1 |
| 76 | Opp Udaipur | 32.714650 | 76.662530 | 1 |
| 77 | Near Salpat | 32.760190 | 76.703200 | 1 |
| 78 | Near Shakoli | 32.768927 | 76.703059 | 2 |
| 79 | Near Karpat | 32.770181 | 76.710197 | 1 |
| 80 | Chirput | 32.842010 | 76.772072 | 1 |
| 81 | Urgas | 32.878769 | 76.786379 | 1 |
| 82 | Urgas Nala | 32.873326 | 76.789469 | 1 |
| 83 | South of Suraj Tal | 32.761661 | 77.388234 | 1 |

Figure 2: Himachal Pradesh: Avalanche Field Sites



*Source: TARU 2013*

Figure 2 shows the distribution of observed sites of avalanche in the background of avalanche probability zones.

## 2.5 Snow Avalanche Probability Zones Classification

The multiplicative function is used for calculating avalanche risk index.

$A_{\text{Risk index}} = f\,(S, A, L)$ *Where:*

$A_{\text{Risk index}}$ = *Avalanche risk index*

$S$ = *Slope*

$A$ = *Aspect*

$L$ = *Land cover*

### 2.5.1 Categorisation of Avalanche Risk Index

The avalanche risk index contains the highest value as 27. These are the zones where all three parameters (slope, aspect and land cover) favor the occurrence of a snow avalanche. The lowest value is zero, where at least one of the parameter have nil (zero) probability for avalanche. Based on the above analysis the results were classified into four probability risk indices. A value “0” is considered as zone of nil probability and “4” being high probability of occurrence.

**Table 6: Categorization of Snow Avalanche Probability Zones**

| Probability Category | Probability Type | A Risk Index Value |
|---|---|---|
| 0 | Nil Probability | 0 |
| 1 | Low | 01-09 |
| 2 | Medium | 10-18 |
| 3 | High | 19-27 |

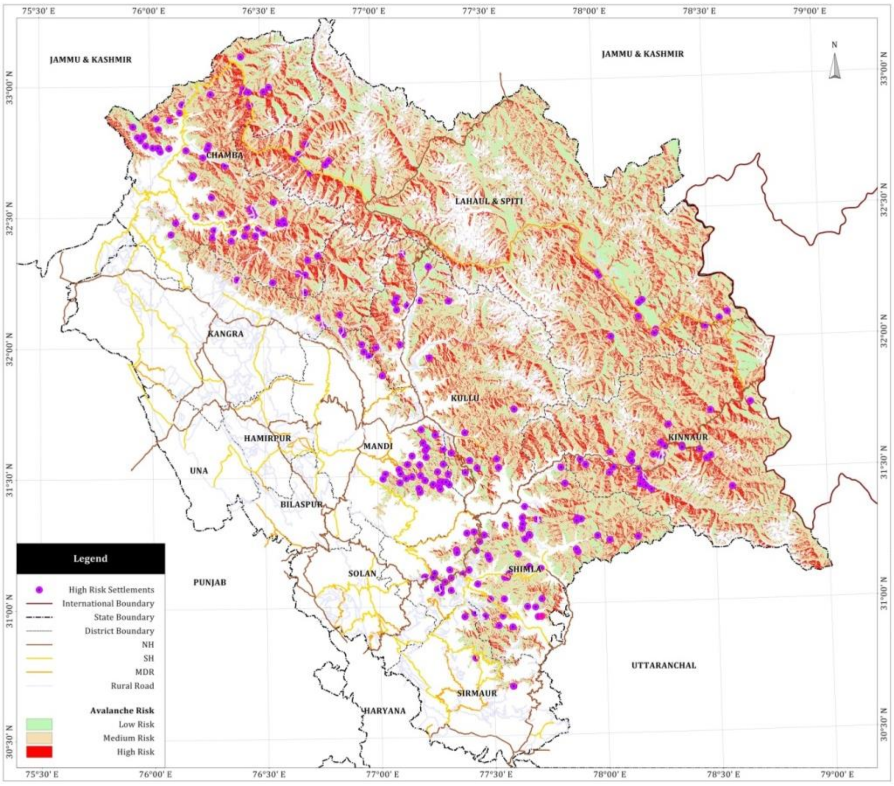
**Table 7: Himachal Pradesh: Snow Avalanche Probability Zones**

| Probability Category | Probability Type | Area (sq. km) |
|---|---|---|
| 0 | Nil Probability | 8,068 |
| 1 | Low | 21,385 |
| 2 | Medium | 5,076 |
| 3 | High | 424 |

*Note: Values calculated above 2000 meters.*
*Due to tolerance Limit, variations in total area are ±2.16 percent***.**

The snow avalanche probability zones for Himachal Pradesh is presented in Figure 3. The high probability zones are the ideal sites for the occurrence of snow avalanche following snow fall. These regions have least frictional resistance for avalanche failure; hence the flow path and run-out surface analysis of these regions must be analyzed in detail for further understanding of snow avalanche damage capabilities.

**Figure 3: Himachal Pradesh: Avalanche Probability Zones**



*Source: TARU 2013*

# Chapter 3: Conclusions

Almost 1.2% area of Himachal Pradesh falls under category of high avalanche probability zone, whereas 14.5% area has moderate probability. Rests of the region (i.e. 84.3%) have low to nil snow avalanche probability. However, 99% of avalanches do not have adverse affect and work as a process of maintaining glacier mass balance and as a low-magnitude high frequency mass movement process.

The highly potential areas, identified in category 3 should be monitored at the time of winter snowfall, as these reach highways and infrastructure. The proven method of controlled sound and blast mechanism should be initiated to trigger avalanches to avoid hazard to life and structures during heavy snow events in the high probability zones.

The study on snow avalanche hazard can be strengthened provided the following set of data and variables are made available:

1. Snowfall data/ meteorological conditions
2. Snow properties(snow structure and mechanics)
3. Analysis of avalanche path configuration and gradient at micro level.
4. Properties of snow rupture and run out zones in the probable areas.
5. Debris carrying capacity of snow avalanche, if any (for understanding damage potential).

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