Anthropocene bearing on Snow-Avalanche Disasters over the West Indian Himalayas: an appraisal

Abstract:

The Himalayas is massive mountainous hills of altitude (≈2km to ≈6.5km) garlanding India in the north extending about 2500km arc-shaped snowy glaciers covering parts of Afghanistan, Pakistan, India, Nepal, China, and Bhutan at various heights in sub-tropics. Snow avalanches in winter with flood and landslides have maximum fatalities with increasing vulnerability in West Indian Himalayas (WIH) dropping temperature to ≈ -60^{0}C against other countries like Pakistan, Afghanistan, Tajikistan, and Turkey. The ignored calamity encountered with unplanned relief to inaccessible areas warrants a DRR approach with modern structural interventions under declining glacier expanse. The present study envisions the various avalanche occurrences in the three most pretentious states Jammu & Kashmir, Himachal Pradesh, and Uttarakhand, in WIH. Various pieces of literature, media news were compiled from 1950 onwards, visiting some avalanche-prone areas and inferring that the wintery western disturbances initiate snow deposition at icing temperature and rolling down to the runout zone smashing people, flora, fauna, economics, anthropogenic structures, and communication disrupting life, livelihood and physical/ psychological health of the victims. The vulnerability area designation, awareness among people, disaster mitigation by PPP mode, and combined effort on war footing basis of line departments like SASE, BRO, defense, and state/central federal organization.

Keywords: Disaster risk reduction, Early warning system, Snow Avalanche, SASE and BRO, western disturbances, West Indian Himalaya,

Introduction:

The avalanche is fast sliding snow-mass movement on the mountain slopes conjoint to icy steep regions when the downslope of steep mountainous terrain drives huge detached snow, ice, and allied debris like rocks and vegetation of mountains. They can be rock initiated, ice instigated or debris triggered. These trivial avalanches/sluffs, which transpire in outsized numbers, are common and unimportant in the Himalayas. The huge avalanches at times encompass large slopes (a kilometer or more in length) with the huge mass of snow, which occur intermittently and are apocalyptic. Humans since evolution exposed to the threat of these sliding Snowmass as homosapiens reside in high altitudes of mountainous regions. The impact of these avalanche disasters has regular exposure to the western Himalayas and the trans-Himalayan range. Recently, heavy snowfall of up to 2m befell at many places on the high altitudes of the Pir-Panjal range between 16-20 February 2005, 300 people lost their lives resulting in avalanches in Anantnag, Doda, Poonch, Pulwama, Udhampur and Kinnaur (Nepal) districts of J&K. The U'Khand flash flood pointed towards the weakening of rock mass due to freezing. Over. Recently on 22 Feb 2022, seven Indian soldiers were dead in the Kameng sector of Arunachal Pradesh India.

The Himalayas is massive mountainous hills of altitude (≈2km to ≈6.5km) garlanding India in the north extending about 2500km **(Fig 1).** They are arc-shaped snowy glaciers covering parts of Afghanistan, Pakistan, India, Nepal, China, and Bhutan at various heights in sub-tropics. The blocking highways including pedestrian and village roads.

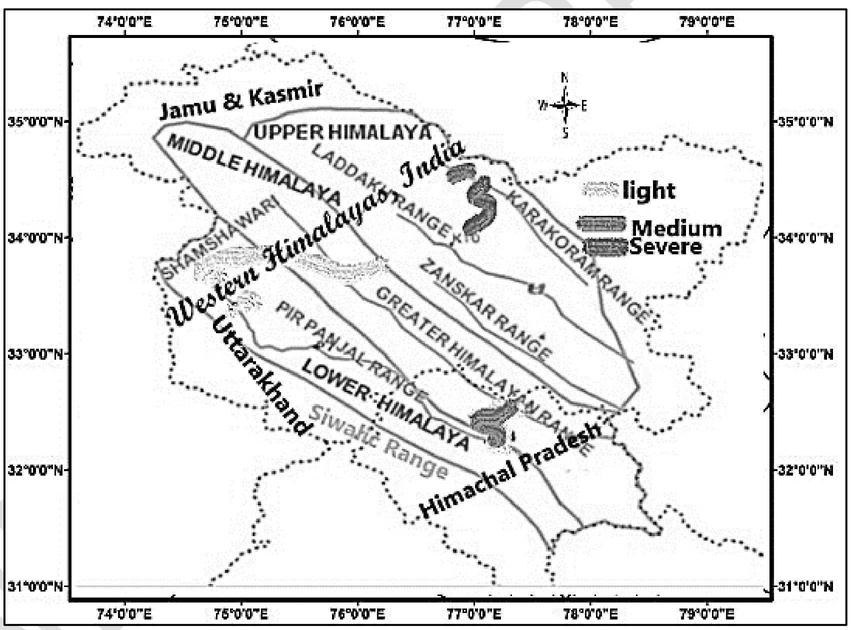

Fig 1: The Western Himalayas with Avalanche prone areas (Source Modified Gusain et al. 2009[1])

Pir-Panjal Ranges are under disruption of communication due to avalanches on the national and state highways between Jammu to Srinagar (NH-44), Naugam to Kaiyan, Chowkibal to Tangdharand, and many other roads. The climate in the Himalayas altitude based and roads./NH existing are Srinagar to Leh and Bandipur to Gurez, India's border line, road to different passes are frequently visited by Avlanches. Elevation wise western Himalayas are the *Lower Himalayas*

(2km to 3,000m), with heavy rainfall and reasonable temperatures, the Greater Himalayas (3 to 4km) are cooler with snowfall but dry. The Karakoram Range (4km to 6km), houses the K2 peak (global 2^{nd} highest) and the Siachen glacier (the border of India, China, &Pakistan). The increased military activities in border areas, the establishment of army camps, and frequent plying of service military vehicles have surged the avalanche activities in Himalayan areas. The Amarnath shrine area needs to be solitary and no chanting of mantras demands to observe a silent zone under a pristine biome.

Fig 2: The avalanche risk areas WIH (Source: Mongabay, 4 May 2018, NDTV 18 Nov 2020)

Indian western Himalayas (WIH) comprises of Siwalic (350 to 1500m), Lower (Inner Himalayas 1500-4500), greater Himalayas and Karakoram range called Tibetan Plateau or Alpine zone (even the third pole in the globe) as per Govt of HP (Disaster Mngt. cell – 2019) (**Fig 1**). The area houses the largest numbers of glaciers beyond the apex poles i.e. North or south poles. Canova's[2] study on avalanche and 150years tree ring transformations in western Himalayan slopes reveals about 500 tree ring anomalies and 38years of avalanche disasters in the area from 1855 to 1970 whereas there are significant upsurges in both numbers of disasters and affected areas beyond the 1970s, **(Fig 2)** (Gullet 2018[3]). Recent avalanches, EQs, and floods arising out of snow melts in glaciers have posed problems to Indian soldiers along the LOCs and border check posts and have taken more than 1000lives since 1986. Many passes are closed during winter for snow/avalanche activities as per Govt of HP.

Few recent avalanche disasters passed through the Indian Himalayas given in Table -1 narrate how frequently such hazards made the life of mountain people in high altitudes miserable. J & K faced avalanche deaths of ≈350 in 2005 and 2012 and about 125 fatalities. Siachen, the world's

2nd largest retreating glacier beyond the poles, is 73, 541.7, and 108.3km respectively, downsizing by 5m/yr (Raina et al., 2008[4]).

Table 1: List of recent Avalanche hazards exposed to Indian Himalayas with fatalities and losses

#	Avalanche	State	date	Deaths	Losses	Source
1	Rishiganga/Dhauli-Ganga joining Tapovan hydel Pr.	U'-khand	9-13th Feb 2022	nil	Scar in snow washed away by flash flood	Kalachand, Sain, Wadia Inst. of Himal. Geology
2	West Kameng;	Arunachal Pr.	6-8th Feb 2022	7dead	Army guards	WIHG
3	Chamoli	U'Khand	7th Feb 2021	200dead /missing	27mcum snow (Ronti peak)	https://www.indiatvnews.com/710943
4	Dhauliganga valley	Chamoli, U'Khond	23 April 2021	11 died	Indo Tibet border	Sharma et al, 2021[5]
5	Rishi Ganga valley	Chamoli, U'Khond	7th Feb. 2021	20 dead/ >150 miss.	debris flow induced STDS	Sharma et al, 2021[5]; TOI 12th
6	Solang Village, Gurez	J&K	15th Feb 2020	18killed & 200missing	broke dams/ bridges,	Economic Times15 Feb 2020, 06.04 PM
7	Roshan Post in Tangdhar	Kupwara dist.J & K	18 Nov 2020	01dead/ 2injured	Security post affected	NDTV 18th Nov.
8	Tangdhar; Gurez; Kup -wara	J&K;	4th Dec 2019	03 dead	Near LOC in North Kashmir	Indian Express December 4, 2019
9	Batalik Sector; Ladakh	J & K valley	13 Jul, 2018	09 dead/ 2 rescued	Soldiers at Machhil post	Economic Times
10	Gulmarg ice festival closed	J &K	18 Feb 2017	20 soldiers	Both side border died	Nair A., Ind. Today (Publn 20 Feb 2017)
11	Kambhu, Srinagar	J&K, HP	Jan-Apr2014	51dead	LOC, Civilians:	Kumar et al., 2014[6]
12	Derahdun	U'Khand;	3 Feb 2013	2dead	Civilians; WD	
13	Siachen ;Deradun	UKhand;	16 Dec 2012	20 dead	LOC; soldiers	
14	(Lahul &Spiti)	J&K	Mar 2011	2dead	Heavy snowfall	Kumar et al 2014[6]
15	Gulmarg	J&K	8th Feb 2010	17dead	Border soldiers	Economic times 8th
16	Pir-Panjal Range WD effect	J&K	16-20 Feb:2005	278(24 soldiers)	4.5m snow fall Gulmarg	Mallik et al 2022[7]
17	Gulmarg	J&K	Feb:1996		4.5m snowfall	Unit-14 Avalanches: Case Studies; eGyankosh
18	Uri Sector; Monang post.	J&K	23rd -28th Mar1997	7dead	- 7.0^{O}C Temp. Slab avalanche	
19	Mahu Mangit, Banihal	J&K	25th Feb 1998	11dead	3m depth snow pack fractured	
20	Lahaul and Spiti	J&K	March 1991	snow fall Jan-Mar	Transport ceased	Kumar et al., 2014[6]
21	Lahaul &Spiti	Hima.Pr.	Jan 1975	NA	EQ; loss roads	
22	Lahul and Spiti	Hima. Pr.	March, 1978	30 dead	Road/property damaged.	Avlanche atlas 1991[8]
23	Lahul and Spiti	Hima. Pr.	March, 1979	237 dead	Road disrupted.	
24	Pir Panjal ; Rajouri	J& K and Him. Pr.	Dec 1982	≈126 dead	Avalanche and under snow	IMD disaster event 1982[9]

Hima. Pr.: Himachal Pradesh U' Khond: Uttarakhond; EQ: Earth quake; WD- western Disturbance

Source:www.yourarticlelibrary.com/geography/avalanches-damages-preventive-measures-and-avalanche-prone-areas-in-india/14070; egyankosh.ac.in/bitstream/123456789/25175/1/Unit-14; Govt of HP (Disaster management 2019[10] and 2015[11])

From the distribution of available data, the inference is maximum avalanche occurrences during the first quarter months of the year, where the maximum frequency of the disaster is optimum in the month of March (Table 1), Podolsky et al, 2009[12].

Review of literature:

Avalanches, regular hazards in snowy mountains, victimize people and property accompanying the present climate change (CC), anthropogenic intensity, frequency, and types are changing, distressing more and more of avalanche committal and trauma, Strapazzon et al (2021)[17]. The present warm climate over the Indian Himalayas is welcoming avalanche disasters for the last decade, Ballesteros-Cánovas et l., 2018[2], Giacona et al., 2021[18].

The buried victim's survival is 50% due to asphyxia if extricated for more than half an hour due to ice accretion in the nostrils and mouth cavity or otherwise from accumulated debris-covered over the prey, (Brugger et al., 2001[19], Statham et al., 2018[20], Strapazzon et al., 2021[21]). Risk of Hypothermia is common as the repercussion of most natural disasters like floods, earthquakes, Tsunamis even in avalanche risk chain and casualties areas, Wang et al., 2005[22], Zafren et al., 2018[23], Strapazzon et al, 2021[21], Oshiro et al., 2022[24]

Western Himalayas in India is in exposure to frequent landslides and increasing snow avalanches due to earthquakes, warming up, and heightened snow melting prompts light-absorbing impurities (LAIs) like dirt, debris, dust, and elemental carbon (EC). The flow from tributaries contributes to fluvial influx through the rivers the Ganges, Brahmaputra, Indus, and the Yangtze, like snow in mountainous areas of Canada, and Switzerland, Jain N., (2018)[25], Sinickas et al., (2016)[26], Singh et al., 2020[27], Thind et al., (2021)[28]. The risk analysis for future challenges, along with development, geomorphology, and LU/LC (land use and land cover) scheduling is essential because of increased avalanche, and landslide occurrences by using GIS and RS (Singh et al 2020[29]). The West Himalayas have had increasing winter rain, average temperature, and avalanche risks since 1970 with augmented anthropogenic activities, (Statham et al., 2018[20]; Puzin et al., 2019[30]). Stimulating landscape features, current orogeny, and meteorological settings are substantial aspects claimed against mass movements initiating avalanche disaster, Alean et al., 1985[31]; Mandal J. 2017[32], Meena et al., 2021[33], Mondal 2022[34].

In avalanches, the gravity slips of mass (rock, ice, soil, debris, and water), ground for remarkable indemnities in high snow-covered mountainous hills globally. The dynamics and the movement of mass under actions of gravity are differing by rolling, falling, sliding, and flowing, Li, et al.

2021[35]. At times, the avalanche is triggered by eruption, flood, lahar, earthquake, or rockfall or combined, Waitt et al., 1983[36], Podolskiy et al., 2010[12], Sanders et al (2014)[37], Ha et al 2019[38] and 2022[39]. Density of vegetation, forest, global warming, western disturbances (WD), snow fall and human activity have surged the snow avalanche activities in West Indian Himalayas, Chaudhary et al., 2011[40], Canovas et al, 2018[2], Wester et al, 2019[41], Strapazzon et al., 2021[17], Yang et al., 2022[42], Kanwar et al., 2022[43].

The necessity for study:

The avalanche hazard has become increasingly vulnerable to the people, flora, fauna, and ecology of the western Himalayas in India. Apart from natural calamities like temperature rise, the upsurge of carbon dioxide has transformed the past climate. Most strikingly, the surge in anthropogenic activities like vehicular traffic, road construction, agriculture, tourism, military activities, deforestation, and human settlements are increasing the risk and vulnerability of the avalanche in the Indian Himalayas. The climate warming in the Himalayas and continuous melting of snow and ice in the peaks and glaciers may bring alarming modification in the scale, extent, and annual rate of incidence of avalanches that shall shift ITCZ, and alter the mountain landscapes and associated socioeconomic systems of the area. The decadal dry periods prevailed in India ranged from 1961 to 70, 1971 to 80, and 1981 to 90, (Atri et al., 2010[44])

It is high time to have a scientific investigation of the snow-avalanche Hazard and to impart well-coordinated action with improved risk management. The players, who monitor the threats and impacts, are explored from various source publications. The favoring organizations are India Meteorological Department (IMD), Snow & Avalanche Study Establishment (SASE), and available literature on print and TV Media discussed.

Snow climate in WIH:

The avalanche areas classified as maritime (Huge snowfall with moderate temperature) or snow climate (less temperature and mild snowfall). WIH falls under maritime category. The altitude, slope, aspect, and ground conditions induce avalanche in WIH are >3200m, 30^0 to 45^0, SE to SW, forest, boulders, Tall grass and bushes (Mcclung et al., 1993[45],Sharma et al, 2000[46])

Earthquake and Avalanche co-incidences:

Seismic events cause avalanche events and vice versa (Heck et al., 2019[13]) **(Fig 3).** The notable earthquakes that transpired in WIH are Kangra (1905/ M- 8.0), Kinnaur (1975/ M- 6.7), Dharmasala (1978/ M- 5.0), and (1986/M-5.7) in Himachal Pradesh, as per National center for disaster, ND. The receding rate of the WIH glacier at Barashingri, HP was 44.3m/year was the highest and the minimum was 13.3m/years, Podollskiy et al (2010)[12,] NDM book HP, Ch- 14[14],

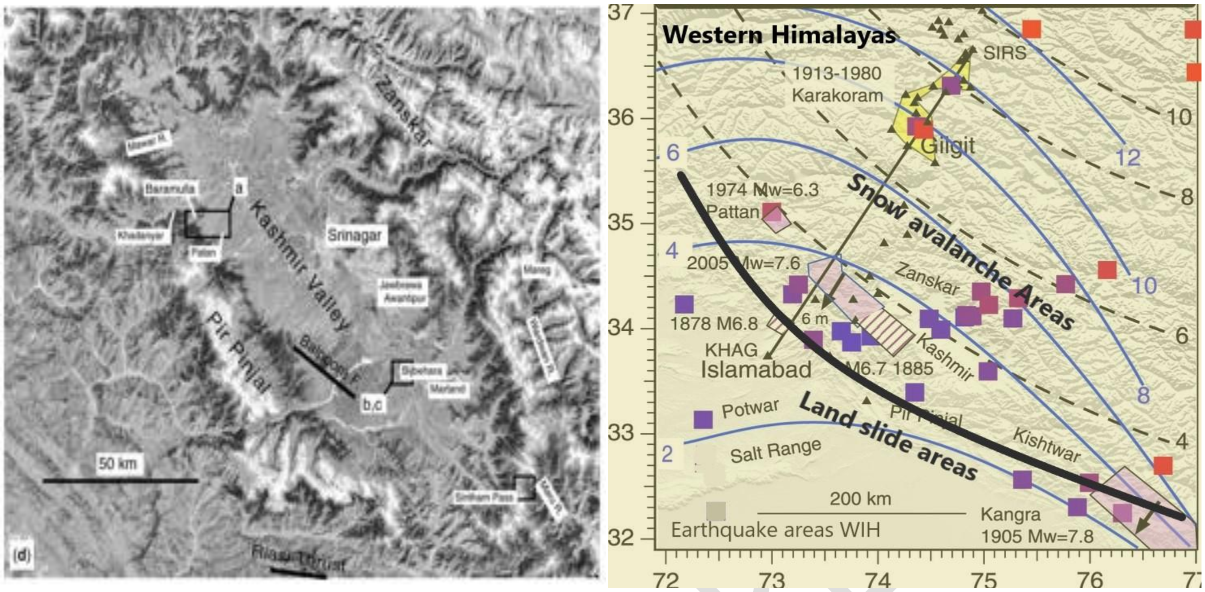

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Fig 3: EQ region in Lower, upper and greater Himalayas, (Pirpanjal, greater Himalayas, Zanskar, Laddaku Korakaram range) Source modified: Bilham R. 2019[15]

Major Snow avalanche on earth:

Past avalanche deaths were about 10000 in Italy 1916, 4000in Peru in 1962, 2200 in Peru in 1970, 200deaths in Lahaul Valley avalanche, India during 1979, and 42deaths in Gokyo avalanche in Nepal during, 1995 (Wiki data). Afghanistan, Pakistan, India, and Nepal are the worst sufferers of snow avalanche impact. Avalanche calamities have taken 216 lives on 1st Mar 2015 (NDMA data), 124people on 27th Feb 2015, in Panjsir province, and Salang pass in NE Afghanistan. Nepal is not free from avalanches and EQ. on 11 May 2015; the Hindustan times of Nepal reported of 200people trapped in Langtang valley (Rasua) in the Kyanjin Gompa area. The data reveals that the focusing area of avalanche in the world is Afghanistan, India, Peru, Japan, and Italy, *etc*. McIntosh. The Himalayan arc in India's north has become prone to avalanche, Gahalaut 2021[16]),

Geology of western Himalayas:

Indian Himalaya has, extends for ≈2500 km as a chain of folded types of mountains garlanding from east to west (72^0 96°E long. and 26°N to 37°N lat.). These furrow-type chains of mountains are datable to the upheaval of the Himalayas from the Pleistocene epoch consequent upon the thrusting of the Eurasian Plate. The Himalaya's perform as an obstruction to the glacial katabatic airstreams flowing from Central Asia but depriving India that maintain the subcontinent warmer. The high altitude mountains has unique diversified biological, frosty, and fluffy biome. The frequency, amplitude, and intensity of the snow avalanche are higher in the western than in the northern Himalayas (Laxton et al., 2008[47]). The complex geology and the diverse disparities of geological settings in snowy over-burdens make it difficult to forecast an avalanche for the meteorologists, scientists, and forecasters working on such disasters in the area (Singh et al, 2020[29]).

Fig 4 (a): Dhauliganga hydropower project affected breaking of glacier at Joshimath Feb. 7, 2021. Fig 4(b): The Avalanche risqué area inHimachal Pradesh Feb'2019

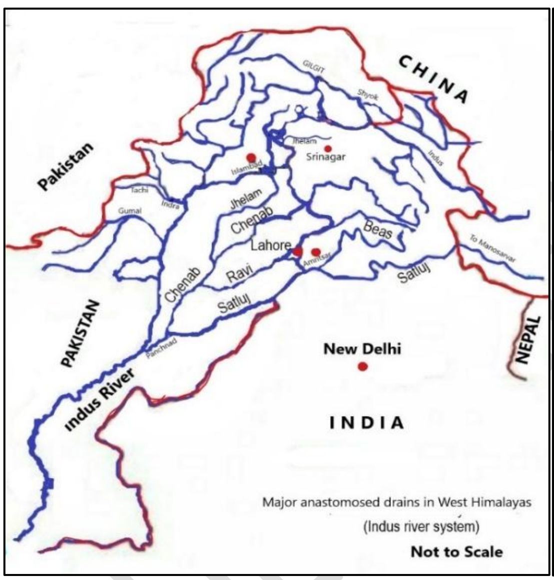
The avalanche occur under conditions of snowstorm Strong western disturbance, when the overburden surpasses $200kg^2$ after filling the terrain irregularities like Rishiganga and Dhauliganga power house project in the year 2021 **(**Fig 4(a) and Fig 4(b) (Singh et al, 1998; Podolsky 2010 [12]).

The anastomosis of drains:

The Indian Himalayas has a huge number of anastomosed channels conjoined to give large rivers like the Indus, the Ganges, and the Brahmaputra. The Indus is flowing in the western segment whereas the other two have formed the largest delta in the world, the Ganga-Brahmaputra delta in the east. However, the Indus River has a large number of gullies, drainage channels, Branch Rivers debouching the Arabian Sea flowing through three states, the Himachal Pradesh, Jammu, and Kashmir, and Punjab (**Fig 5(a) and Fig 5(b**).

Role of Meteorological players:

Western disturbances (WD's) and the exorbitant mountainous ranges (seven) play a pivotal role in deciding the geological factors in the Indian Himalayan range. The impact of the meteorological disturbances is Surface Atmospheric Temperature (SAT), Rainfall, Snowfall, and associated hazards like cold snow hazards, high floods, and extensive Avalanche geophysical incidences. The IMD started to study the glaciers in 1972 through a geological survey of India, and the Dept. of Science and Technology under the Hydro met directorate, to have study about water balance, climate, seasonal snow spread, and snowmelt in the Himalayas (Attri et al., 2010[44]). Studies reveal an increase in CO_2 conc, SAT in Indian Himalayas, global warming, lowering of WD influence in the area, shifting of ITCZ (Inter-tropical convergence zone i.e. (average of out-going long-range radiation OLR) have caused significant transformations in the geo-hydro-bio atmosphere of the mountainous expanse. (Dimiri et al., (2007[49]), Naresh Ku et al., 2015[50], Mishra et al, 2022[51], Dimiri et al, 2022[52])



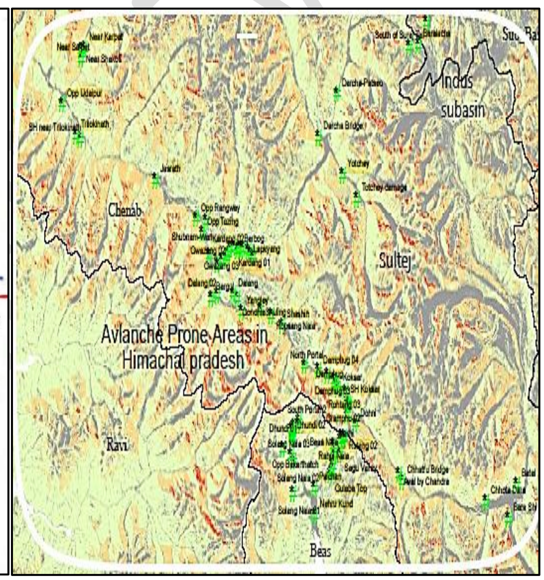


Fig 5(a): The WIH anastomosed river system Fig 5(b): The major avalanche areas in Himalayas

(Source: Raina et al 2008[4], Taru 2013[10])

Activities of forecasting agencies:

The worst sufferers of snow avalanches are the son of the soil, soldiers safeguarding the motherland, the service providers like pavement, Dam, transport other outside people in the expanse. It is pertinent to provide the stakeholders with expert advice from local line departments, the Mountain Meteorology Division (MMD) of the National Weather Forecasting Centre (NWFC) under IMD, and particularly SASE under the aegis of DRDO. The AFC (Avalanche Forecasting Centre) and MMC (Mountain Met Centre) units have developed stochastic and soft computing models to predict avalanches for immediate dissemination in the hit areas.

SASE developed avalanche prediction practices using soft computing models, through the GIS technique, Remote sensing data utilization, and UAV survey for avalanches in the Himalayas. They have surveyed, designed novice techniques, and built avalanche control structures in the area. Through mitigation schemes, SASE has developed various types of control structures in strategically focused areas. SASE has recommended solutions protecting the highways, railway lines, ropeway, chutes (Dhundi), and the protection of transmission lines, (Nayak R., 2005, updated 2012[53]).

Cause of Avalanches

There two types of avalanches are either loose snow avalanches or slab avalanches with further, sub-classified depending upon snow involvement (dry, damp, or wet), cover, origination in a surface layer or total snow cover and fall during the avalanche hazard. Avalanches prerequisites steep slope, depth of snow cover with an intermittent weak layer, and a trigger to initiate drive like earthquake (Singh et al, 2002[54]). The fall of snow mass is due to the slightest misbalance of snow mass causing unstable equilibrium on a steep slope when the natural angle of repose is exceeded. Later-generation of high momentum accelerates with more snow mass and slides the snow and debris mass onto the ground. Avalanches of dangerous size, originate on steep slopes with angles of repose ranging from 30 to 45^0. Avalanches originate in slopes ranging from 45^0 to 50^0 sluffs; common are small avalanches in some cases. The mud or snow avalanches can have to trigger externally by Icefall, earthquake tremors, rock falls, thermal changes, blizzards, and anthropogenic loud sounds such as shouts, machine noise, and sonic booms (Singh et al, 2005[55], Mishra et al., 2021[56]). The change in ecology, anthropogenic military activities, and Global warming have triggered avalanches in the WIH.

Types of Avalanche

Generally, the dry, loose snow avalanches are small and few achieve sufficient size to cause damage. With the onset of melting, the wet loose snow avalanches are common. They grow more occasionally, and reach a destructive size, especially when confined to a gulley. Slab avalanches initiate in the snow with ample internal cohesion to enable a snow layer, or layers, to react mechanically as a single entity. They accumulate to generate wind that drifted very high in the hard slab. A dangerous, unpredictable, slab avalanche (wet, dry, new, or old), that fractures freely along a characteristic line, sliding initiated when the slab face stands perpendicular to the slope either partly or wholly along a mountain slope along the fracture as stress release zone, that is variable. The gross sub-division is full-length or surficial dry and wet avalanches (Hao et al., 2021[57], Bodaballa et al., 2022[58]). The most damaging slab avalanches comprised of dry snow typically spawn as a dust cloud like CB (cumulonimbus) cloud. The whirling snow slide created from soft slabs was identified as powder snow avalanches. Snow crystals mixed with air to form an aerosol, which appears as sharp confined dense gas falling down the gradient with the snow-head. The high dense snow has enormous destructive power though at lower velocity.

The track of the avalanche

Heavy snowfall for a short extent has a greater chance of avalanche manifestation. Avalanches reach speeds of up to 200 km/hour and can exert great forces leaving a track, smashing structures, and can uproot or snapping off large trees. Tree rings depict the number of avalanches in the area exposed. Occasionally, an avalanche can run way up the slope across the valley from the avalanche path repeated exposure. Such paths have a panoramic view and the lands are less prone to pass many winters even decades without a serious avalanche. Avalanches are independent of specific terrain features. They prefer to follow narrow gullies or ravines to travel. They seldom travel in broad, less varying slopes, even in ridges or spurs. The longitudinal profiles of the paths may be concave, convex, or stepped. The Convex slopes are more vulnerable to avalanche hazards than concave slopes. On stepped paths, small avalanches will often stop on a bench some distance down the track while larger ones will run the full length of the path.

Avalanche Hazard Mitigation zoning:

In the Indian Himalayas, large numbers of avalanches have been reported having avalanche sites extending more than one km and snow volume of thousands Cum. An avalanche hierarchy consists of Formation Zone, Middle Zone, and Runout Zone. Avalanche Hazard Mitigation using Control Structures and Artificial Triggering of Avalanches. Various control structures are categorized based on the avalanche zone. These control structures are designed to keep in view the specific nature of particular avalanche sites.

Table 2: The Avalanche prone areas zoning and the hazard mitigation measures/structures

1.	Avalanche Zone	Hazard Mitigation Measures/ structures
2.	Formation Zone	Snow Bridges, Snow Rakes, Snow Nets, Snow

		Fence, Jet Roof, Baffle Wall
3	Middle Zone	Deflecting Structures, Snow Galleiy
3.	Runout Zone	Retarding or Diverting Stnictures, Catch Dams

The other way of zoning is Zoning Avalanche areas are red zone, Blue zone, or yellow zone. The utmost perilous zone is that where avalanches are recurrent. Such avalanches have bearing pressure > 3 MT/ m^2. The Blue Zone has avalanche pressure < 3 MT/ m2 and housing and livelihood activities are permitted with proper preventive measures but must be vacated at the advent of a storm on warning. In the yellow avalanches zone, the hazard seldom occurs.

The Impact of Snow Avalanches

The avalanches damaged people, flora or fauna, and even manmade structures if obstruct the way. Over 1,000 Indian soldiers, including over 35 officers, have lost their lives in the Siachen Glacier-Saltoro Ridge region since April 1984. The debris that emerged blocks highways, rail, and roads of any kind. The huge thrust and fast velocity of moving snow, debris, and the burial of the areas in the run-out zone. During summer, the avalanche-prone areas are less vulnerable and at least risk but deserted in winter. In general, land use within an avalanche area should not include buildings intended for winter and early spring occupancy. Structures including power lines, highways, railroads, and other land use, within the avalanche paths and run-out zones, should be properly designed against the lateral impact with all preventive measures prescribed by IS code and NDMA guidelines 2009.

The aftermath of the disaster

Since after the myth of the disaster, everything is under the debris and snow, mostly in remote places, search and rescue operations are mandatory to address the emergency. The seven 'D' impacts mainly are death, disability, disease, distress, damage to Health Services, damage to the Economy, and Damage to the Environment. The fatalities related are 55-65% (mainly due to suffocation), but the rest who survived are in urgent need of medical attendance otherwise they die from Hypothermia or trauma injuries. The self or companion risqué become crucial and locating the victims has become easier by use of GIS, DGPS, and UAV fixed with sensors and cameras. The equipment used is Emergency Position Indicating Radio Beacons (EPIRB) fixed with a global positioning system. SASE at present not involved in risqué operation, it is high time to create public or community awareness and techniques of rescuing with avalanche forecasting network on PPP mode. The only option is the involvement of the community with expert personnel in public-private partnership mode to address the problem of search and rescue services to be in discipline (Das et al., 2011[59], Muhammad et al, 2019[60], Shugar et al., 2021[61], Dematteis et al., 2021[62].

Impact on flora and fauna:

Global warming contributes to an upsurge in the frequency of annual avalanches in the Western Indian Himalayas (WIH). The dendro-geomorphology study of tree ring data (150YBP) and linked it with snowfall data by Ballesteros-Concova's team [2], in 2018 to track the geospatial avalanche effect on the tree trunks. The WIH houses about 57 million people and acknowledged as one among the 34 "biological hotspots" of the globe, which is changing with the change in climate Tiwari et al, 2017[63]. The inference was the sparse occurrence of avalanches pre-Anthropocene and even none from 1940 to 1950. Then gradually increased from 1970 onwards and in the 21st century, the hazard frequency is high and regular Bob Yirka 2018[64].

EWS for Snow Avalanche Hazards

Early Warning Systems EWS employ two methods to predict avalanches, like snow cover structures (fault patterns), particularly for slab avalanches. The other method uses climatologic meteorological factors like temperature, wester disturbance, type, pattern, and quantum of snowfall, snowstorms, *etc. The snowmelt is the common and prime cause of the disaster; the major inputs to forecasting models are snow* cover, terrain, and atmospheric meteorological parameters. GIS technology using Satellite RS data is considered the most efficient tool against the prediction models. The satellite data used are MODIS, AWiFS, AVHRR, LISS-III, WiFS, PAN, Cartographic Satellite (CARTOSAT), I KONOS, Quick bird, etc. During cloud cover, the microwave (AMSR-E, SSM/I, Radar sat, ENVISAT) imagery is in use. The Quick Response Teams (QRTs) are equipped with gadgets /equipment as State Disaster Management Authorities (SDMAs) in alliance with District Disaster Management Authorities (DDMAs), and NDRF.

Hazard protection:

The increased military activities, communication routes, escalation in winter tourism, built of hydroelectric projects (HEP), transmission lines, and upsurge of urbanization in snowy areas. Protection against avalanches warrants riskless and safe buildings, roads, townships, and growing projects in these areas innocuous from avalanches. Judicious action plans, safe zoning procedures, and strict construction adherence by experts are the wise solutions. Failing the risk avoidance, in the case of transmission/power lines, roads, and railroads, the stipulations to reduce with the implementation of appropriate structural controls and safety measures. From past data and historical information, avalanche-prone well-identified areas and avoid building any structure involving winter use in these areas. Agricultural and recreational activities that take place during the non-avalanche months are relatively safe. Explosive techniques were in practice for the deliberate release of avalanches in past. The technique is to cause many smaller and controlled avalanches and thus avoid large destructive avalanches.

Engineering structures for the control of snow avalanches are:

i) Supporting structures in the formation zone prevents initiating or retarding movement before the snowball gains momentum.

ii) Retarding earth mounds or stone/concrete walls and terraces, rigid structures built in terraces or cliffs.

iii) Deflecting and retarding structures in the run-out zone to push the dropping snow away from structures in critical locations with massive structures of earth, rock, or concrete. Breakers, tri, or tetrapod's with roughness and crosscurrents set structures placed facing the snow currently.

iv) Direct protection to individual structures avalanche sheds built immediately adjacent to the target.

v) Avalanche sheds or shelters are merely roofs over roads or rail lines that allow avalanches to cross the road/railroad without interrupting or threatening the traffic.

The border roads organization (BRO) along with SASE, a vast network of roads in the high altitude snow-bound areas in WIH areas of Leh in Jammu and Kashmir, Sikkim, Arunachal Pradesh, Himachal Pradesh, and Uttarakhand, plays a major role in the operation of snow-avalanche clearance. The BRO keeps a record of these avalanche zones and appraises the SASE about the fresh occurrence of avalanches. The SASE and BRO are responsible for the identification and monitoring of snow avalanches. The SASE authorizes the responsibility for the zonation of avalanche-prone areas and the forecasting of snow avalanches. Central and state governments in association with the BRO will be responsible for implementing clearance and control strategies against identified snow avalanches. The construction of mitigation structures, detection devices, protection kits, and marking of the winter route is the duties of SASE and BRO.,

Artificial Triggering of Avalanches using Explosives

Artificial triggering of avalanches is an active and cost-effective method of mitigation of avalanche hazards that control the time of release and size of the avalanche. Artificial triggering involves the use of blast waves generated by the explosion to apply additional pressure loading at high strain rates to the snow layers and split them into fragments. It causes the release of unstable snow-mass in the form of a small snow avalanche. Successful artificial triggering involves continuous evaluation of snowpack conditions to identify the suitable window for the application of explosive loading. The target areas where triggering actions are needed are Cornice prone areas for artificial triggering. The making of Artificial Avalanche by Triggering using 84mm RL by Gulmarg Indian Army in collaboration with SASE.

Avalanche moderation processes:

Retarding mounds near Shri Badrinath Shrine and the large monolithic stone (Kedarnath) in the runout zone of an avalanche had saved the temple in the recent past. The common practices of avoidance avalanche impact are land use (LU) precincts, transitory evacuation, or artificial triggering. The constant rise in people and their activity in the area has warranted either moderation or prevention of initiation by building structures like damming, retarding mounds, snow bridges, gulley wires, snow fences, etc.

Fig 6 (a): Snow bridges

Fig 6(b): guywires, snow cable nets,

Fig 6(c) : Snow fences in avalanche area

Fig 6(d): Jet roofs avalanche prone area

Fig 6(e): Snow avalanche dams Fig 6(f): Deflecting berms

However, the common hard structures to moderate, prevent initiation and protect structures are (a) direct protection targets, Pavements, rail lines;(b) deflecting and/or channelizing rolling snow;(c) blocking and storing snow by dams; (d) backing up snow initially, and (e) reducing avalanche hazard frequencies baffles or fences (Fig 6(a) to fig 6(f))

Avalanche Hazard Mitigation WIH

SASE with Cryosphere Science and Technology deploy and facilitate troops for operational mobility and precision avalanche forecasting in *western Indian Himalayas (WIH) avalanche-prone areas covering J&K, HP, and Uttarakhand*. Their Mountain Meteorological Centre is at Srinagar (J&K), Jammu (J&K), Sasoma (J&K), and Joshimath (U.K.), through HQ SASE Manali (HP) covering a 2000Km^2 area. SASE established observatories and (AWS) automatic weather stations at altitudes up to 5500 m (M.S.L) in Siachen Glacier. SASE has mapped using GIS/RS techniques, the avalanche sites, and routes/road axes in avalanche-prone areas for both Army and civilian movement areas. Avalanche awareness programs were conducted with the display of personal protective equipment (PPE) for the army and civilian population residing in avalanche-prone areas in WIH, particularly in the Central and Western Himalayas. They focus on:

i. Computational avalanche forecasting of mountain weather
ii. Avalanche hazard mitigation using control structures and artificial triggering
iii. RS/GIS technology for terrain visualization, snow cover information extraction
iv. Snow cover and avalanche physics: Modelling and simulations
v. High altitude observations network and instrumentation

Avalanche forecasting is practiced at various spatial scale levels. The common models used are k-NN Models (k-Nearest Neighbors or eNNio model).

Soft computing methods

Since the optimization of the avalanche hazard problem is complex, any classical analytical optimization algorithm is not applicable. Therefore, the modern Nature-Inspired Optimization (NIO) techniques adopted and results proven to provide good approximations through software techniques are Genetic Algorithms, Particle Swarm Optimization (PSO), and Artificial Bee Colony (ABC) algorithm. The other WRF model is able to predict weather parameters quantitatively for up to the next six days. Because of this linking, the prediction period of the eNNio model extended up to six days. The accelerated Calibration of the eNNio Model uses data-parallel computing with Graphical Processing Unit (GPU) is much more straightforward today with NVIDIA® CUDA and other parallel programming frameworks. NIO techniques such as the Artificial Bee Colony (ABC) algorithm, which compute-intensive. Hidden Markov Model (HMM) for avalanche forecasting in Pir-Panjal and Great Himalaya and a Decision Support System (DSS) for Karakoram Himalaya using Multi-Criteria Decision Making (MCDM) problems. SASE has responsibilities to identify avalanche zones in release areas, safe launch location, the time window of artificial triggering, and safe artificial triggering practices with trials conducted at an avalanche site in Gulmarg, J&K in Feb. of 2018

Numerical Weather Prediction

During winter, the Western Himalayan region is particularly prone to severe weather events due to the movement of synoptic systems known as Western Disturbances (WDs). Heavy snowfall and gale winds associated with these WDs can cause snow avalanches. Accurate prediction of WDs and associated precipitation plays an important role in the prediction of avalanches in snowbound areas of the Western and Central Himalayan region. Since large gap areas in the Western and Central Himalayan regions where there are no observations available, Numerical weather prediction models along with the satellite data assimilation are used to simulate and forecast weather. The Weather Research and Forecasting WRF model (ARW-WRF; model version) output is provided to the users in Jammu and Kashmir, Himachal Pradesh, and Uttarakhand Himalaya.

Slope, Aspect, Relief, and Rugosity:

It is found that the avalanche generally occurs in mountainous having slopes ranging between 20^0 to 60^0 but the frequencies are very high when the gradient is ranging from 30^0 to 45^0, which is the best angle of repose. The leeward wind and solar exposure initiate avalanche profiles on snowy slopes.

The surface slope facing the sun decides to have a profound impact on the snowpack and hence the wet avalanche in mid-amplitudes. The incident insolation is more direct on the southern slope than the northern slope. The northward and east-facing slopes are exposed to less heat so colder in NH (Northern Hemisphere). In WIH, most of the mountainous slopes faced towards India are either North or NE, or East. The WIH is highly prone to avalanches with less relief.

The roughness of the rolling slope of the terrain behaves as either free sliding or a cohesive layer that can trap snow during descending the slope. Bald surface, grass covering, and mountainous flora having less cover perform as a perfect sliding slope. Big trees, bushes, orchards, and shrubs, help to resist the role of snow along the downslope Panditra et al., 2019[65]. Intervening terrace of water bodies or smooth herbs makes the surface idle rolling surface that can moderate snow avalanche hazard Risk Assessment, Himachal Pradesh, 2015[10].

The avalanche risk index is a multiplicative function used for calculating.

Risk index = f (S, A, L) Where: Risk index = Avalanche risk index; S = Slope; A = Aspect; L = Land cover

The HP state disaster risk assessment, 2015 and reported that the slopes <20^0, 20-30^0, 30 – 45^0, 45 -60^0 and >60^0 are 8220km^2, 9308km^2, 13801km^2, 4139km^2, and 253km^2 respectively. As per the Hazard, Vulnerability & Risk Analysis atlas of Himachal Pr., 2015[10], the optimum range of angle for the high vulnerability of avalanche is 30^0 - 45^0 the slope angle.

GIS / RS use for Avalanche study

GIS/RS are the best use to analyze the avalanche for its occurrence, prediction, or devastation**,** SASE has developed an Analog Ensemble Weather Forecast System (AE System) for local-scale weather forecasting at six stations belonging to the Shamshawari Range, Pir- Panjal Range, Great Himalayan Range and Karakoram Range in the Northwest Himalaya (NWH), India. Developed AE system utilizes in-situ surface meteorological observations for generating local scale weather forecasts three days in advance and verification of previous days' weather forecast generated by it. AE system functions as an independent local scale weather forecast system and it is not dependent on data/forecast products from external sources. AE system predicts air temperatures (maximum air temperature, minimum air temperature, and ambient air temperature), surface atmospheric pressure, wind speed, relative humidity and categorical qualitative weather forecasts/quantitative precipitation amount forecast three days in advance at the local scale over the NWH (Khatiwada, et al., 2019[66],Yriyan et al 2020[67], Altaweel 2020[68])

Discussion:

The avalanche (snow) is common in winter extreme climate, snow fed areas, high relief with large slope (>1 in 300) and triggered by earthquake. The avalanche disaster is sporadic in eastern and infrequent in central and regular in western Himalayas in India. The height favourable are >3km. IMD has reported very little past historical evidence before the epoch Anthropocene (1950) being the warden of disaster. The avalanches statistics reveal the disaster are in upsurge trend from 1970 and onwards. The anthropogenic activities in the glaciers, military accomplishment, increased earthquake tremor, global warming, erratic onset and withdrawal of monsoon, unrest BoB and the Arabian Sea can have influenced the rise of snow avalanches in the western Himalayas. In recent past (08th Feb 2022) an avalanche in Arunachal has taken seven Army personnel which is uncommon in Northeast Himalayas (The print; 12 February 2022).

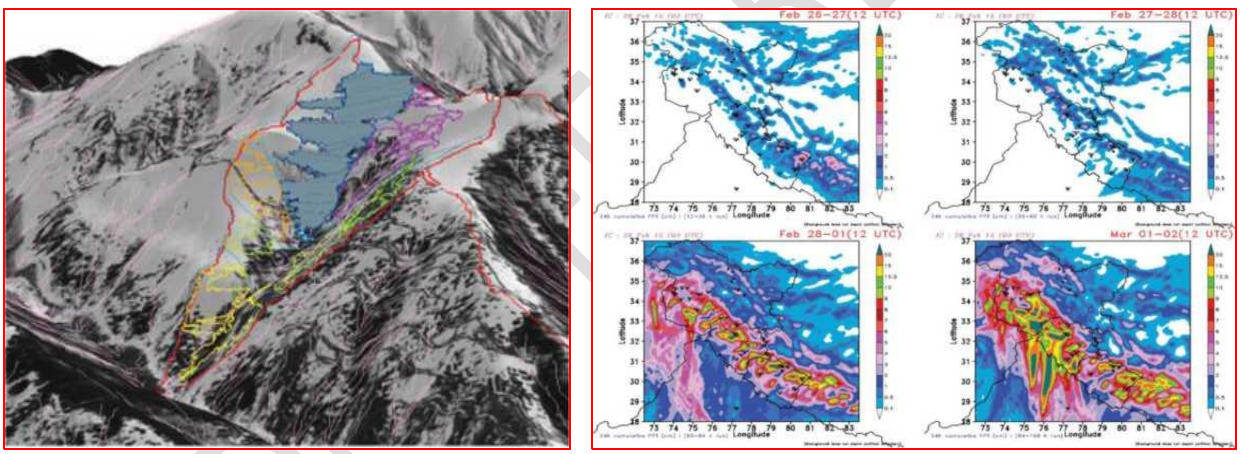


Fig 7(a): The slope & hazard polygons by GIS-based spatial model; Fig 7(b): Precipitation forecast over west/central Himalaya by WRF mesoscale in 9X9 km resolution model (Source: Google)

The States of J&K and Himachal Pradesh have highly vulnerable followed by Uttarakhand. Snow- avalanches remotely affect northeastern states like Sikkim and Arunachal Pradesh. J&K state has high interstate connectivity in hill slopes. Most of these roads have the risk of landslides at lower altitudes and upper reaches by snow avalanches. The village roads wind up on way to some of the important passes on Pir- Panjal and the Great Himalayan range during snowfall. The BRO or the state roads organization maintains the interconnectivity within various valleys. The mitigation and avalanche challenges are shared by the state, BRO, central, SASE, and the defense organizations. The responsibility for road clearance, evacuations, pre, and post-trauma attendances, issuing of avalanche warnings, and maintenance of highways, railways, and airports along with all short-term measures shared by all. Poor coordination at times throws the affected victims in distress, as so many people's responsibility is no man's accountability.

Initially, people have chosen hit and trial methods to safeguard themselves depending on the relief system for facing hazards but the DRR approach is deployed with adequate EWS. In past, people were consulting agencies like the SASE or State Government rescue units to address at the time of hazard occurrences. Now print, cloud data, and electronic media are updated to the aware public of the recent developments. Factors affecting snow avalanches (dry or wet) in the WIH area are a strong western disturbance, heavy snowfall, snowstorms, earthquake tremors, industrialization, heavy transportation activities, vibrations, and flash floods, etc.

Recommendation for avalanche disasters:

On move to avalanche prone hazard and the areas the action plans warranted are (**Fig 8**):

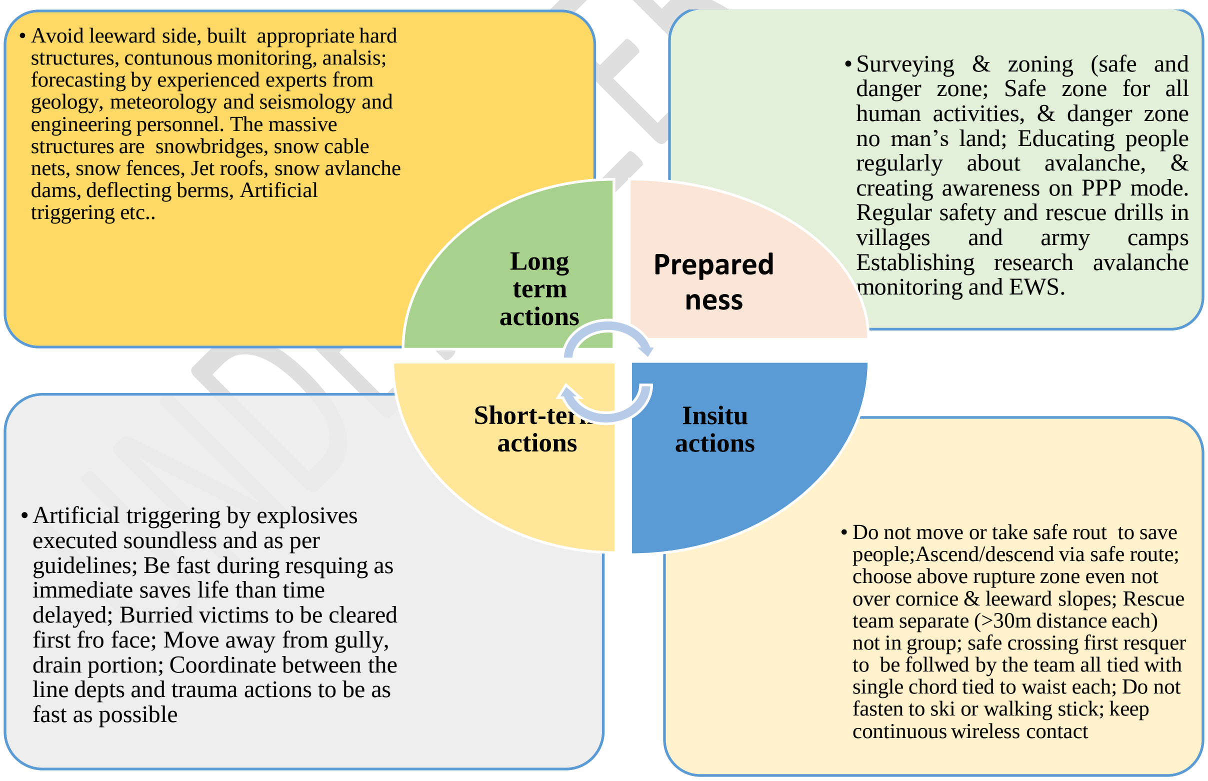


Fig 8: Action plan framed for the avalanche prone areas in WIH

Over exploitation of Himalayan ecology, geology, mineralogy, hydrology, Indian summer monsoon and human resources have put the WIH to severe climate change prospective inviting weather that is more disastrous. Steps to protect such road axes from avalanche threats by putting control structures in the path of avalanches are in progress. Such control structures are existent on the National Highway-1 A (J&K) and at Badrinath (Uttaranchal). Since controlling avalanches action plan permanently, EWS warrants improving avalanche-forecasting techniques. The practice of DRR by SASE needs war footing approaches. Regular researches, workshops, training programs, etc. need to have widespread awareness, impact assessment, and short and long-term mitigation activities avalanche hazards.

CONCLUSION

Avalanches in the Indian Himalayas are a recurring phenomenon. During Anthropocene, the epoch avalanche threat has surged up in high altitudes and steep slopes of snowy WIH steep gulley. It is of opinion that most of the snow avalanche exposed areas are >3500m altitude, slopes within the range $30-45^0$, north-facing convex slopes. The combating avalanche in sloped hilly mountainous areas with no or little, mostly among uneducated mass is a hard nut to crack. The avalanche exposure training, proper zoning, preparedness, DRR risk assessment, accurate forecasting, and permanent preventing structures, and all of the above the strong coordination between the line departments during and after myth shall reduce the risk, vulnerability, and impact shall reduce.

COMPETING INTERESTS DISCLAIMER:

Authors have declared that no competing interests exist. The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors

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