# ASSESSMENT OF GEO-HAZARDS AND MITIGATION MEASURES AT PALCHAN STATION, MANALI (HIMACHAL PRADESH)

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**ABSTRACT**

Palchan station is situated near Manali in the Kullu district of Himachal Pradesh (India) at right bank of river Beas and Pagal Nallah along NH-3 at an altitude of 2400 meters (approx.), whereas village Palchan is located towards left bank. In the vicinity of this station, there are threats of avalanches in winters and flash floods during rainy season. The effect of avalanche and flood are studied for the safety measures of the Palchan station.
Three vulnerable points of the Pagal Nallah from where flood may likely to enter into the settlement area during peak flood discharge are considered for the further analysis. In addition to the field visit, optical remote sensing products of this area were also analyzed to understand the topography of the terrain, characteristics of the avalanche sites and spreading of debris deposition. The satellite imageries are also used to study the extreme events.
Avalanche flow simulation software developed by DGRE is used to study the threat of avalanche hazard and it was found that the station is not located in the trajectory of avalanche flow path. To estimate the peak flood discharge of Pagal Nallah, different methodologies i.e. based on local flood level indication using Manning's equation, rational method, Dicken' s formula and Inglis formula were used. The maximum discharge obtained from observed data is 1021 cumecs. The protection structure along the river embankment proposed at three locations each having dimensions 25 m long and 3.5 m high. These structures having trapezoidal section Guide wall made up of stone masonry with side slope 2:1(H : V) to be provided on bank of Pagal Nallah. In addition, reinforced stone pitching having welded mesh made up of 10 mm diameter TMT bars at spacing of 35-50 cm c/c. A synthetic rubber mat (25 mm thick) with accessories to be placed on top of water side vertical face of protection wall to impart abrasion resistance and provide high impact strength against flowing boulders of varying size from 50 cm to 150 cm.

**Keywords:**. Palchan Station; Avalanche Hazard; Flash Floods; Remote Sensing; DGRE Software; Peak Flood Discharge; Embankment Protection; Disaster Risk Reduction.

## 1. INTRODUCTION

Mountainous regions around the world face significant threats from natural disasters like snow avalanches and flash floods, which can severely impact human lives, infrastructure, and the natural environment. These hazards are often the result of a complex mix of terrain features, changing climate conditions and hydrological dynamics. Snow avalanches, typically triggered by heavy snowfall or sudden temperature shifts, have caused major damage in mountain ranges such as the Indian Himalayas and Alps [Margreth et al., 2003; Bartelt et al., 2012]. At the same time, flash floods—marked by fast-moving water carrying debris—are becoming more common due to shifts in rainfall patterns and melting glaciers, especially in places like Central Asia [Rahman et al., 2014], Nepal [ICIMOD, 2020], and northern India [Dobhal et al., 2013].

To better understand and manage these risks, recent studies have stressed the need for integrated hazard assessments that combine remote sensing, on-the-ground data collection, and advanced simulation tools [Gruber and Haeberli, 2007; Singh et al., 2015]. Models like RAMMS and DGRE (erstwhile SASE) Avalanche Simulation Tool have proven useful in countries like Switzerland and India for simulating avalanche paths and identifying high-risk zones [Bartelt et al., 2012; Kumar et al., 2019]. Similarly, flood risk mapping through empirical methods and GIS-based modeling has become a go-to approach in remote Himalayan regions with limited data [Thakur et al., 2017].

Despite these technological strides, many mountain communities in India—such as the village of Palchan in Himachal Pradesh—still lack detailed, multi-hazard risk evaluations. This study aims to address that gap by assessing avalanche and flood risks in the Palchan area through a combination of fieldwork, simulations, remote sensing analysis, and empirical flood modeling. The goal is to provide practical insights that can help guide safer infrastructure planning and more effective disaster preparedness in Himalayan settlements.

### 1.1 STUDY AREA

Palchan Station is situated in the Kullu district of Himachal Pradesh, around 10 kilometers from the popular tourist town of Manali. Nestled in the Pir Panjal range of the western Himalayas, the station lies at an elevation of about 2,350 meters above sea level, right bank along National Highway-3 and close to the confluence of the Pagal Nallah and the Beas River.

The catchment area of the Pagal Nallah spans roughly 12.2 square kilometers as shown in Figure 1, with elevations ranging from 1,937 to 5,838 meters. This mountainous terrain experiences heavy rainfall during the monsoon and significant snowfall in winter—sometimes accumulating up to 10–12 meters between November and April.

Pagal Nallah acts as a natural drainage for snowmelt and avalanche debris. During snow avalanches, large amounts of snow and rock flow into the nallah, contributing to erosion and debris buildup. Over time, this has led to noticeable changes in the landscape. For instance, near the upper boundary of the Palchan Station, debris flow has deposited large boulders and caused erosion on the side facing the camp. Another concern is a retaining wall built on the left bank of the nallah toward Solang to hold excavated material from the construction of the Atal Tunnel. While intended as a protective measure, this wall has altered the natural flow and increased flood risk in the area.

The nearby Manali–Solang highway, a key lifeline for both locals and tourists, also faces a growing threat during the rainy season. The flash flood on July 25, 2024, triggered by a cloudburst in the upper Anjani Mahadev region, highlighted just how vulnerable this area is. The flood caused widespread damage to roads and various infrastructure, and temporarily cutting off access to the Manali-Leh highway. These recurring events underline the urgent need for a comprehensive hazard assessment and long-term risk reduction measures in the Palchan region.

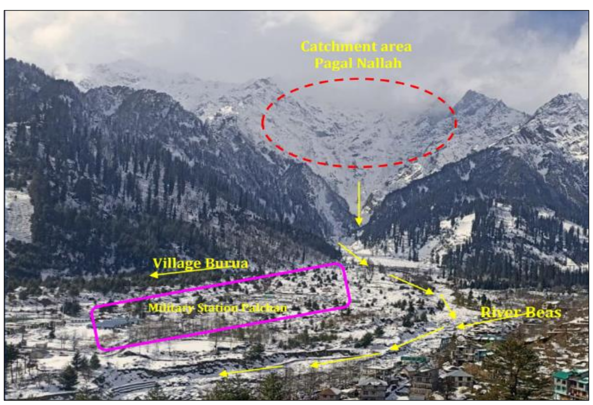


**Fig. 1:** Study Area

## 2. METHODOLOGY

The following multi-pronged approach was adopted to assess the avalanche and flood hazards impacting Palchan Military Station and to propose appropriate mitigation strategies:

**i. Ground Reconnaissance**

A comprehensive field visit was conducted to collect ground data near Palchan Station and study the previous work carried out in this axis.

**ii. Topographical and Hydrological Assessment**

The study involved understanding the terrain characteristics, climatic variability, snowfall distribution, and avalanche behavior in the region. Estimation of peak flood discharge for the Pagal Nallah was carried out using multi-source satellite data, ancillary datasets, and in-situ field observatory records.

**iii. Remote Sensing and Time-Series Analysis**

Optical remote sensing imagery across multiple timeframes was analyzed to detect snow accumulation and debris deposition.

**iv. Numerical Simulation of Avalanche Dynamics**

Avalanche flow simulations were conducted for the Pagal Nallah catchment using DGRE's Avalanche Simulation Software to model runout distances, impact pressure and affected areas. The simulations aided in delineating potential risk zones that could directly or indirectly affect the infrastructure.

**v. Recommendation of Protective Measures**

Based on the simulation outcomes, field insights and hydrological analysis, site-specific engineering interventions were proposed. These include the design of guide walls, RCC protection structures, and recommendations for future planning to enhance the resilience of Palchan Station against avalanche and flood events.

### 2.1 Summary of Ground Observations

(i) The Palchan Station is located at a lower elevation compared to the nearby stretch of Pagal Nallah in the vicinity of the Pinnacle Hydro Energy Project, as depicted in Fig.1.

(ii) A 2 MW hydroelectric power house constructed on Pagal Nallah by M/s Pinnacle Hydro Energy Project has significantly narrowed the natural stream width at the site, which now measures approximately 22.5 meters. This constriction has increased the potential flood risk towards the Palchan station.

(iii) On the right bank of Pagal Nallah, directly opposite the power house, signs of erosion and flood marks were observed. These indicate high floodwater velocity and depth, likely resulting from the stream's convergence upstream and divergence downstream of the power house.

(iv) A water intake point (locally referred to as a Kuhl) is situated downstream of Hydro Project site and on the right bank. It diverts water from Pagal Nallah for agricultural use in Burua village and also passes through the Palchan Military Station. The elevation of the Kuhl intake and the stream bed is approximately the same, suggesting that during peak flood discharge, water could potentially spill into the military station from this point (Fig. 2).

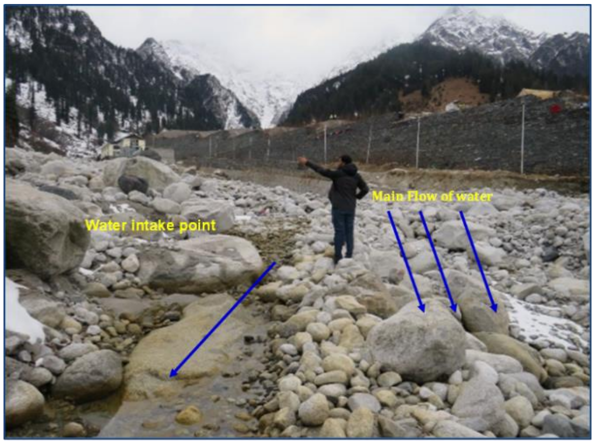


**Fig.2:** Bed of Pagal Nallah and Water intake point

(vi) Just downstream of the intake point, a pathway connecting villages Burua and Solang crosses Pagal Nallah near the boundary of the Palchan station. As both the path and stream bed are at the same elevation (Fig. 3), floodwaters could enter the station from this location during high flow events.


**Fig.3:** Crossing of path to village Burua and Solang

across Pagal Nallah

(vii) Multiple locations along the stream exhibit bank erosion, with several spots observed to be currently eroding or at high risk of future erosion.

(viii) The Palchan Station is also exposed to avalanche hazards. Two minor avalanche paths are located behind the station. Furthermore, the Pagal Nallah catchment contains numerous avalanche gullies that converge near Anjani Mahadev temple and contribute to the stream. Given the area's experiences heavy snowfall, a detailed assessment is necessary to evaluate the potential avalanche impact on the military station.

**2.2 Analysis of Geospatial Data for Understanding the Terrain Topographic and Snow Conditions**

Geospatial data plays a critical role in assessing terrain characteristics and snow dynamics, particularly in complex mountainous regions such as Pagal Nallah catchment near the Palchan Station. High-resolution satellite imagery and digital elevation models (DEMs), specifically the ALOS PALSAR DEM with ~12.5 m spatial resolution, have been utilized to analyze terrain topography. Contour intervals of 200 m for the complete watershed and 50 m for the Pagal Nallah catchment effectively illustrate altitude variations (**Fig. 4)**.

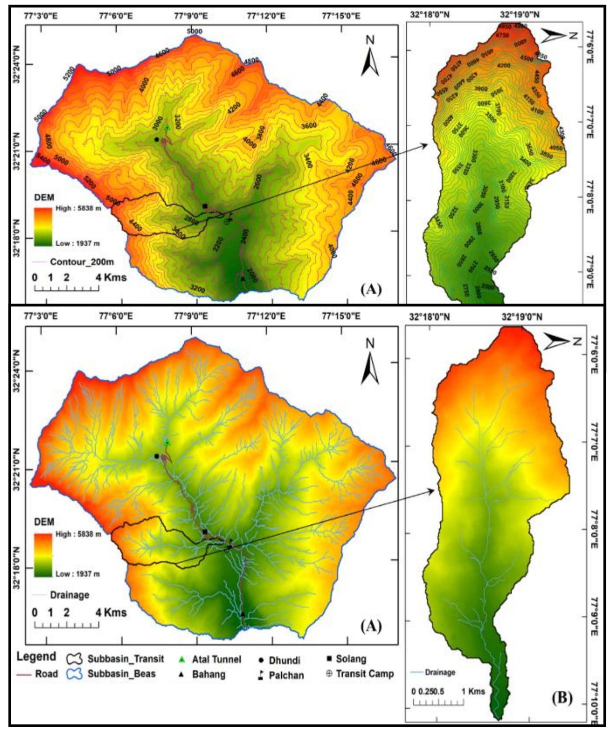


**Fig.4:** Altitude variation and drainage network in the (A) Beas Sub-basin and (B) Pagal Nallah catchment calculated using ALOS PALSAR DEM at contours 200 m and 50 m, respectively

Using ArcGIS, the drainage network was delineated, and slope and aspect maps were generated (**Fig. 5)**. These maps reveal that the catchment exhibits steep slopes exceeding 30º with a dominant aspect between North (N), North-East (NE), and South-East (SE), which are critical parameters for avalanche hazard assessment.

Sentinel-2 optical satellite data (2019–2022) further provided seasonal snow cover maps and quantitative estimates of snow distribution, showing a snowline shift from ~5300 m in summer to ~2000 m in winter **(Fig.6 & 7)**. True color composites were created using bands 4, 3, and 2 (RGB), enabling clearer visualization of snow conditions **(Table 1)**.

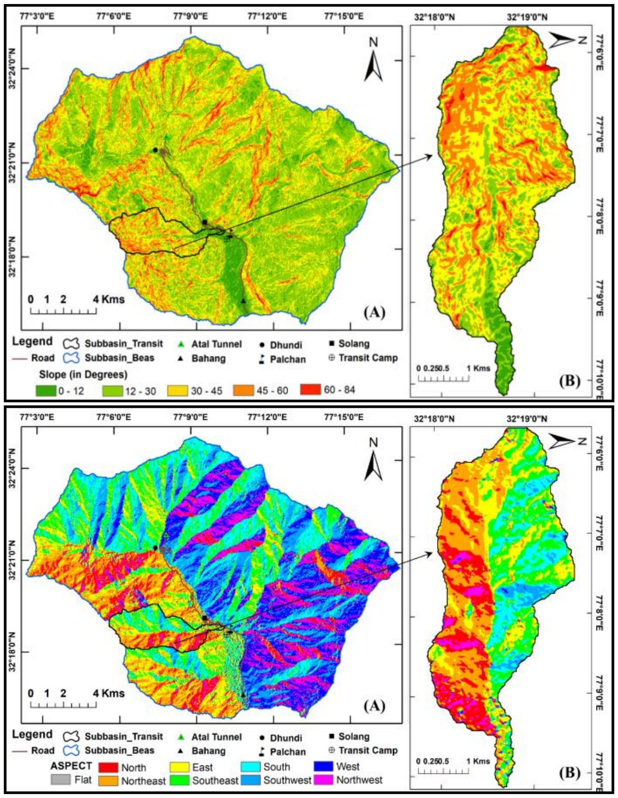


**Fig. 5:** Terrain Slope and Aspect information for the (A) Beas Sub-basin and (B) Pagal Nallah catchment calculated using ALOS PALSAR DEM

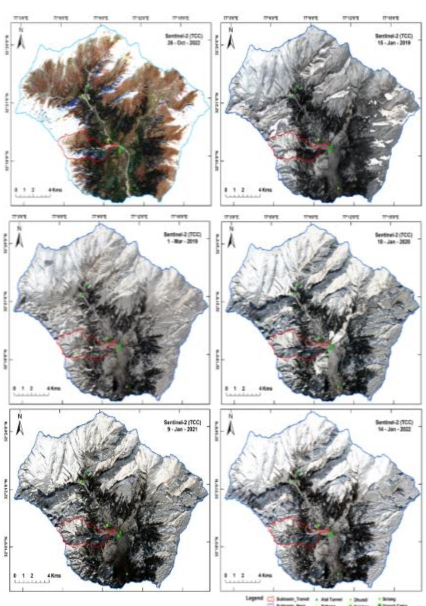

**Fig.6:** Snow cover maps generated using Sentinel-2 (time-series 2019 to 22, spatial resolution ~10 m) optical satellite imagery

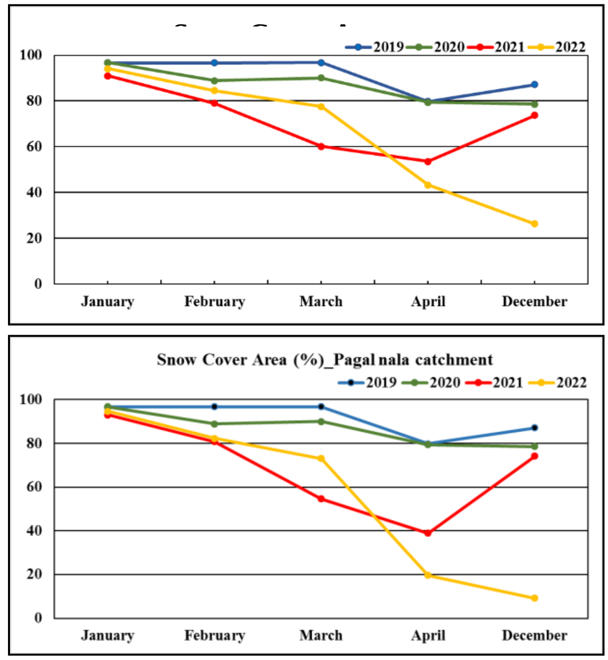


**Fig.7:** Quantitative estimates of aerial extent of snow using processed satellite imagery

Table-1: Sentinel-2A and 2B data bands specification

| Sentinel-2 Bands | Central Wavelength (µm) | Resolution (m) |
|---|---|---|
| Band 1 - Coastal aerosol | 0.443 | 60 |
| Band 2 - Blue | 0.490 | 10 |
| Band 3 - Green | 0.560 | 10 |
| Band 4 - Red | 0.665 | 10 |
| Band 5 - Vegetation Red Edge | 0.705 | 20 |
| Band 6 - Vegetation Red Edge | 0.740 | 20 |
| Band 7 - Vegetation Red Edge | 0.783 | 20 |
| Band 8 - NIR | 0.842 | 10 |
| Band 8A - Vegetation Red Edge | 0.865 | 20 |
| Band 9 - Water vapour | 0.945 | 60 |
| Band 10 - SWIR - Cirrus | 1.375 | 60 |
| Band 11 - SWIR | 1.610 | 20 |
| Band 12 - SWIR | 2.190 | 20 |

Field observations and satellite images confirmed debris-filled channels with no vegetation in the formation zone, and no permanent water bodies were detected. While recent satellite data showed no active avalanche events, past occurrences were validated by local reports and historical imagery, including evidence of avalanche deposits near the Anjani Mahadev temple in April 2018. Additional analysis of the Palchan station area showed consistent channel width (~46 m) despite debris deposition observed in 2010 and 2017 imagery **(Fig.8)**. These geospatial insights are crucial for hazard assessment and planning in high-altitude military and civilian zones.


**Fig.8:** Changes observed in the Pagal Nallah and Beas River channel using satellite imagery (Source: Google earth)

### 2.3 Avalanche Dynamics Study of the Pagal Nallah Catchment area

To assess the avalanche hazards in the Pagal Nallah catchment area, particularly in proximity to the Military Station Palchan, a simulation-based study was carried out using an in-house software developed by the Defence Geoinformatics Research Establishment (DGRE), formerly SASE. The model employed in this software is grounded in depth-averaged mass and momentum conservation equations, assuming continuum flow, incompressibility, and the absence of snow rheology. Voellmy's (1955) empirical friction law was used to represent energy dissipation, incorporating both Coulomb (μ) and turbulent (ξ) friction parameters. The numerical solution was obtained using a finite volume approach. The model is specifically designed for dense flow avalanches and does not account for powder snow avalanche behavior.

Key inputs for the simulation included a 12.5 m resolution Cartosat Digital Elevation Model (DEM), slope maps and historical snow accumulation data from the Dhundi observatory. Potential release areas were identified using terrain slope angle criteria, selecting zones with inclinations between 28° and 50°, which are commonly associated with avalanche initiation. Release depth was estimated based on the maximum three-day snow increment observed over a 24-year period, extrapolated to a 100-year return period using statistical methods, yielding a reference fracture depth of 2.44 m. This value was further corrected for elevation, slope and local wind conditions to better represent actual snow load conditions at each release site.

Simulation results revealed detailed estimates of avalanche flow depth and velocity for 41 identified potential release areas. The spatial distribution of these results demonstrated that, although significant avalanche activity could be expected in the region, the runout distances did not reach the Palchan Station. This finding was further corroborated by remote sensing analysis of historical satellite imagery, which showed no evidence of avalanche deposition near the station. The simulations also confirmed that the avalanche flow generally terminated before reaching Anjani Mahadev temple, which is located at a considerable distance from the Palchan Camp (**Fig.9**). These findings suggest that while the Pagal Nallah catchment exhibits conditions favorable to avalanche formation, the direct threat to the Palchan Station from avalanches remains low.

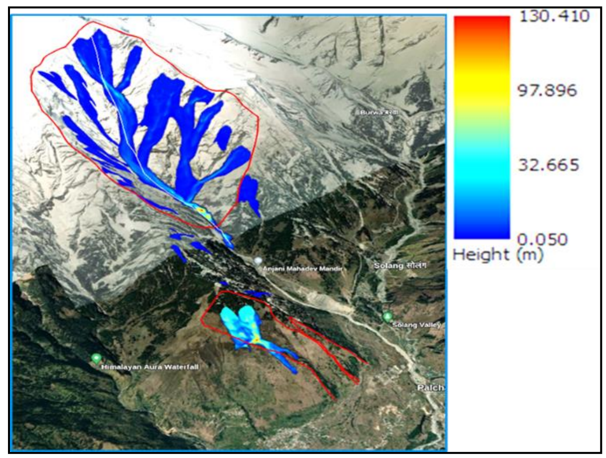


**Fig.9:** Maximum avalanche flow depth simulation

### 2.4 Hydrological Analysis

Efforts were undertaken to obtain hydrological data for Pagal Nallah and the Beas River, with a focus on two key locations: the left bank of Pagal Nallah near the Pinnacle Hydro Energy Project adjacent to Solang Parking and the left bank of the Beas River near Palchan village where the Beas Kund Hydro Energy Project is located.

#### 2.4.1 Estimation of Peak Discharge at Pagal Nallah

**(a) Maximum Flood Estimation from Local Physical Indicators**

In the absence of recorded gauge and discharge data at Pagal Nallah, peak discharge was estimated based on field evidence and physical markings. During the DGRE team's field visit, locals indicated the highest observed flood level was approximately 3 meters above the existing bed level of Pagal Nallah near the Pinnacle Hydro Energy Project.

The maximum flood has been computed by manning's formula:

$$Q = \frac{A * R^{\frac{2}{3}} * S^{\frac{1}{2}}}{n}$$

where:

- A is the cross-sectional area (67.5 m²),
- R is the hydraulic radius (2.37 m),
- S is the slope of the channel (0.18), and
- n is the roughness coefficient (0.05 for mountain streams),

the estimated peak discharge at Point A **(Fig.10)** was calculated to be **1021 cumecs** (36,038 cusecs).


**Fig.10:** Location of Guide walls, drainage system and Burwa village path

**Table 2:** A summary of calculated discharge values is presented below:

| S. No. | Method Used for discharge calculation | Calculated Discharge |
|---|---|---|
| 1 | Local Physical indication | 1021 cumecs |
| 2 | Rational Method | 240 cumecs |
| 3 | Dicken's Formula | 226 cumecs |
| 4 | Inglis Formula | 317 cumecs |

Additional empirical methods such as Dicken's formula, Inglis method, and the Rational method were also employed to estimate the peak flood discharge. The value derived from local physical indications (1021 cumecs) was adopted for further evaluations, particularly to assess flow behavior at downstream locations (Points B and C), where floodwaters are prone to encroach upon Palchan Station.

At both Point B (near the water intake of Burua village) and Point C (a critical crossing connecting Burua and Solang Nallah via Palchan) **(Fig.10)**, the same discharge was assumed. Using iterative solutions of Manning's equation for the changing cross-sectional geometry, the required depth of flow was determined to be **1.9 meters**. Consequently, vertical Guide walls of at least 1.9 meters, plus a freeboard, are recommended to manage peak flow safely.

### 2.4.2 Estimation of Velocity at Points B and C (Fig.10)

The velocity at Points B and C was determined using the hydraulic radius and Manning's equation. With the depth of flow d=1.9 m, the resulting average velocity was calculated as **12.2 m/s**.

### 2.4.3 Flow of boulders/ debris in Pagal Nallah during cloud burst/ Flash flood

The Pagal Nallah catchment, with an average slope of 0.18, is prone to high-velocity flow and substantial sediment transport during cloudburst or flash flood events. Field observations confirmed the presence of boulders up to 2 meters in diameter, as well as mixed gravel and debris. Given the high velocity of flow (12.2 m/s), sediment is likely to be transported via suspension, saltation, and traction, with significant potential for downstream impact and morphological changes.

### 2.4.4 Scour

Scour depth was assessed using Lacey's regime equation:

$$\mathbf{R} = 1.35 * \frac{q2}{f}$$

where q = 22.68 cumecs/m (unit discharge) and silt factor f=8 (for boulder stage). The estimated scour depth was **5.33 meters**, indicating substantial risk to foundations and nearby structures, corroborated by field evidence of erosion at the Pinnacle Hydro Power Project site.

## 2.5. Proposed Solutions & Recommendations

Following a comprehensive assessment that included the analysis of existing data, field surveys, local stakeholder consultations, avalanche flow simulations, and remote sensing techniques for identifying avalanche and flood debris, a set of feasible solutions has been formulated to mitigate geo-hazards threatening the Palchan Station. These proposed measures are tailored to the unique topographical and environmental conditions of the area, ensuring both practicality and effectiveness. The proposed interventions are outlined below:

### 2.5.1 Proposed Guide Walls at Points A, B, and C (Fig.10)

To mitigate flooding near the Palchan station and safely channel water into the natural stream without overtopping, the construction of guide walls has been proposed at Points A, B, and C. These walls will each be 25 meters in length and 3.5 meters in height, with thickness based on structural design requirements. The walls must seamlessly integrate with the existing ground profile on either side. Pinnacle hydro energy project is constructed at left bank (within main course) of Pagal Nallah, which has narrow down the width of the stream, which results in the change of its course as well as deposition of boulders on the right embankment side. The deposition of boulders (varying sizes) has formed concave curvature at right embankment side, which further increased the elevation of Nallah bed at this point. This deposition may cause the probability of flood to overflow from the right embankment and may affect the Palchan Military station. In order to overcome the effect of curvature and increased flow depth toward right embankment, it is recommended to increase the free board height ~1.5 m.

At Point B, a water channel intake supplies irrigation water to village Burua. To maintain this flow, a suitably sized RCC Hume pipe will be embedded within the guide wall, the inlet point of hume pipe should be covered with MS grating to prevent clogging due to deposition of coarse sediments in the pipe. In normal discharge conditions of the stream, to achieve the self-cleansing velocity and uninterrupted supply of water towards Burua village, it is emphasized that inlet point of hume pipe should be laid at bed level of stream with sufficient slope

Additionally, a passage for residents at Point C has been recommended to facilitate local access to the village.

The side slopes stabilizing the guide walls will follow a 2:1 (H:V) ratio. In the construction of guide wall, boulders should be filled and compacted in layers along with sand and all-in-aggregate of good quality available in the Nallah bed to minimise the voids and provide adequate strength and density to the structure. The water-facing slope will be protected by 60 cm thick stone pitching, reinforced with adequately sized wire crates and PCC $1{:}1\frac{1}{2}{:}3$ to withstand hydraulic forces, as per the design calculation:

t = 0.06 * $Q^{(1/3)}$

t = 0.06* $1021^{(1/3)}$ =0.6 m = 60 cm

In order to minimize the effect of abrasion due to flowing boulders (varying sizes) in flood situation, it is recommended that reinforced stone pitching to be provided on the upstream, downstream, and upper face of the guide wall, and launching apron. Welded mesh made up of 10 mm diameter TMT bars embedded with PCC at spacing of 35-50 cm C/C should be used for the construction of reinforced stone pitching. The stones of suitable diameter are required to be embedded with Cement Concrete (1: 1.5: 3) of thickness 3 cm clear cover in the welded mesh as shown in **Fig. 11**.

To prevent scour and toe undercutting, a launching apron will extend from the pitching on the Nallah bed. Its required thickness is calculated as:

T = 1.9 × t = 1.9 × 0.6 = 1.15 m

The apron width is approximately 8 meters (1.5 × 5.33 m), and a reinforced concrete cut-off wall will be installed at the apron's end to provide additional protection against scouring.

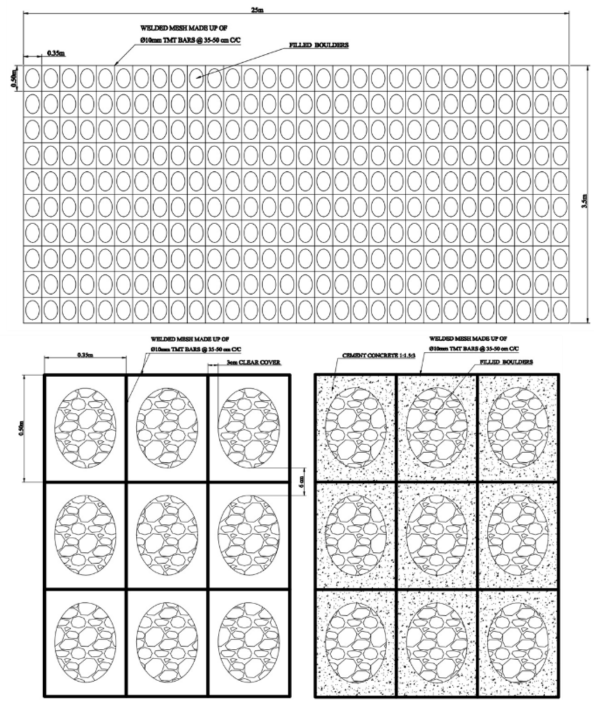


**Fig. 11.** Reinforced stone pitching on faces of guide wall & Apron

**2.5.2 Proposed RCC Protection Wall Against Erosion on the Right Bank of Pagal Nallah**

Visual inspection during the site visit revealed multiple erosion-prone spots along the right bank of Pagal Nallah. To address this, the construction of RCC protection walls has been proposed at vulnerable locations. These structures will consist of two vertical RCC walls built monolithically, enclosing a core of boulders and all-in aggregate.

The wall height will be a minimum of 5 meters in narrow channel sections (<25 m width), and horizontal stiffeners will tie both walls together at 1.5-meter intervals to enhance stability. This composite design aims to reduce bank erosion and ensure structural integrity during peak flows.

A synthetic rubber mat to be placed on top of water side vertical face of protection wall to impart abrasion resistance and provide high impact strength against flowing boulders. The synthetic rubber mat should be durable-shock absorbent and highly resistant to wear and tear, environment friendly (25 mm thick) preferably made up of 2 mm EPDM (Ethylene propylene diene terpolymer) on top, 23 mm recycled tyre rubber underneath.

## 3. RESULTS AND DISCUSSION

The assessment of geo-hazards near Palchan Station was conducted through an integrated approach combining geospatial data analysis, field observations, avalanche simulation modeling, and hydrological computations. The study aimed to evaluate both avalanche and flood risks, and to propose mitigation measures for safeguarding infrastructure and human lives.

### 3.1 Geospatial and Terrain Analysis

Satellite imagery and DEM (Digital Elevation Model) data were employed to evaluate the terrain characteristics of the Pagal Nallah catchment and surrounding regions. The analysis revealed a rugged topography with steep gradients, narrow valleys, and evidence of past debris deposition, indicating susceptibility to flash floods. Snow cover mapping and terrain shading analysis further helped identify potential avalanche source zones.

### 3.2 Avalanche Simulation Results

Avalanche simulations were carried out using the DGRE-developed tool, incorporating terrain features and snow accumulation patterns. The results indicated that while there are multiple avalanche-prone slopes in the vicinity, the Palchan station itself lies outside the direct avalanche runout zones.

### 3.3 Hydrological Findings

To estimate flood risk, peak flood discharge from Pagal Nallah was calculated using four different methodologies: Manning's equation, Rational method, Dicken's formula, and Inglis formula. Among these, the highest discharge observed was 1021 cumecs, which was taken as the design value for structural recommendations. Field indicators, including flood marks and sediment deposits, corroborated this discharge value.

### 3.4 Structural Mitigation Measures

Based on the risk assessment, three vulnerable points (Points A, B, and C) were identified along Pagal Nallah where floodwaters are likely to breach into the settlement area. Guide walls of 25 m length and 3.5 m height were proposed at each of these locations. These are designed with reinforced stone pitching, integrated RCC hume pipes (at Point B), and access paths for locals (at Point C). Stone pitching and wire crate protection were recommended to reduce scouring and enhance wall stability.

On the right bank of Pagal Nallah, an RCC protection wall was proposed to arrest ongoing erosion. The wall design includes dual monolithic RCC faces filled with boulders and aggregate, stiffened with horizontal ties at regular intervals. Additional protection measures, such as synthetic rubber mats for impact resistance, were included to counter large boulder strikes during flood events.

## 4. LIMITATIONS

The above proposed solutions have been carried out on the basis of available inputs of terrain data, satellite data, local information from locals, field visit at site and field experience of snow and avalanche hazard management by the DGRE team. Due to non-availability of the snow-met data for the catchment area of Pagal Nallah (~for 100 years), the fracture depth for avalanche flow calculations have been statistically calculated using Gumble distribution based on the available data of Dhundhi observatory. Also, due to the non-availability of rainfall data for the Pagal Nallah catchment, the rainfall data of nearby Solang observatory has been utilised for estimation of peak discharge at Pagal Nallah. The available information of the area has been analysed as per the best scientific knowledge and capabilities to understand the snow and avalanche scenarios, estimated peak flood discharge and assessed the avalanche hazard at the Palchan Station. Though DGRE team has put in their best efforts to provide the best solution, actual avalanche and flood conditions may vary due to unforeseen natural driving forces and may be addressed as and when required.

## 5. CONCLUSION

This study presents a comprehensive hazard assessment of avalanche and flood threats around the Palchan Station and its surroundings. Through the integration of satellite data, field surveys, simulation modeling, and empirical hydrological analysis, it was determined that while avalanche impact on the station itself is limited, flash flooding from Pagal Nallah poses a significant risk.

Three vulnerable locations were identified for structural intervention, with guide walls and erosion protection features recommended. The proposed solutions are grounded in field observations and engineering practices tailored to the Himalayan terrain.

Furthermore, the analysis underscores the importance of multi-hazard risk evaluation in planning and maintaining infrastructure in mountainous regions. The findings and recommendations from this study are expected to contribute toward disaster risk reduction, improved safety, and resilience planning for both defense establishments and civilian settlements in similar geographies.


## 6. ACKNOWLEDGEMENT

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12) Hydrological report of MSP-6 & MSP-10 (avalanche sites), Prepared by Secon Surveys Private Limited, Bangalore.

13) Detailed Project Report SERAI SHEP 2.0 MW Distt. Kullu (H.P).