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PRELIMINARY REPORT ON THE ASSESSMENT OF LANDSLIDE SITES IN KINNAUR DISTRICT, HIMACHAL PRADESH

Submitted
to
STATE DISASTER MANAGEMENT AUTHORITY
GOVERNMENT OF HIMACHAL PRADESH, SHIMLA

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Date: **BR Thakur**

CONTENTS

1. INTRODUCTION

Landslides and related mass movement processes are common hazards in hilly terrains. An estimate by Guzzetti (2023) reveals that landslides occur in about 17.1% of the landmasses and about 8.2% of the global population is exposed to this hazard. The Indian Himalayan region is one of the major landslide hotspots, where landslide magnitude varies from a single rock fall (Sarkar et al. 2018) to the collapse of the entire mountain slope (Pradhan et al. 2019). Occurrences of landslides in this mountain often caused extensive economic damage and loss of life. An estimate by the National Disaster Management Authority (NDMA) (2019) reveals landslides caused a monetary loss of Rs. 150 crore per annum in India. In the recent past Indian Himalayan region has witnessed some catastrophic rainfall-induced landslide (RFIL) disasters, including Kedarnath event in 2013 (Martha et al. 2015), Kotropi landslide in 2017 (Pradhan et al. 2019), Batseri landslide in 2021 (Sharma et al. 2022), Dima Hasao event in 2022 (Das et al. 2022) and Tupul landslide in 2022 (Baruah et al. 2023). Following these events, some cascading hazards such as landslide dam formation, and valley blocking incidents are also observed (Martha et al. 2015; Sharma et al. 2022).

Himachal Pradesh with 55673 km2 and supporting about 7 million people lies in North-western Himalaya-environmentally fragile and ecologically vulnerable. Increasing incidences of disasters like cloudbursts, flashfloods, landslides and avalanches, all attributed to anthropogenic activities and climate change are giving Himachal Pradesh a new catchphrase ‘Land of Disasters’. Fragile ecology of the state, coupled with large variations in physio-climatic conditions, makes it susceptible to climate issues and natural disasters. Physiographically, the State is divided into three main units: Lower Himalaya, Middle Himalaya and Great Himalaya. Each unit faces distinct hazards based on rock types, soils and local climate. Monsoon is vital for the young, vulnerable Himalayan region, but it also poses risks. It destabilizes slopes, causing loss of life and property damage.

Intense, short-duration rainfall events, known as 'cloudbursts,' are a common occurrence in the Himalayas and a major cause of annual monsoon-related damage in various parts of the state. During the monsoon season of 2023, the state experienced substantial damage, resulting in financial losses exceeding ₹9,500 crore and the loss of more than 500 human lives (Emergency Operation Centre, Government of HP, 2023).

Central Himachal Pradesh has been the hardest-hit region, with severe losses in terms of human lives, livestock and property. Significant losses in the state occurred during two distinct monsoon depressions. The first, coinciding with a Western Disturbance from July 9th to 11th, 2023, caused extensive damage. Second spell from August 13th to 16th, 2023 brought continuous heavy precipitation and accentuated further damage and a series of slope failures in various districts of Himachal Pradesh including Kinnaur.

It is in this backdrop, the State Disaster Management Authority (SDMA), Government of Himachal Pradesh vide letter no. Rev (DMC) (F) 11-09/2021-L M dated September 21, 2023, approached the Department of Geography and the University Institute of Technology (UIT), Himachal Pradesh University, Shimla, to conduct preliminary studies of six landslides in Kinnaur district. This report presents the findings of these investigations and proposes short- and long-term mitigation measures for selected landslide and land subsidence sites in Kinnaur district, Himachal Pradesh.

2. DATA BASE AND METHODS OF STUDY

The preliminary study used both primary and secondary data. Primary information, including landslide history, population and affected infrastructure, was gathered from local residents and nearby areas during field visits conducted in December 2023. The rocks were identified in the field based on physical properties observed in hand specimens. The measurements of foliation, joints (discontinuous plane), other structural orientation and slope face (direction of slope face and its inclination) at each site were determined using a Brunton Compass with the zero-zero method. The regional geological setup was studied using a geological map from the Geological Survey of India.

To conduct a topographic survey of each landslide, a DJI Mini 2 UAV (Drone) was used to capture highly accurate aerial images from multiple points. The 2D images taken from different points were then post-processed using the JDIFLY application to create a panoramic view of each landslide. A differential global positioning system (DGPS) survey was conducted at each landslide site to create contours at 1-meter interval. This survey helped in understanding the topographic make up of each landslip and subsidence incidences. The detailed and highly accurate contour plans of each landslide will aid in designing and implementing mitigation measures at each site.

During the field visit, adequate soil samples were collected from each landslide site and analyzed at an ISO certified and NABL accredited soil testing laboratory in Solan.

In order to analyze the geotechnical properties of each landslide, grain size analysis (IS: 2720 Part 4:1985) has been conducted to determine particle sizes within the range of 0.075 mm to 100 mm. Atterberg's Limits (IS: 2720 Part 5:1985) have been used to establish the liquid and plastic limits of the soil. Bulk density & dry density (IS: 2132:1986) have been employed to calculate soil moisture on a volume basis, with bulk density playing a critical role in this calculation. Specific gravity (IS: 2720 Part 3:1963) has been determined to understand the phase relationships of soils, such as void ratio and degree of saturation. Direct shear (IS: 2720 Part 13:1986) test has been conducted to experimentally determine the shear strength of soil materials, which represents the maximum resistance to shearing. Permeability (IS: 2720 Part 17:1986) has also been measured to assess how quickly water can pass through the soil. Besides, hydraulic conductivity is then determined, as it describes the soil's ability to transmit water and its impact on slope failure.

Besides, the relevant information relating to the landslides has been gathered from the existing literature. Local residents were also interviewed to gather additional information about occurrence of landslips and local knowledge-based mitigation measures. This information was then combined with scientific insights.

3. GEOLOGY OF HIMACHAL PRADESH

Geologically, Himalayan Mountain ranges in Himachal Pradesh are part of Northwestern Himalaya, which is composed of Outer Himalaya (Sub-Himalaya), Lesser Himalaya, Higher Himalaya and Tethys Himalaya from south to north. To the southwest of Himachal Pradesh, lies the Indo-Gangetic Plains, characterized by alluvium. Indo-Gangetic Plains are separated from the Himalayas by a regional thrust known as the Himalayan Frontal Thrust (HFT). The Outer Himalaya consists mainly of the Sirmaur Group and Siwalik Group dominantly composed of clastic sediments. The Lesser Himalaya is bounded by the Main Boundary Thrust (MBT) in the south and the Main Central Thrust (MCT) in the north, the Lesser Himalaya is predominantly exposed to the east of Himachal Pradesh. Its thickness diminishes northwestward in the Satluj Valley region. This region comprises of the meta sediments and volcanics, encompassing formations such as Rampur-Berinag, Shimla Group, Shali–Deoban, Chandpur, Blaini, Krol and Tal formations, along with Klippen units of the crystallines of Chail and Jutogh groups. The Higher Himalaya, thrust over the Lesser Himalaya along the MCT (Jutogh Thrust), includes gneiss, schist and granitoids. In the Beas and Satluj valleys, it is classified into the Chail, Jutogh, and Vaikrita groups, while the Lahaul Group is situated in the west. Further north, the Tethys Himalaya features granites, metapletic sediments and limestones. **Fig. 1** shows the geological map of Himachal Pradesh.

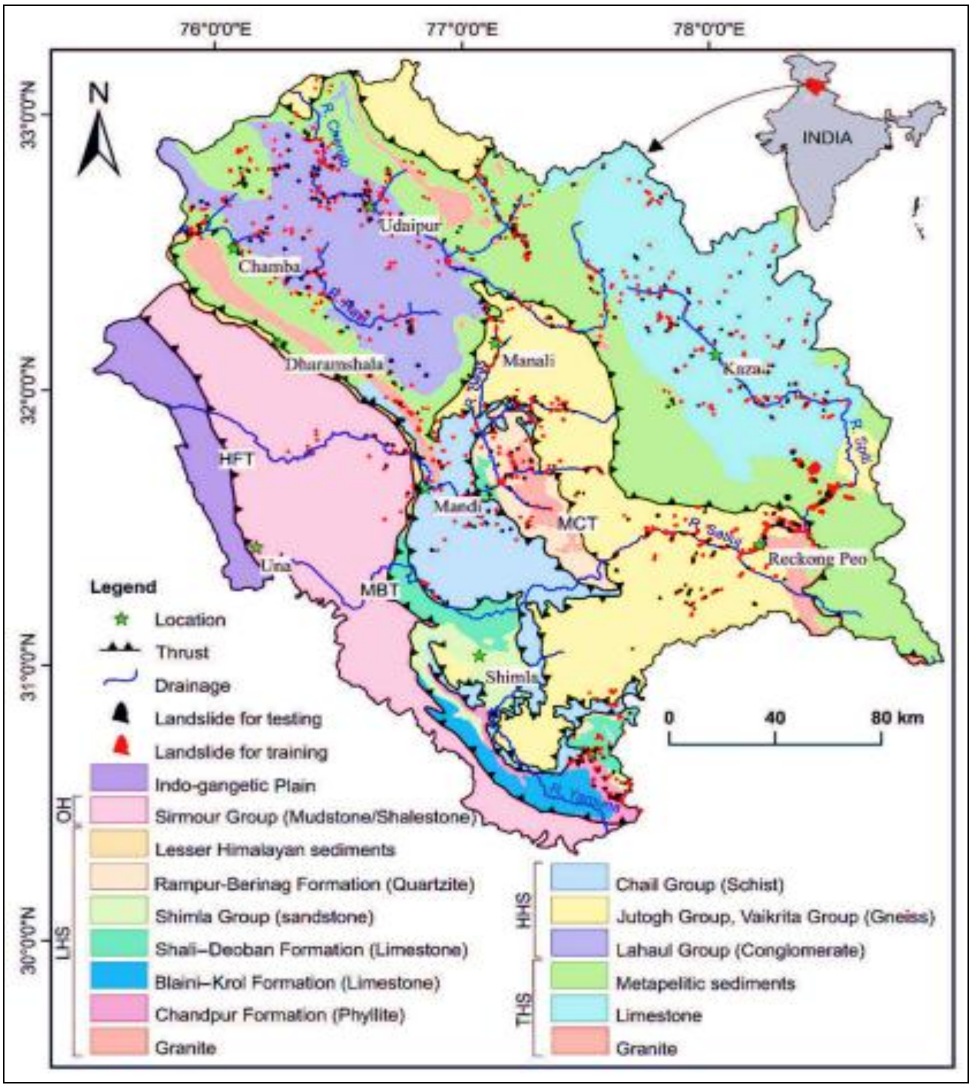


Fig. 1 Geological map of Himachal Pradesh marked with various lithostratigraphic units, regional structures, landslides and major rivers originating from the Himalayas (modified after GSI, 1996).

The geological landscape of the Himachal Himalayas reveals a variety of terrains, each playing a part in the complex and ever-changing geological history. The Himachal Himalayas consist of four main parts which include the outer Himalayas, lesser Himalayas, higher Himalayas and Tethys Himalayas. Each has its own unique features and geological history. Towards the south of Himachal Pradesh, the Indo-Gangetic Plains sprawls across the foothills of the outer Himalaya, the outer Himalaya is separated by the HFT from the alluvium deposited by the Himalayan rivers. The Outer Himalayan geological formations are marked by the presence of sandstone, mudstone, shale and conglomerates, painting a vivid picture of the geological evolution of the Himalayas.

Moving further north, the Lesser Himalaya is bounded by the Main Boundary Thrust (MBT) in the south and the Main Central Thrust (MCT) towards the north. Traversing northwest into the Satluj valley, the thickness of the Lesser Himalaya gradually diminishes. Within this region, an array of lithologies unfolds, which are divided into different groups and formations, the Rampur–Berinag Formation, Shimla Group, Shali–Deoban Formation, Chandpur Formation, Blaini, Krol and Tal formations. Besides, the Klippen units of the Chail Crystalline and Jutogh groups make the geological setting more complex.

The Higher Himalaya, thrusts over the Lesser Himalaya along the MCT, locally known as the Jutogh Thrust. The Higher Himalaya is comprised of gneiss, schist and granitoids. In the Beas and Satluj valleys, this geological entity is further classified into the Chail, Jutogh and Vaikrita groups. Toward the west, the Lahaul Group adds further geological complexity to the Himachal Himalaya. Heading further north, the Tethys Himalaya is a geological realm known for its granites, metapletic sediments and limestones. This northernmost stretch completes the geological panorama of the Himachal Himalaya, contributing its unique geological features to the overall landscape.

Himachal Pradesh's geology is fragile due to its location in an active tectonic zone. This is compounded by population growth and expanding urban areas, leading to increased construction. As per National Disaster Management Authority’s post disaster needs assessment (PDNA) report (2023), Himachal Pradesh is vulnerable to 25 out of 33 types of hazards identified by the High Powered Committee (HPC) of Government of India and classified into 5 subgroups including geologically related disasters such as landslides. Landslides in Himachal Pradesh occur due to a combination of factors, including the tectonically unstable terrain, monsoons and high-intensity earthquakes. The Himalayan region's steep slopes and geological instability further enhance the vulnerability to landslides. Unsustainable human activities like deforestation, road construction, terracing and changes in agricultural practices have increased the susceptibility of the region to landslides. Himachal Pradesh's hilly areas face ongoing threats from landslides, resulting in loss of life, property damage, soil erosion, and disruptions to infrastructure (Post Disaster Needs Assessment (PDNA) Report (2023):p.165).

3.1 GEOLOGICAL SET-UP OF KINNAUR DISTRICT

The geology of Kinnaur district in Himachal Pradesh reveals a diverse range of rock formations, offering insights into the region's complex geological history. These formations, with their varied mineral compositions and textures, describe the bedrock of the area and contribute to understand the geological evolution of Kinnaur area. One of the prominent lithologies in Kinnaur is the Black Shale with intermediate Quartzite. Dolerite, an igneous rock, signifying past volcanic activity, and granite (an intrusive igneous rock), stand out as a resilient and enduring geological feature. Cherty Argillaceous Dolomite, characterized by its unique composition, adds a distinctive touch to the geological diversity. Carbonaceous Slate and Phyllite, both metamorphic rocks, suggest episodes of intense heat and pressure in Kinnaur's geological past. Limestone, a sedimentary rock often formed in marine environments, adds another layer to the narrative, hinting at the region's connection to ancient seas. The presence of Migmatite, a rock that has experienced partial melting, provides a glimpse into the dynamic geological processes that have shaped Kinnaur area. Marble and White Massive Quartzite showcase the region's metamorphic transformations, with the former suggesting the recrystallization of limestone into marble. Carbonaceous shale, siltstone, and sandstone make up the geological layers, providing clues about the sedimentary sequences that have formed over time.

In brief, the diverse geology of Kinnaur district plays a crucial role in the occurrence of landslides. The sedimentary formations, such as carbonaceous shale and siltstone, are prone to weathering and erosion, making them unstable and susceptible to landslides. Similarly, the presence of metamorphic rocks, like schist and gneiss, can also contribute to landslides due to their fractured nature and variable strength properties. The geological history of Kinnaur district, shaped by these rock formations, has created a landscape that is prone to landslides, highlighting the intricate relationship between geology and natural hazards in the area.

4. LOCATION AND ACCESSIBILITY

The present preliminary study covers the six landslide sites within the administrative border of Kinnaur district in Himachal Pradesh. Kinnaur district also shares its international border with China also. Given the mountainous terrain, the district is well-connected with a network of village roads as well as NH-5.

Fig. 2 illustrates a detailed location map outlining six specific landslide/subsidence sites surveyed during the field visit in the Kinnaur district, Himachal Pradesh.

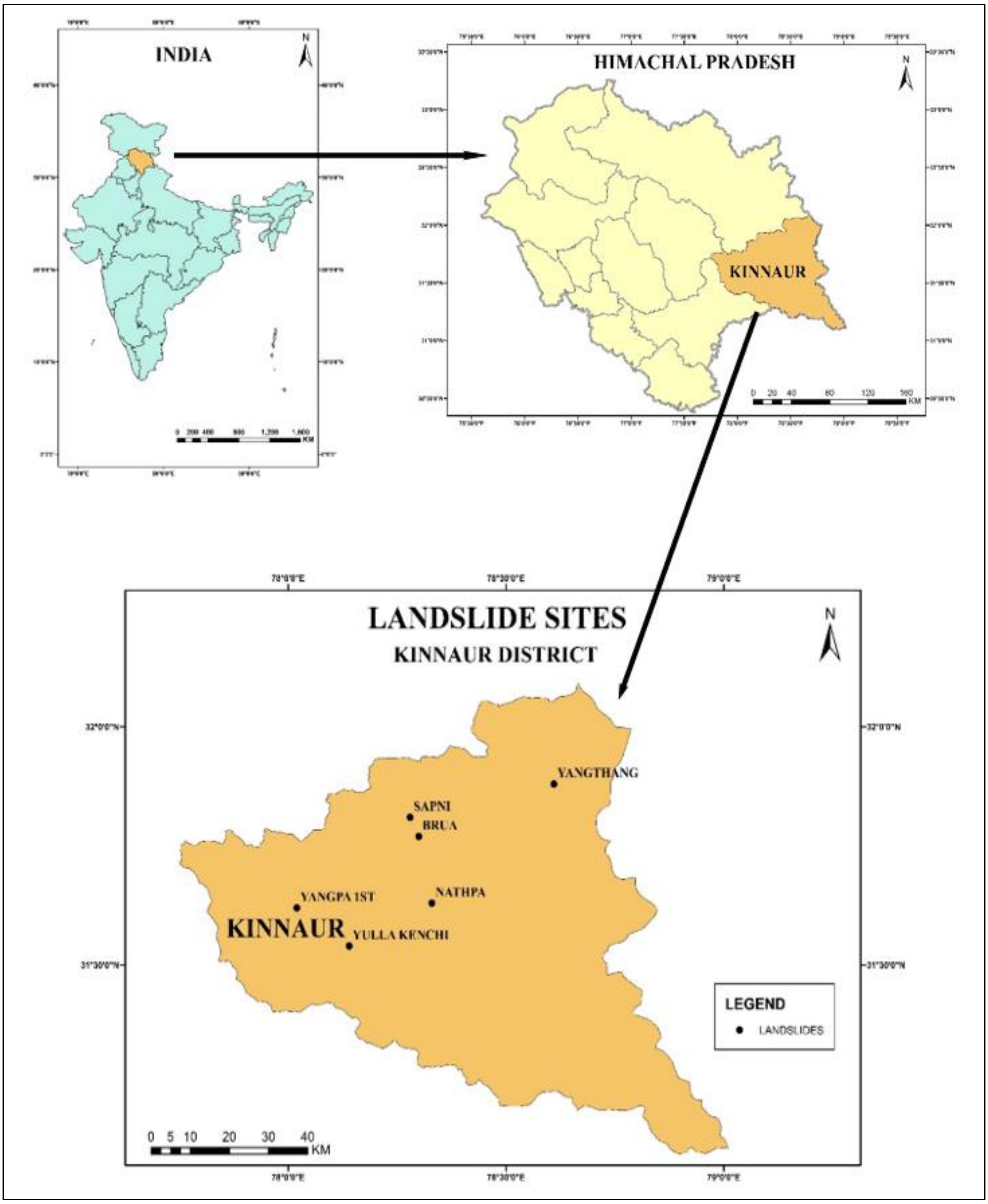


Fig. **2** Location map of landslide/subsidence sites located in the Kinnaur district, HP.

5. RAINFALL

The monthly rainfall data from the year (2019-23) for the Kinnaur district of Himachal Pradesh, has been graphically illustrated in charts **(Fig. 3)**, providing a detailed visual representation of precipitation patterns (source: IMD, Shimla, HP). The bar chart reveals a notable increase in rainfall for July 2023, with 192 mm recorded, significantly higher than in previous years. This spike in precipitation coincides with increased landslide activity in Kinnaur district, underscoring the link between heavy rainfall and slope instability. The data suggests that the intense rainfall may have been a key factor in triggering the landslides observed during the period.

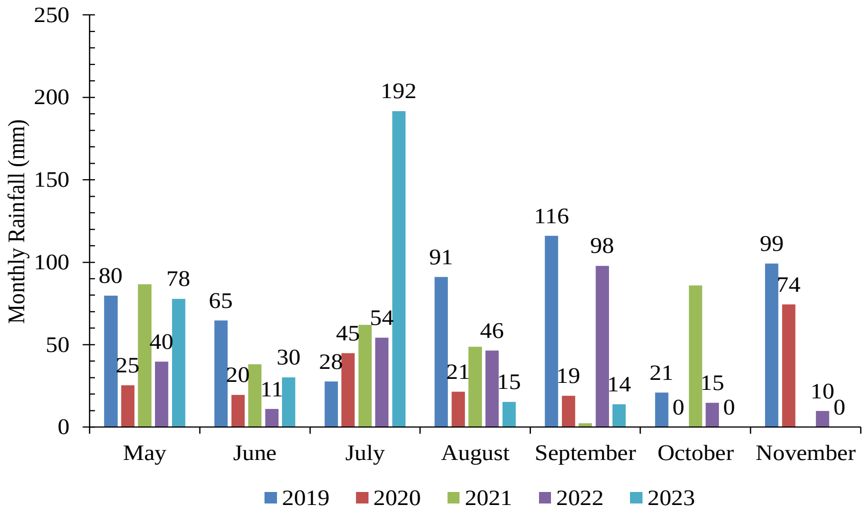


Fig. 3 Monthly rainfall data for the year (2019-23), district Kinnaur, HP
(Source: IMD, Shimla, HP)

6. RESULTS AND DISCUSSION

6.1 YANGTHANG LANDSLIDE

The Yangthang landslide is located in the Pooh sub-division, Kinnaur district of Himachal Pradesh along the NH-5 (Latitude: 31°53'31", Longitude: 78°37'9"). The region has been a persistent geological concern since its initiation in the year 2000. This region experiences subsidence during the summer months, aggravated by a notable freezing and thawing action due to the occurrence of approximately 1.5 to 2 feet of snowfall. The site, characterized by seepage and loose strata, is located around 1 km from the village of Maling Dogri, with a population of approx. 30 persons. The village faces annual road blockages due to the recurring landslide activity. Over the years, this geological phenomenon has taken a toll on local agriculture, with 1-2 hectares of agricultural land affected in 2005, including disruptions to apple orchards. Seepage, a perennial issue persisting for 12 months, is attributed to an unknown underground water source. The rocks display high seepage water outflow, occasionally frozen, and the increased water outflow during summer snowmelt enhances slope instability. Proximity to Nako Lake on the northern side of the landslip indicates a potential link between seepage and slope failure. This recurring landslide has significantly affected NH-05, leading to substantial subsidence on the highway. In response, the Border Roads Organization (BRO) has constructed a new 17 km long road through the upslope to circumvent road closure issues.

Geologically, Yangthang is a constituent of the Tethys Himalaya, characterized by Leucocratic granite from the Nako Granite Formation. The area exhibits Tourmaline-bearing granites and pegmatite veins near the failure slope, underlain by the Kioto Formation of the Lilang Group. The exposed rocks are extensively fractured and deformed, revealing four distinct sets of non-continuous planes. In general, slope face of Yangthang landslide is 52^{o} in N257^{o}. Top portion of the slope near the crown portion is very steep (80-90^{o}) while the rest of the slope is inclined at an angle of 52^{o}.The slope is steep varying between 52° to vertical, bedding plane is dipping into the slope. The strike of the bedding plane ($J_{\circ}$) is 193° dipping 103°/21°, and the strike of other joints are J_1 - 335° and J_2 -61° having dip data as (245°/65°) for J_1 and (331°/67°) for J_2. **Fig. 4** presents the contour map of the Yangthang landslide prepared at an interval of 1 m. It reveals a complex terrain with steep slopes, particularly near the crown with angles close to vertical, which transitions to a consistent incline of 52 degrees along the main body of the slide. The contours' delineation indicates a high degree of slope instability, with varying angles indicative of multiple potential failure planes. **Fig. 5** and **Fig. 6** portray the panoramic view and the field photograph of the site respectively. Loose debris material observed at the site in addition to surface water outflow poses a significant threat, endangering the houses situated in the vicinity **(Fig. 7, Fig. 8** and **Fig. 9)**.

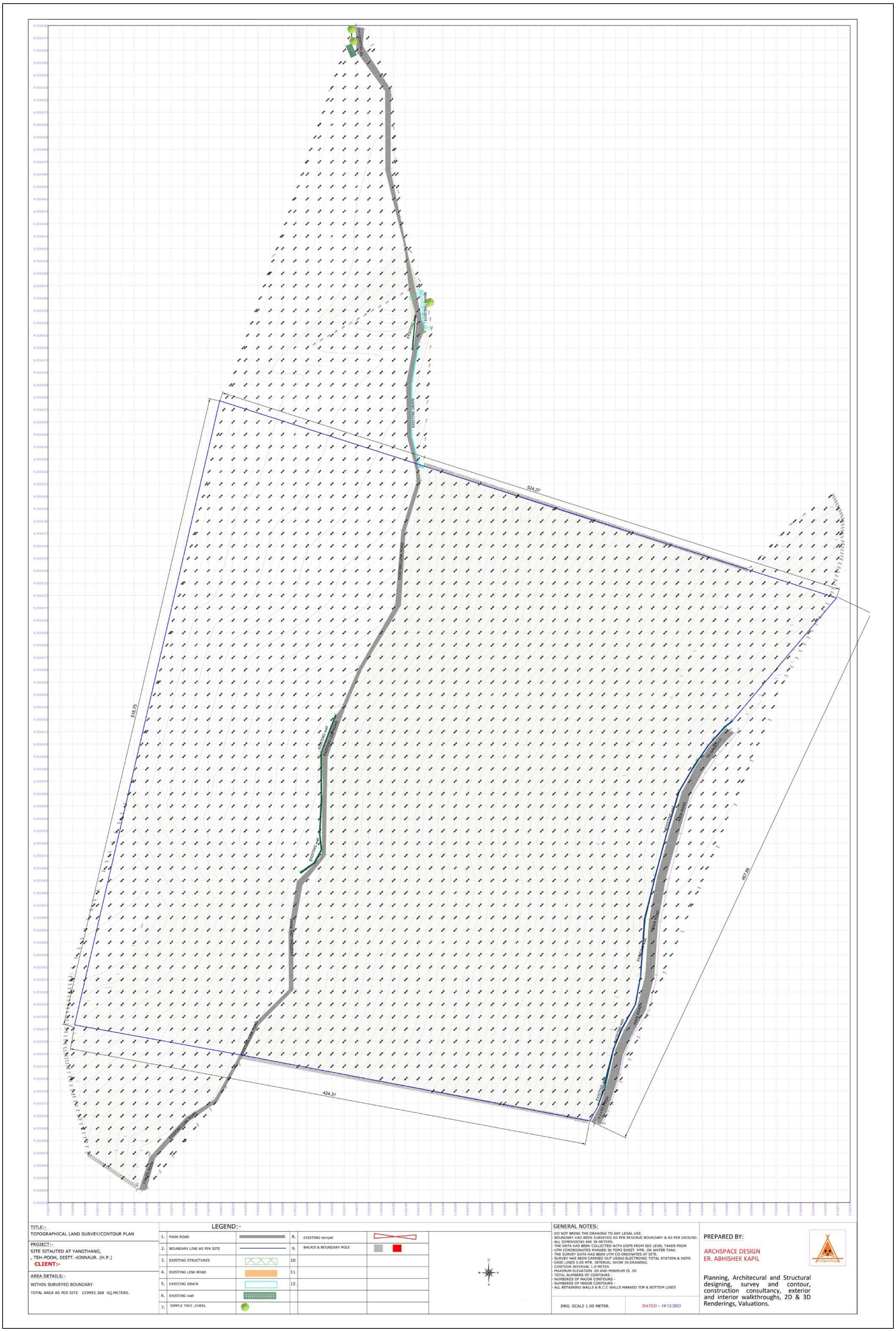


Fig. 4 Contour map of the Yangthang landslide. The map is prepared based on a geodetic UAV survey.

Fig. 5 A panoramic view of Yangthang site, Kinnaur district

Fig. 6 Field photograph of Yangthang landslide, Kinnaur District, HP

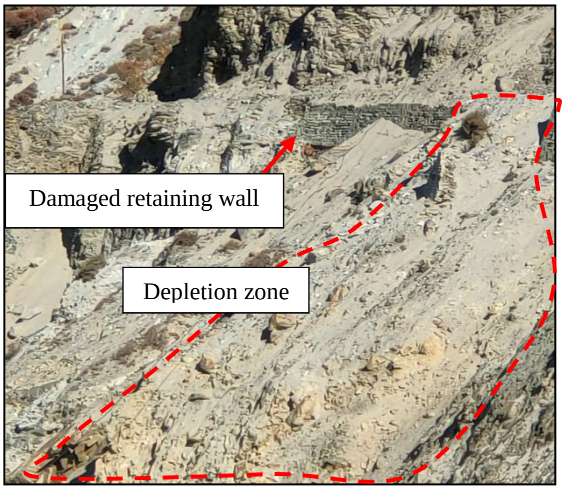


Fig. 7 Loose debris slide with rills

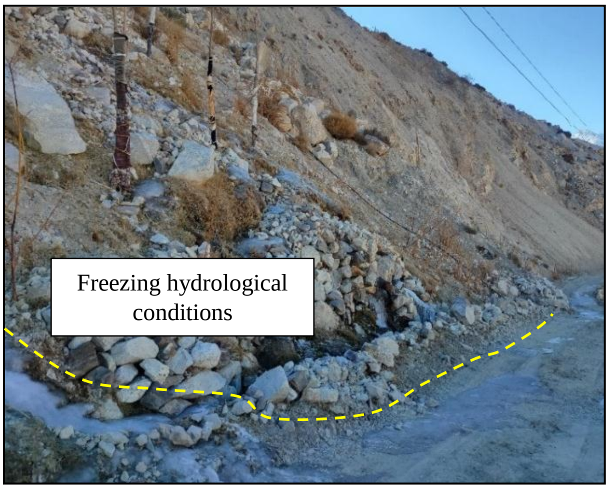


Fig. 8 Freezing of surface water outflow during the winters

Fig. 9 Landslide-prone houses at Yangthang site

Causative Factors

- The landslide's subsidence may be attributed to its highly deformed rock mass and active tectonic forces, which compromise structural integrity. This geological vulnerability is intensified by continuous water outflow and seepage dynamics, amplified by freeze-thaw cycles that reduce shear strength and promote soil and rock mass displacement.
- The slope's instability may have been significantly influenced by continuous seepage from an unidentified underground source and water outflow, with these effects further intensified by freeze-thaw cycles. Seasonal snowmelt might have enhanced these conditions by increasing water pressure in the soil and rock mass, thereby undermining the slope's stability.
- The destabilization of the area may have amplified by the anthropogenic alterations, notably through road construction activities that entail slope cutting for NH-5. This not only removes critical lateral support but also alters hydrogeological conditions, increasing slope instability by changing natural water drainage pattern and increasing susceptibility to erosion.

Short Term Mitigation Measures

- Identification of the source area responsible for dripping water along the distressed slope, particularly considering the unique freeze-thaw dynamics and the presence of underground water sources as observed during the field survey.
- To implement a strong drainage system, build lined drains that follow the contour of the slope. These drains should be designed to stop both surface and subsurface water from flowing down the slope. This involves making sure the drains can handle large amounts of water during summer snowmelt and can withstand freeze-thaw cycles. There is need to position the drains strategically to catch both surface and subsurface water, redirecting it from the slope.
- Construction of paved drains at road level in the slide zone, considering the high seepage and freeze-thaw conditions. The drains should be efficiently designed to handle significant runoff, aligning with the area's steep slopes and natural water flow patterns.

Long Term Mitigation Measures

- Construction of a Random Rubble Masonry (RRM) retaining below the road combined with a soil-nailed wall above the road. It is crucial to ensure that the foundation of RRM wall rests on the parent rock, rather than on unstable debris material, to ensure resilience against the region's active tectonic movements. While designing these structures, attention must also be paid to the steep slope gradients, potentially reaching vertical angles, and to aligning with the precise joint orientations ($J_{\circ}$, J_1, J_2) for optimal wall alignment and stability. The drainage aspect involves design of weep holes and integrating comprehensive French drain systems that can handle both surface water and subsurface flow, particularly critical given the noted seepage issues. Utilizing geotextile filters within the drainage system could also be beneficial to prevent clogging and maintain the efficiency of water evacuation.
- Above the road, a soil-nailed wall offers a versatile and less intrusive alternative. Proper drainage integration is equally important in the soil-nailed wall to handle the area's water flow challenges.
- The landslide region characterized by its Leucocratic granite and fractured rock formations, a focused bio-remedial strategy should be implemented. This involves targeted plantation program using local species such as Changma, Apple, Apricot, Safeda and Rubinya in consultation with the Forest Department. These species may well-suit the area's unique geology and climatic conditions, including the noted freeze-thaw cycles and the specific soil composition. The deep-rooting nature of these plants can help stabilize the soil, reduce surface runoff and enhance slope stability.
- Besides, considering the impact on local agriculture, particularly apple orchards, and the proximity to residential areas, this bio-remedial approach can also aid in restoring the ecological balance and supporting local livelihoods.

Note: Given the scale and recurring nature of the landslide and its impact on the local area, it is essential to prepare a detailed project report (DPR) to address the slope instability/ land subsidence in Yangthang.

6.2 BRUA LANDSLIDE

The Brua landslide site is situated in the Kalpa Sub-Division of Kinnaur District, Himachal Pradesh (Latitude 31º27’5” and Longitude 78º10’37”). The Brua village has a population of approximately 1200 persons. Field observations reveal the distinct characteristics of subsidence throughout the village. Notably, the Dulingnag Temple located within the slide-prone area has subsided by around 5m, as reported by villagers, with visible cracks on the temple's structure. The subsidence phenomenon, impacting the entire region was initially triggered after floods in the year 2000 and significantly intensified following flash floods in 2023.

Fig. 10 presents the contour map of the Brua landslide. The 1-meter interval contour mapping of the Brua landslide depicts a slope angled around 45 degrees, nearly mirroring the foliation plane, signaling substantial risk for landslides. The contours hint at zones of deformation and instability, where tension cracks and subsidence are prevalent, crucial for developing a digital elevation model (DEM) that will facilitate the analysis of slope stability and the formulation of corrective measures while preparing detailed project report. **Fig. 11** and **Fig. 12** show the panoramic view and the field photograph of the site respectively. The entire area, flanked by Brua Khad on one side and the village road connecting Brua, is experiencing significant sinking. The inclined trees, colloquially referred to as "drunken trees," indicate the sinking of the village. The consequences included a loss to apple orchards, damage to approximately nine houses (tilting and cracks), existing Gabion wall and concrete stair pathway and farmland affecting an estimated 5 hectares, accompanied by cracks in farmlands covering a similar area as shown in **Fig. 13** and **Fig. 14.**

The region, nestled in the geologically diverse terrain of the North-western Himalayas, is marked by a rich composition of rocks from the Jutogh Group. This geological formation comprises carbonaceous phyllite, schist with garnet and staurolite, amphibolite, quartzite and gneiss. However, the region is not just a canvas of geological wonders; it also grapples with the recurrent challenge of landslides. The intricate geology, combined with the topographical intricacies, gives rise to a complex interplay of factors contributing to the instability of the terrain.

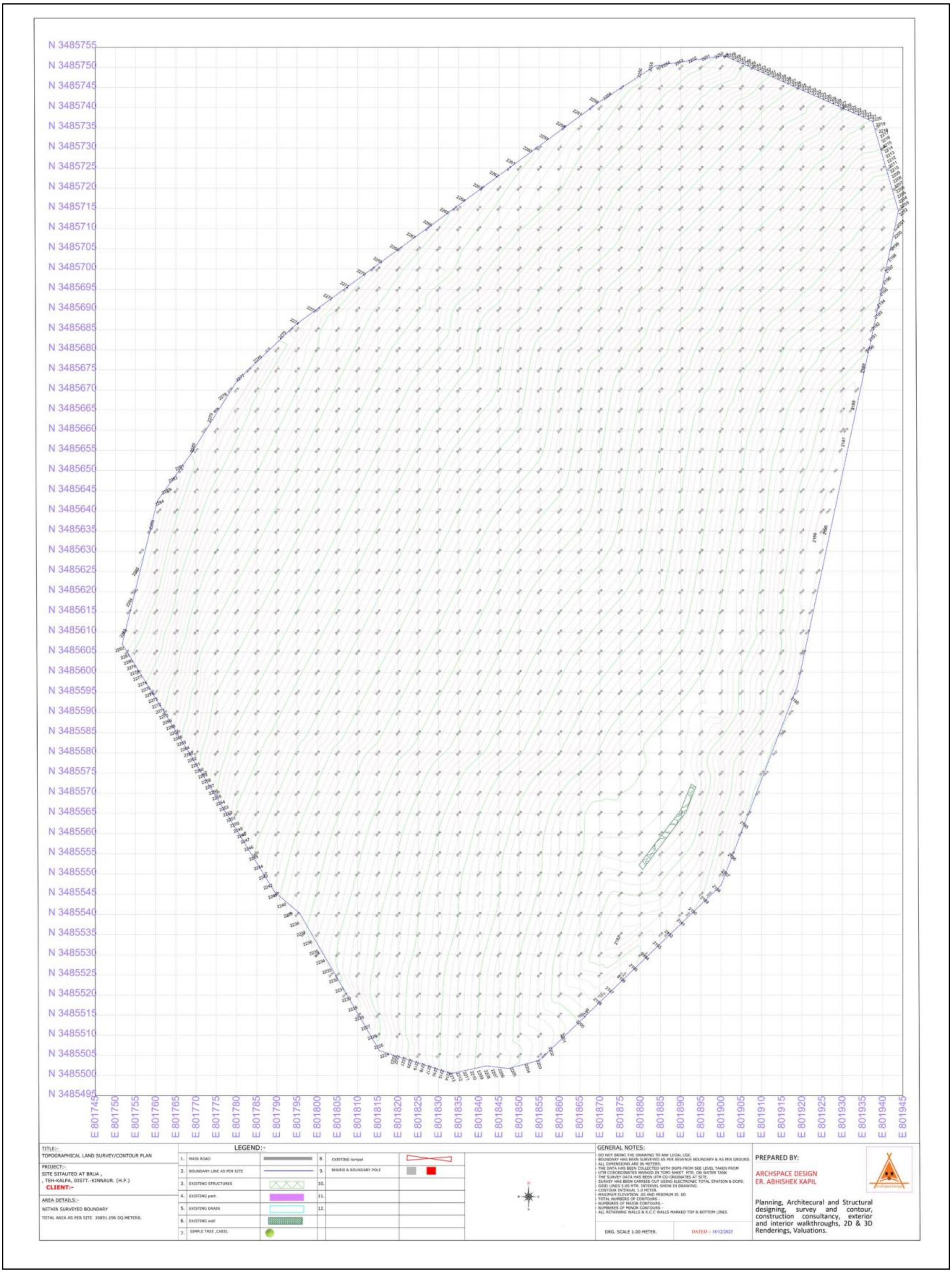


Fig. 10 Contour map of the Brua landslide. The map is prepared based on a geodetic UAV survey.

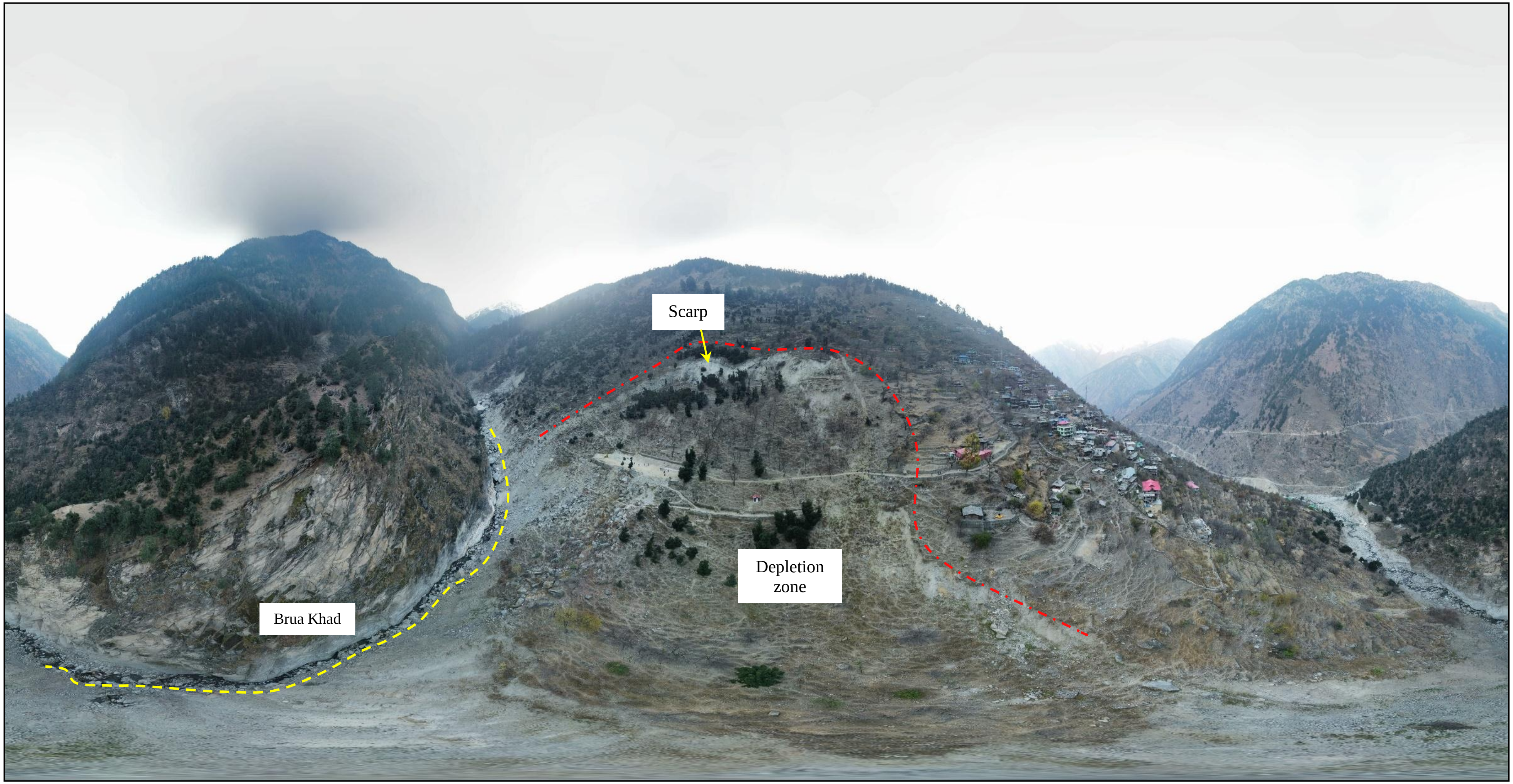


Fig. 11 A Panoramic view of Brua landslide site at Kinnaur, HP

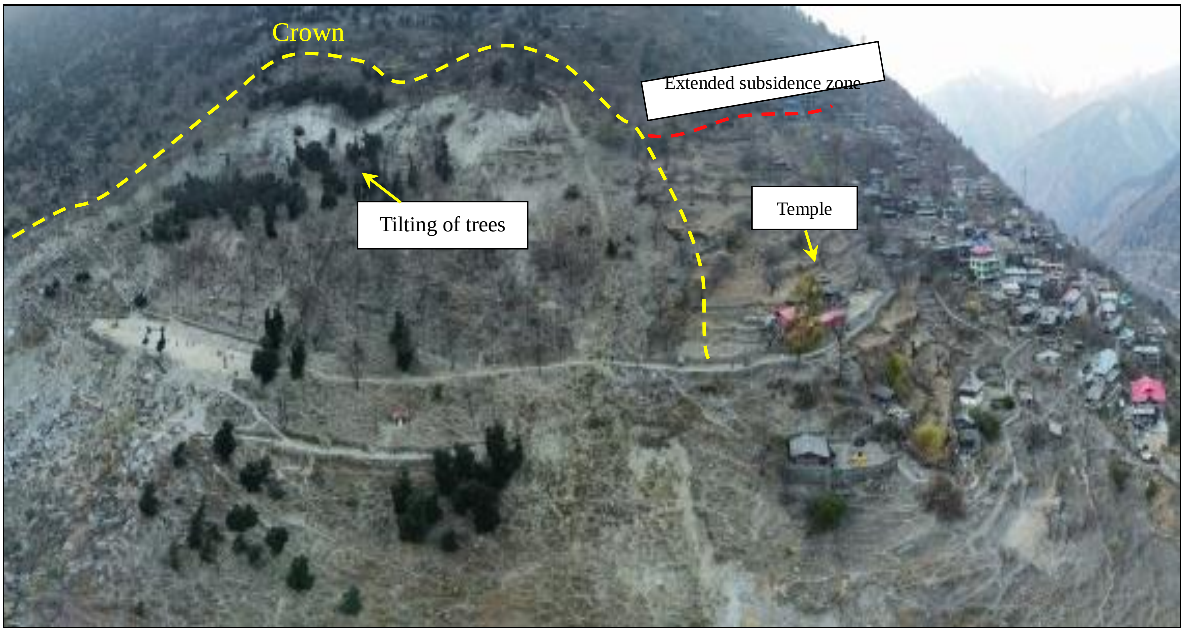


Fig. 12 Field photograph of the Brua landslide using UAV survey.

In the middle of the landslide-prone area, a thick layer of soil and debris hides the fascinating geology below. Nearby schists provide insight into the region's geological diversity. There are three noticeable sets of discontinuities, creating a complex network of potential failure points. The inclination of the slope at 45^0 in the 100 - degree north direction creates a precarious alignment with the foliation plane, which dips 40^0 in the 093-degree north direction. This near-parallel orientation between the slope and the geological features amplifies the instability. Adding another layer to the geological complexity are the Jutogh thrust to the north and northeast and the Kullu thrust traversing the Baspa valley to the south.

These tectonic elements further enhance the susceptibility of the region to landslides, creating a geological milieu that demands careful scrutiny. The planar mode of failure is identified as the predominant mechanism in the Brua landslide occurrence based on the stereo plot as shown in **Fig. 15.** Amidst this geological intricacy, tangible signs of instability manifest on the landscape. Multiple wide tension cracks, stretching from 7 to 10 meters in length, with widths varying between 8 to 10 centimeters, and depths ranging from 10 to 15 centimeters, scar the crown and mid-slope areas. The visible signs of instability are accentuated by the sight of tilted trees on the downslope side, providing a visual narrative of the shallow nature of the landslides. These features, coupled with the observable shallow depth of the soil and debris, point towards a delicate equilibrium disrupted by the forces of nature.

The combined effect of the shallow soil and debris layer, along with the parallel orientation of the slope to the foliation plane, creates a precarious setting. As precipitation infiltrates through fractures, debris and tension cracks, the friction on the debris-rock interface diminishes, ultimately leading to failure. Both geological factors and environmental influences, particularly heavy rainfall, emerge as primary contributors to the ongoing instability. During the field visit, soil samples were carefully gathered from the crown of the slide. The collected samples were tested at the laboratory level in accordance with IS2720 standards to assess the engineering properties of the soil and estimate key geotechnical parameters. In **Table 1**, serial 1 provides a comprehensive list of various soil parameters.

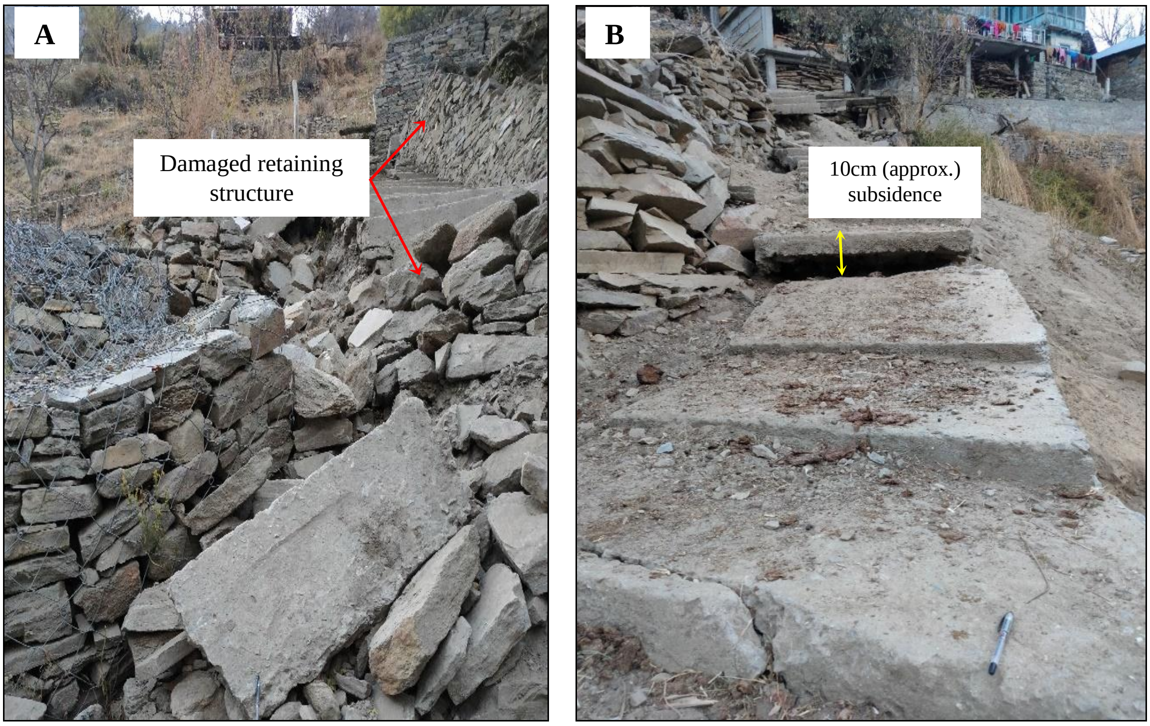


Fig. 13 Landslide induced damages to the existing Gabion wall (A) and a concrete stair pathway (B)

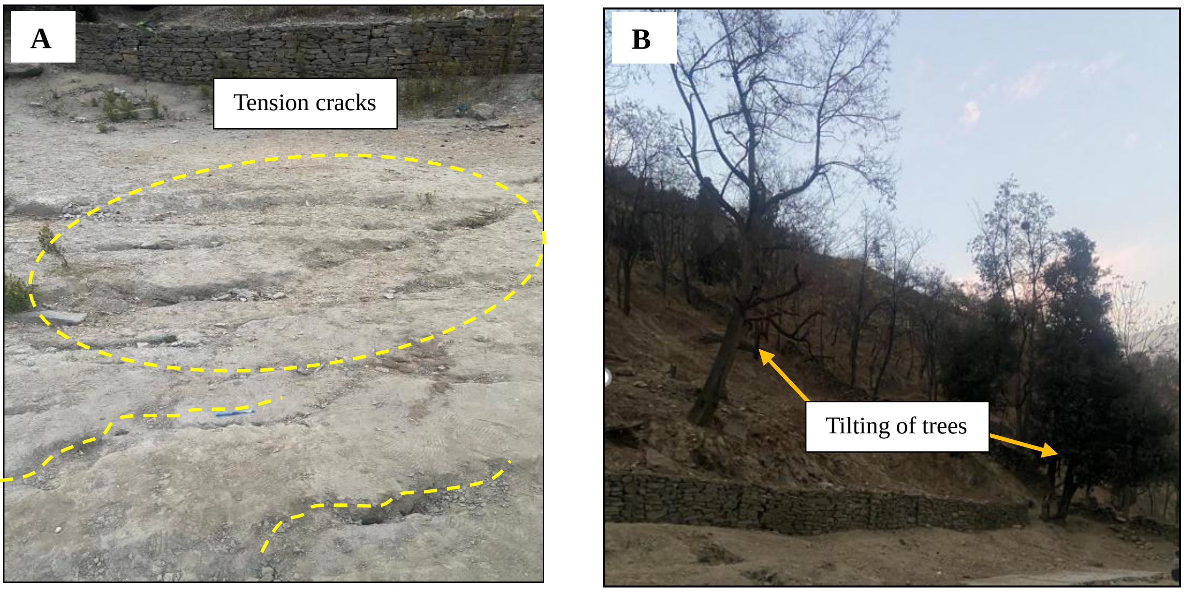


Fig. 14 Prominent Tension cracks on the ground due to subsidence (A) and tilting of trees highlighting drunken tree phenomenon (B)

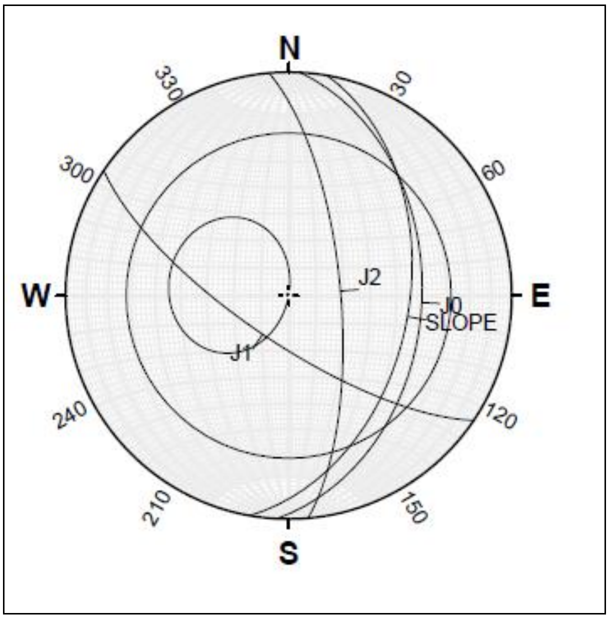


Fig. 15 Stereoplot showing the planar failure along the foliation plane (J0) at the Brua landslide location

Causative Factors

- The rocks of the Jutogh Group, such as carbonaceous phyllite, schist, amphibolite, quartzite, and gneiss, naturally make the slope unstable. Their different physical and chemical properties lead to uneven weathering and erosion, affecting how the slope changes over time.

- Phyllite and schist, which are highly fractured and cleave easily, can turn into slush when saturated by rainfall. This saturation weakens the rock, playing a key role in starting landslides and subsidence.

- The slope is aligned at a 45^0 angle facing north (100 degrees), which is nearly parallel to the foliation plane dipping at 40^0 facing north (093 degrees). This alignment creates weak zones that are prone to failure, increasing the risk of landslides.

- The heavy rainfall in July 2023, which caused flash flood, could have been a major factor in the recent landslide and subsidence. This may have been worsened by erosion at the base of the slope along Brua Khad, especially since the foliation plane is inclined parallel to the slope face, possibly making the slope less stable.

Short Term Mitigation Measures

- Gabion wall construction in areas highlighted by specific slope gradients and rock fracture patterns. The wall foundation needs to be constructed on stable bedrock, notably in regions characterized by phyllite and schist, to align with the site's unique geological features. Utilizing stones locally sourced from the Jutogh Group for filling the gabion walls could enhance both compatibility with the local geology and the overall effectiveness of the walls. Integrating well-designed drainage systems, especially in areas known for high seepage, might play a crucial role in managing water flow and thereby assist in mitigating further destabilization of the slope.

- Construction of concrete toe walls along Brua Khad and in erosion-prone areas of the Brua landslide site. These walls should be designed with sound foundations, tailored to offer resilience against flash floods and subsidence, factors prevalent in this region. The incorporation of effective drainage systems within the village is crucial, aiming to manage water flow and reduce the impact of hydrological forces on slope stability.

Long Term Mitigation Measures

- Bioengineering measures could specifically entail the cultivation of indigenous plant species like apple and khumani (apricot), chosen for their robust soil-binding root systems. These species are particularly suitable given their adaptability to the

North-western Himalayan climate and soil conditions prevalent in the Brua area. Implementing such vegetation strategies would be crucial in areas identified with high soil erosion and landslide susceptibility, as per the field survey data.

- Considering the sustained vulnerability, a more radical proposition emerges-the relocation of the village. With the declaration of the current village as unsafe, the option of moving the community to a safer location becomes a plausible strategy for long-term risk reduction.

Note: Given the magnitude and recurring nature of the village subsidence and its socio-economic impact on the inhabitants, it is essential to prepare a detailed project report (DPR) to address the slope instability/ land subsidence of Brua village.

6.3 YULLA KENCHI LANDSLIDE

The Yulla Kenchi landslide site is located in the Nichar, Bhabanagar subdivision of District Kinnaur, Himachal Pradesh (Latitude: 31°32'54", Longitude: 78°8'21"). The slide has affected around 15-20 homes and resulted in farm subsidence. The landslide, situated 12 km from NH-5 (Chuling), has been fueled by the geological composition of the area, characterized by Gneiss (Mica) rocks with inward bedding and a steep slope. **Fig. 16** presents the contour map of the Yulla Kenchi landslide. The 1-meter interval contour map for the Yulla Kenchi landslide exhibits steep gradients and dissected topography, indicative of the susceptible Mica Gneiss geological structure. **Fig. 17** and **Fig. 18** illustrate the panoramic and the field photograph of the site respectively. **Fig. 19** shows the hard debris material and disintegrated/highly weathered rock outcrops at the Yulla Kenchi landslide. The debris material, ranging from sand to boulders, comprised unsorted material, creating tension cracks at the crown. The hill, highly dissected and prone to toe erosion from river-cutting action, presented layers of quartzite near the crown. The aftermath involved a loss of 2-3 hectares of apple orchards, and the debris deposition measured approximately 2.5-3.5 feet.

The Yulla Kenchi landslide area is geologically situated within the Jaunsar-Western Gneiss Complex (J-WGC), which forms an integral part of the Lesser Himalayan Crystalline sequence. This region is geographically demarcated by significant geological structures i.e. to the south, it is bounded by the Munsiyari Thrust (MT) or the Main Central Thrust-I (MCT-I) near Jhakri, and to the north, by the Kullu Thrust (KT) near Karcham.

Predominantly, the J-WGC is characterized by a diverse assemblage of gneisses and schists. Specifically, the rock formations exposed at the site are predominantly augen gneiss, noted for their distinctive eye-shaped felsic mineral crystals. The analysis of the outcropped rock mass reveals it to be fractured and weathered, with three primary sets of discontinuities identified as J_0, J_1, and J_2. Of these, the J_2 discontinuity is nearly parallel to the slope's gradient, thereby posing a significant risk of failure. Besides, the Raura Gad fault runs parallel to the Raura Gad river, with the observed landslide occurring on its left bank, situated on the lower middle slope. This positioning further accentuates the landslide susceptibility of the area.

Causative Factors

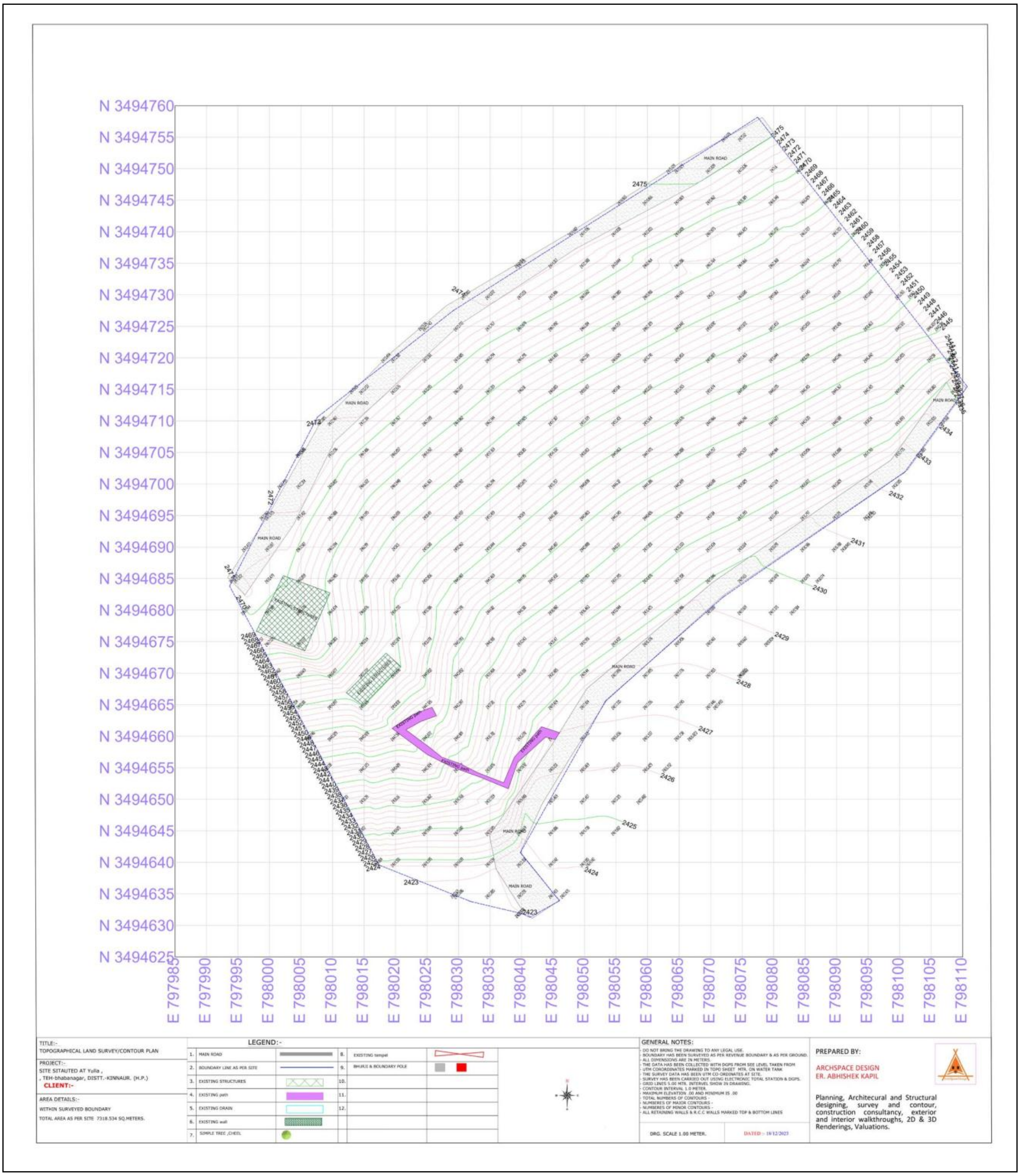
- The heavy rainfall in July 2023 increased the water pressure on the slope, which likely led to the landslide happening.
- The area has highly fractured and weathered Augen Gneiss. The fractures, especially J0, J1, and J2, greatly affect stability, with J2 running parallel to the slope. The site is also at risk due to its proximity to the Raura Gad fault, Munsiyari Thrust (MT or MCT-I), and Kullu Thrust (KT), which introduce structural vulnerabilities from tectonic forces.
- Road construction in the Yulla Kenchi region ignores important geotechnical assessments, such as slope stability and drainage. Instead, non-engineered methods are used without considering the risk of landslides or the geological properties of the area (like the type of rocks and their fractures). This increases the risk of landslides, which can be dangerous for the region's stability and safety.

Short Term Mitigation Measures

- Utilizing contour maps for the identification of existing natural drainage pathways in the slide zone, followed by the *design of a robust drainage system* is immediate solution. The deign needs to consider the unique topographical features and steep inclines of the Yulla Kenchi landslide region. The design should include reinforced lined channels and incorporate subsurface drainage techniques to effectively address the specific hydrological challenges of the area, such as its fractured and weathered Gneiss rock structure and vulnerability to erosion caused by the intense rainfall.

Long Term Mitigation Measures

- Construction of gabion wall in a stepwise manner below the village road passing through the Yulla Kenchi landslide site. This engineering solution will strengthen the road, protecting it from landslides and erosion. This is especially important because the site has fractured Gneiss rock and is prone to high rainfall. The gabion walls will provide essential support to the road infrastructure, ensuring the safety and accessibility of the road for the local community, while harmonizing with the area's step farming landscape.
- A soil-nailed wall above the road offers a flexible and less intrusive alternative. This method involves installing soil nails at strategic angles into the slope, reinforcing the soil mass and increasing overall slope stability. Besides, the incorporation of wire mesh over the soil-nailed surface acts as a secondary reinforcement layer, further mitigating erosion and promoting vegetative growth for long-term stabilization. The flexibility of soil nailing allows it to adapt to the complex terrain and varied slope angles, providing effective stabilization where traditional retaining methods might falter.
- Bioengineering measures with local plant species in consultation with the forest department are other measures. This approach involves using vegetation, particularly species native to the area, to reinforce soil stability and reduce erosion. Selecting plants based on site-specific conditions and expert guidance from the Forest Department ensures compatibility with the local ecosystem and enhances the effectiveness of these measures. This strategy not only contributes to slope stabilization but may also supports biodiversity and ecological balance in the region.



- DO NOT BRING THE DRAWING TO ANY LEGAL USE.
- BOUNDARY HAS BEEN SURVEYED AS PER REVENUE BOUNDARY & AS PER GROUND.
- ALL DIMENSIONS ARE IN METERS.
- THE DATA HAS BEEN COLLECTED WITH DGPS FROM SEE LEVEL TAKEN FROM
- UTM CORORDINATES MARKED IN TOPO SHEET MTR. ON WATER TANK
- THE SURVEY DATA HAS BEEN UTM CO-ORDINATES AT SITE.
- SURVEY HAS BEEN CARRIED OUT USING ELECTRONIC TOTAL STATION & DGPS.
- GRID LINES 5.00 MTR. INTERVEL SHOW IN DRAWING.
- CONTOUR INTERVAL 1.0 METER.
- MAXIMUM ELEVATION .00 AND MINIMUM IS .00
- TOTAL NUMBERS OF CONTOURS -
- NUMBERES OF MAJOR CONTOURS -
- NUMBERES OF MINOR CONTOURS -
- ALL RETAINING WALLS & R.C.C WALLS MARKED TOP & BOTTOM LINES

Planning, Architecural and Structural designing, survey and contour, construction consultancy, exterior and interior walkthroughs, 2D & 3D Renderings, Valuations.

Fig. 16 Contour map of the Yulla Kenchi landslide. The map is prepared based on a geodetic UAV survey

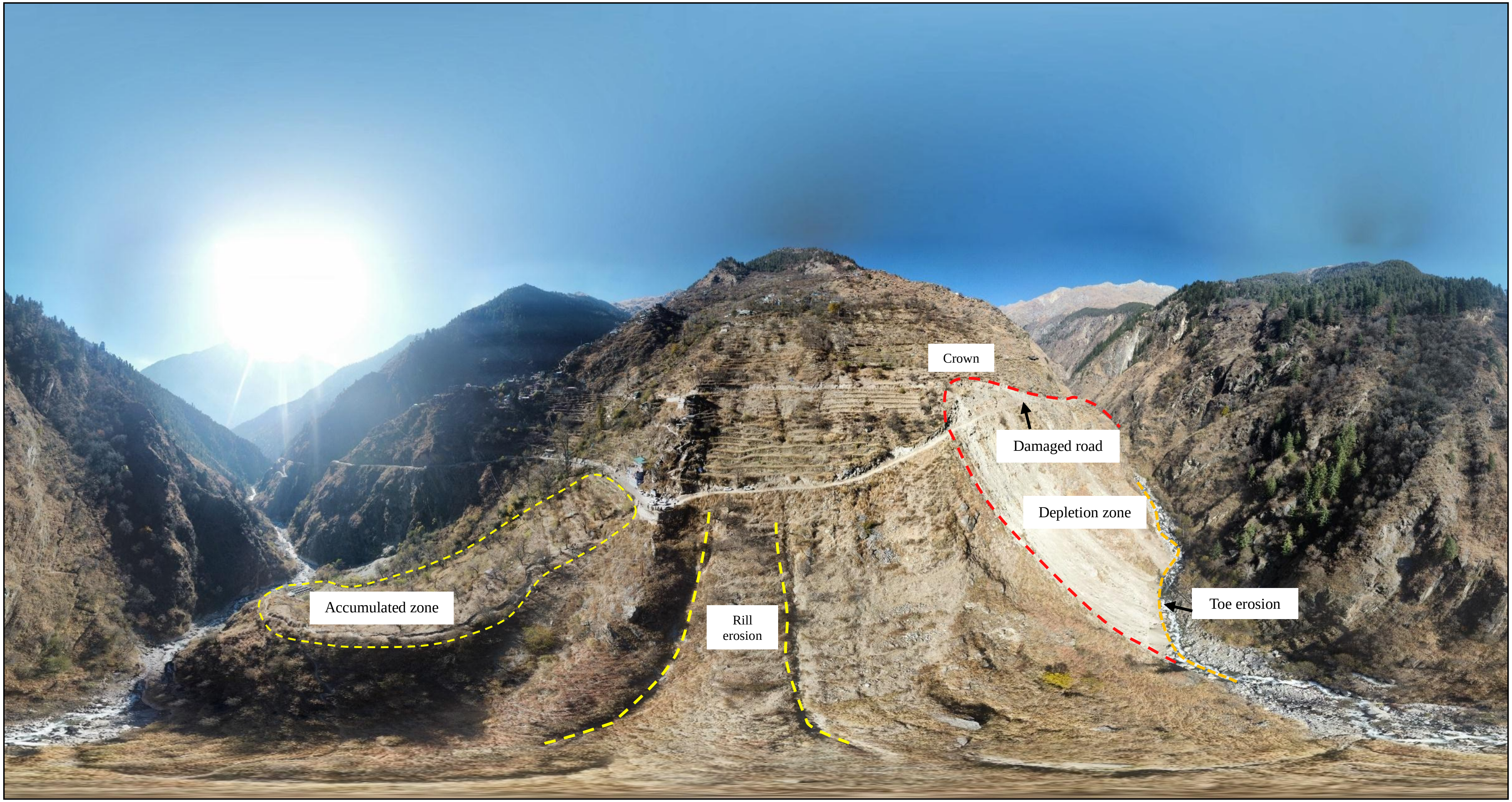


Fig. 17 A panoramic view of Yulla Kenchi landslide site at Kinnaur, HP

Fig. 18 Field photograph of the Yulla Kenchi landslide using UAV, Kinnaur District, HP

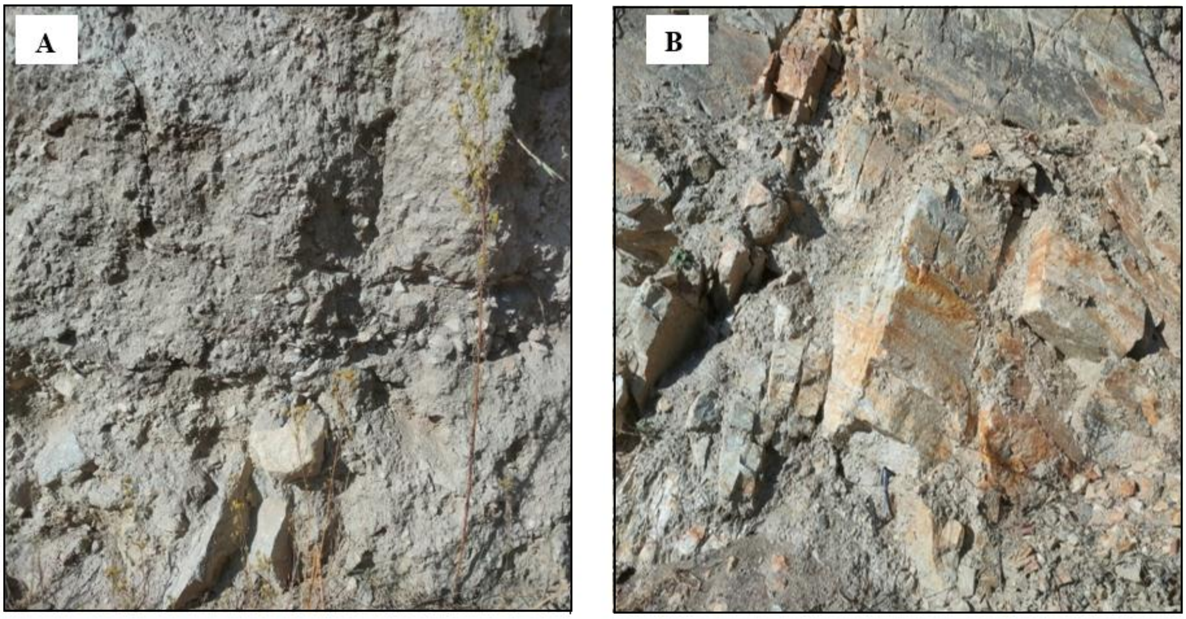


Fig. 19 Hard debris material (A) and disintegrated/highly weathered rock outcrops (B) at the Yulla Kenchi landslide

6.4 SHILANI LANDSLIDE, NATHPA

The incident site is located in Majdhar village, Panchayat Chaura, Nichar tehsil, Bhabanagar, Kinnaur district, Himachal Pradesh. **Fig. 20** presents the contour map of the Shilani landslide prepared at 1 m interval. The contour map provides a detailed representation of the terrain with closely spaced lines indicating steep slopes prone to landslides. **Fig. 21** and **Fig. 22** illustrate the panoramic view and the field photograph of the site respectively. The landslide has occurred during persistent rainfall in July 2023, causing an increase in pore water pressure and soil saturation, leading to debris flow. During the field survey, it is observed that the debris flow might have destabilized the big rock blocks (approx. size: 3 m*3 m*3 m) overlying the slope and, consequently caused damage to houses and apple orchards cultivated on the slope. **Fig. 23** shows the large size rock blocks and wreckage of the collapsed house due to the landslide. During the field survey, water seepage was noticed at the toe of the slope, and the upper side of the slope is found to be damp to wet.

Geologically, the area is formed by rocks of J-WGC, constituting part of the Lesser Himalayan Crystalline, bounded by Munsiari thrust (MT) or Main Central Thrust- I (MCT-I) in the south at Jhakri and Kullu thrust (KT) in the North at Karcham. J-WGC primarily comprises a variety of gneisses and schists. Rocks are not exposed on the site as the slope is formed by thick unconsolidated debris and large rock blocks of gneisses, likely originating from upslope due to past rockfall/slide events and settling there. Gully formation due to runoff (debris flow) is also observable. Tension cracks are visible on the crown portion, ranging from 1m to 5m in length, with apertures/openings nearly 19 cm wide, indicating a potential landslide trigger in the near future. **Fig. 24** depicts the footpath damaged due to subsidence impact. During field visit, soil samples were carefully collected from the crown of the slide to evaluate soil engineering properties and estimate key geotechnical parameters. Table 1, serial 3, provides a comprehensive list of various soil parameters.

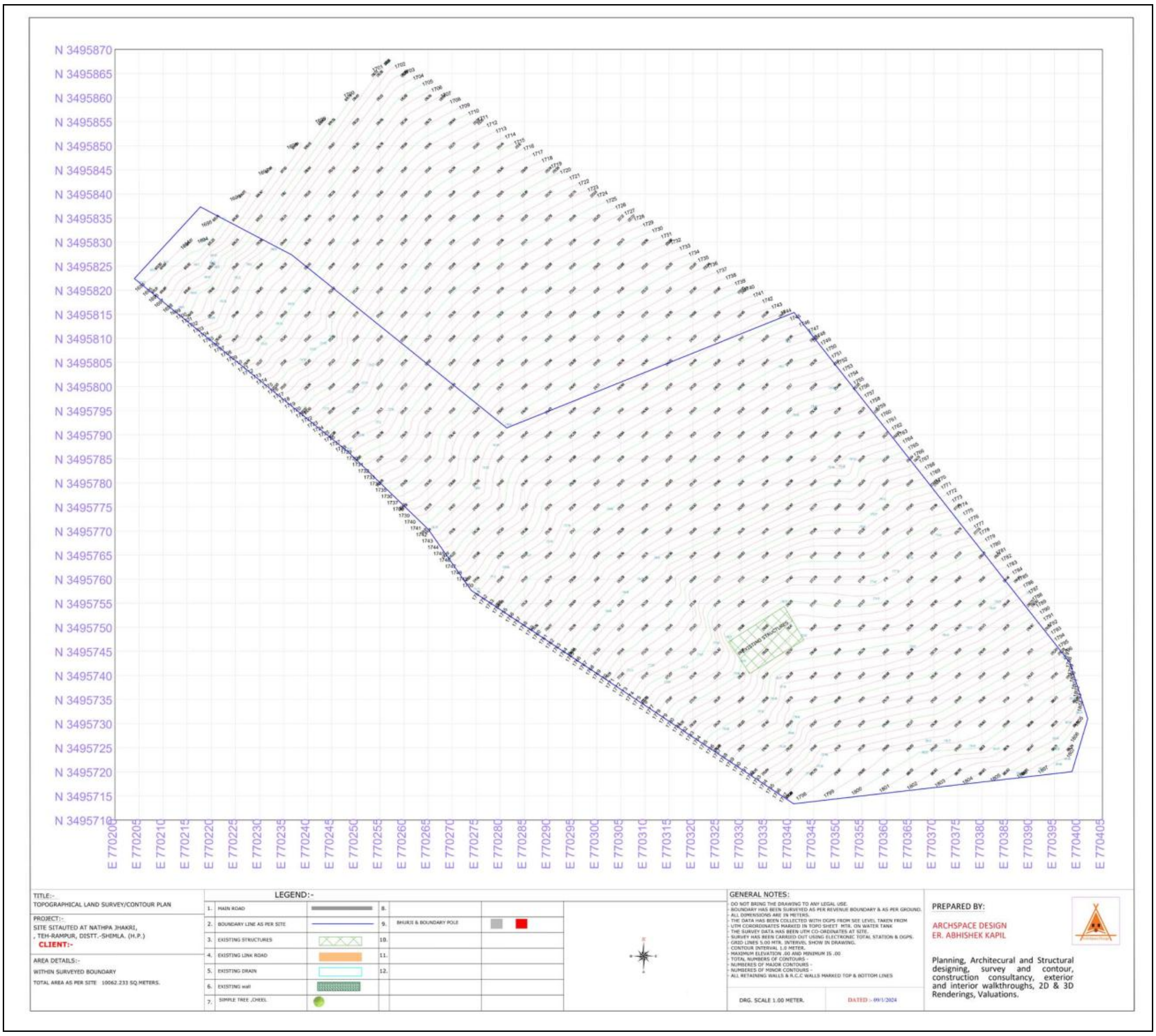


Fig. 20 Contour map of the Shilani landslide, Nathpa, Kinnaur, HP. The map is prepared based on a geodetic UAV survey

Fig. 21 A panoramic view of Shilani landslide, Nathpa, Kinnaur district, HP

Fig. 22 Field photograph of the Shilani landslide site, Nathpa

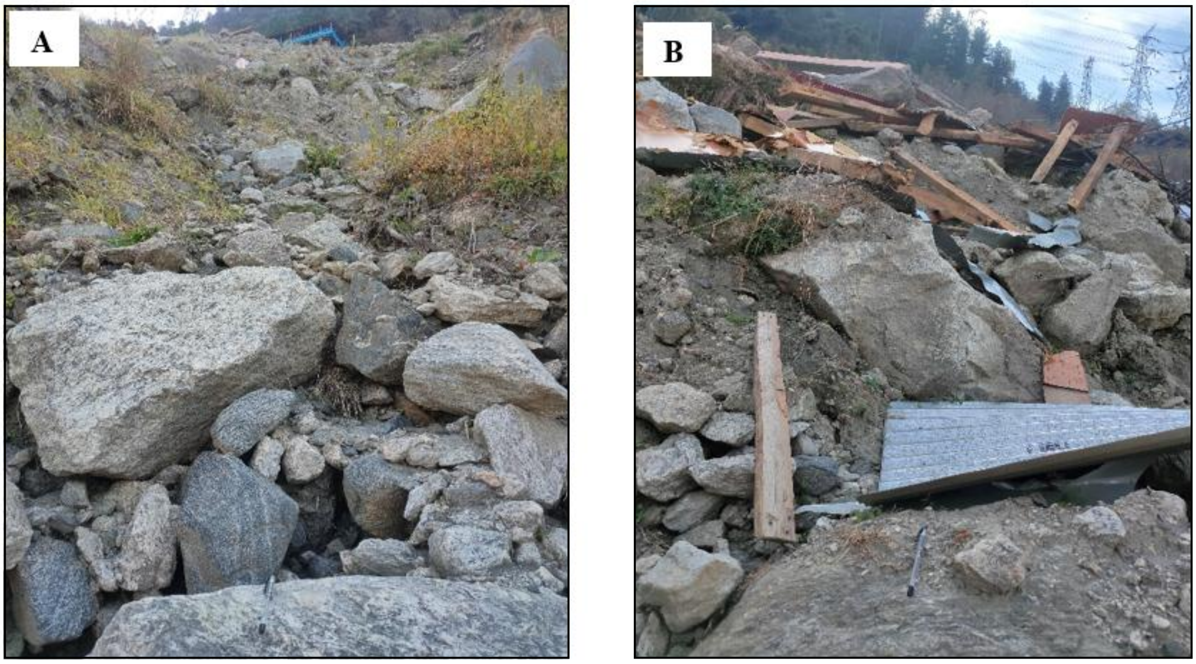


Fig. 23 Large size rock block (A) and a landslide affected household (B)

Fig. 24 Footpath damaged due to land subsidence

Causative Factors

- The saturation of slope-forming materials, triggered by continuous rainfall throughout July 2023, emerges as a key causative factor. This process, influenced by complex hydrological dynamics, is further intensified by the accumulation of pore water pressure within the slope materials. Such conditions, marked by persistently damp and seeping hydrology alongside increased water saturation from surface runoff amid incessant rainfall, might have significantly contributed to the destabilization of the slope.
- Situated within the Lesser Himalayan Crystalline complex, proximate to significant geological structures like the Munsiari Thrust (MCT-I) and Kullu Thrust, the site's geological setting is inherently vulnerable to landslides. The lithology, predominantly composed of gneisses and schists, is particularly prone to slope instability due to the highly fractured nature of schists. The interaction of these schists with water, leading to slush formation, significantly exacerbates slope instability. The schist's reactivity with water, resulting in slush formation, may have led to a critical geological vulnerability and consequently in the occurrence of the landslide.
- The absence of engineered drainage, coupled with the site's natural geological drainage patterns, led to increased water accumulation and infiltration.

Short Term Mitigation Measures

- Identification of the source zone at the slope crest responsible for water ingress and designing a Slope Terrain Management (STM) strategy, including lined drainage systems and step terraces, to efficiently divert water and reduce hydrostatic pressure.
- Further, there is need to construct engineered, contour-aligned drainage channel above the slope's crest, properly sized and lined, to prevent surface water infiltration, thereby minimizing slope saturation and erosion risks.

Long Term Mitigation Measures

- Installation of rock catch fences to arrest the fall of large rock blocks and debris material. The wire mesh specifications, including density and thickness can be calculated based on kinematic analysis for the site.
- Construction of a gabion wall in a step-wise manner, ensuring the foundation is securely placed on intact rock rather than debris or loose material. Use high-tensile, corrosion-resistant wire mesh filled with local material (gneiss and schist).
- Bioengineering measures for natural slope stabilization in consultation with the Forest Department to plant locally adapted tree species like silver oak (Baan) and walnuts. These tree species, chosen for their robust root systems, may enhance soil cohesion and reduce erosion, contributing to the long-term stability of the slope.

6.5 YANGPA-I LANDSLIDE

The incident site is situated within Nichar tehsil, Sub-division Bhabanagar, Kinnaur District, Himachal Pradesh, pinpointed at Latitude: 31°37'23" and Longitude: 78°1'20", located on the left bank of Bhabha *Khad*. The road traversing the landslide zone links Yangpa-I, Yangpa-II and Karaba villages. **Fig. 25** represents the contour map of the Yangya-I landslide. The contour map with 1-meter interval details a steeply inclined terrain at approximately 43°, with closely spaced contours indicating a sharp elevation change. The orientation of the slope is towards the north at 250º. The terrain's steepness and contour pattern are indicative of potential instability and area susceptible to landslide. **Fig. 26** and **Fig. 27** outline the panoramic view and the field photograph of the site respectively. This landslide resulted in a disruption of communication to these three villages for a considerable span of around 3 months. **Fig. 28** and **Fig. 29** show the existing retaining structure at risk and the debris runout and disintegrated rock mass due to the landslide occurrence respectively.

Geologically, the region is characterized by the Jutogh- Wangtu Geological Complex (J-WGC), typified by an assortment of gneisses, schists, and granitic rocks. Gneisses and granitic gneisses predominate particularly in the vicinity of Wangtu. The rock composition within the landslide area predominantly comprises of gneisses. Upon slope assessment, four sets of discontinuous planes (J_0, J_1, J_2, J_3) have been identified, with J_1 and J_2 demonstrating near-parallel alignment to the slope's inclination, rendering them particularly susceptible to instability. The slope angle is about 43° and the slope face is 250º N, joint spacing is 5cm – 8cm. The structural data of the joints J_0 is (26º/38º), J_1 (233º/75) and J_2 (262º/49º). J_2 is the most susceptible joint for slope failure. The rocks present at the site exhibit extensive fracturing, weathering, and disintegration, increasing the vulnerability of the slope.

The initiation of this landslide dates back to 2002. The presence of two pan stocks/small tunnels (one operational and one defunct) further complicates the situation. The construction activities involving underground structures, particularly through blasting, might have widened existing fractures. Subsequently, during heavy rainfall, water infiltration through these fissures intensifies slope instability. Coupled with the discontinuous surface nearly parallel to the slope, the situation becomes increasingly precarious, potentially culminating in slope failure. The landslide type observed is translational, involving both rock and debris material. Notably, the slope remains predominantly dry. It's noteworthy that a PWD steel bridge also exists within the landslide-affected area, warranting careful consideration for infrastructure integrity and safety measures. The survey results indicate that slopes with an inclination of 49º or greater are susceptible to planar failure, as determined by the Markland's Test criteria. Therefore, for engineering activities such as road widening, slope excavation for road construction, or the erection of any other engineering structures, it is imperative to maintain the slope inclination below 49º to mitigate the risk of planar failure. During the field visit, soil samples were also carefully gathered from the crown of the slide slope to assess the engineering properties of the soil and estimate key geotechnical parameters. In **Table 1**, serial 4 presents a comprehensive list of various soil parameters of the landslide site.

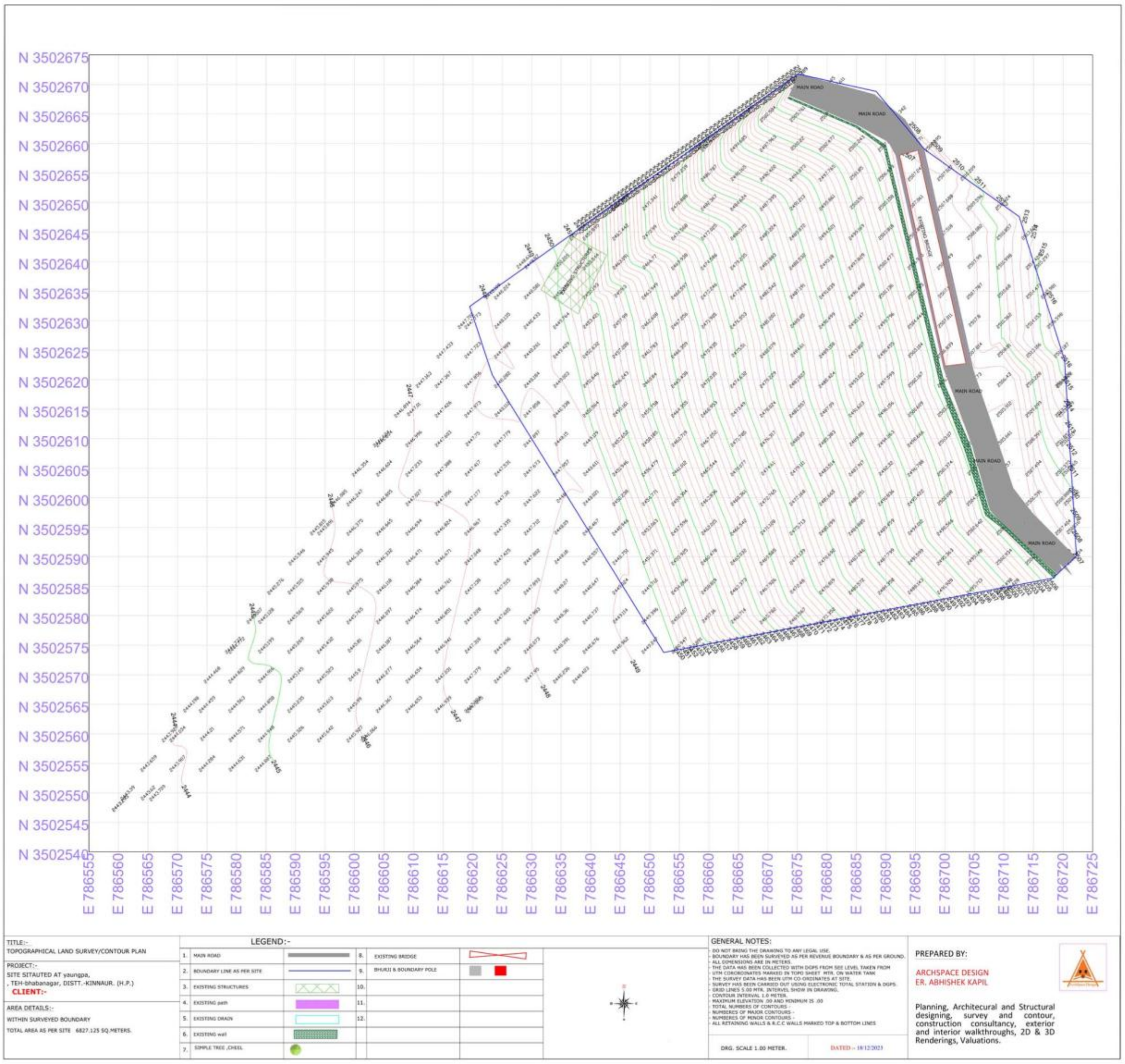


Fig. 25 Contour map of the Yangpa -1st landslide, Kinnaur, HP. The map is prepared based on geodetic UAV survey.

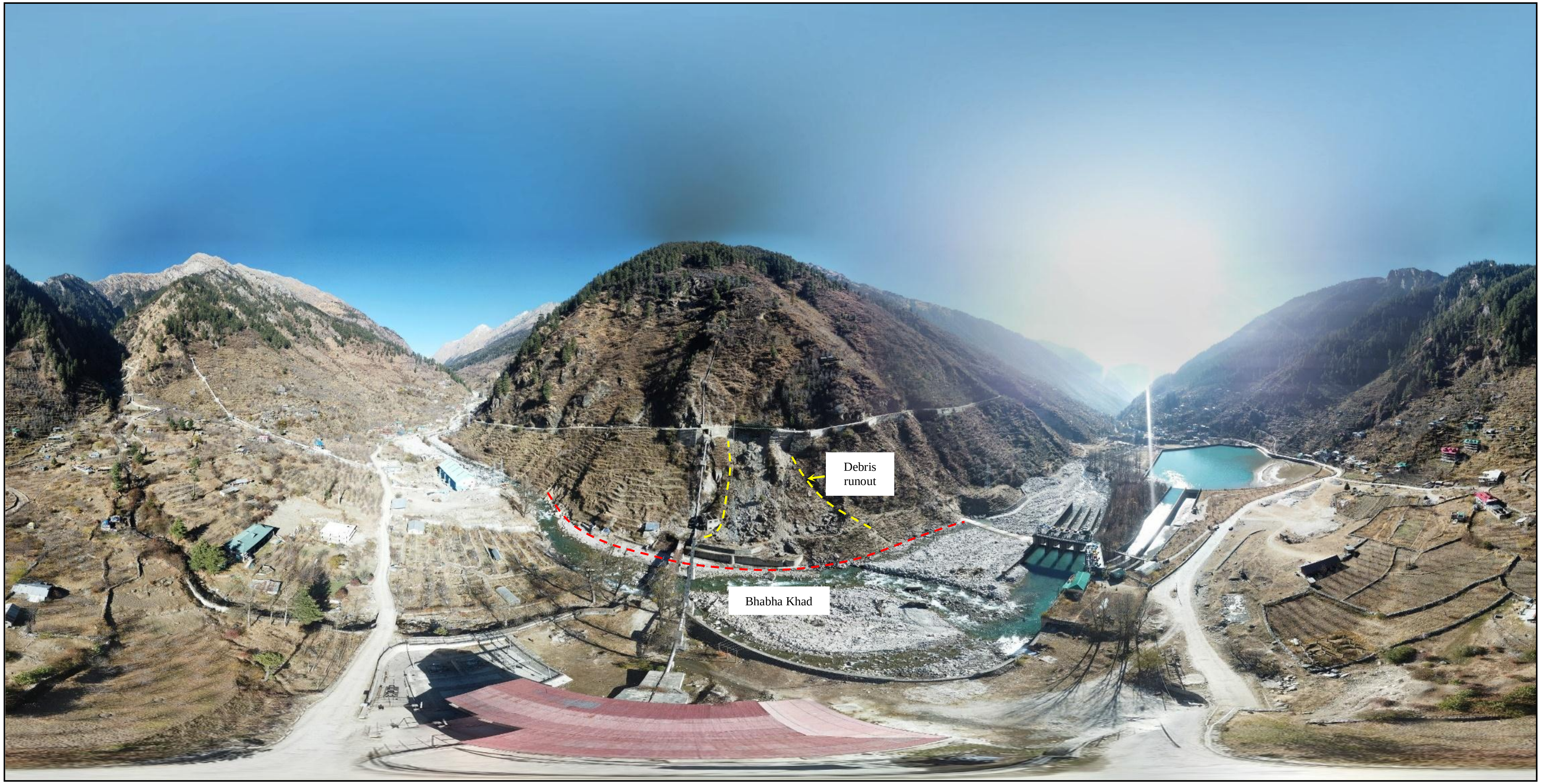


Fig. 26 A panoramic view of Yangpa-I landslide site at Kinnaur, HP

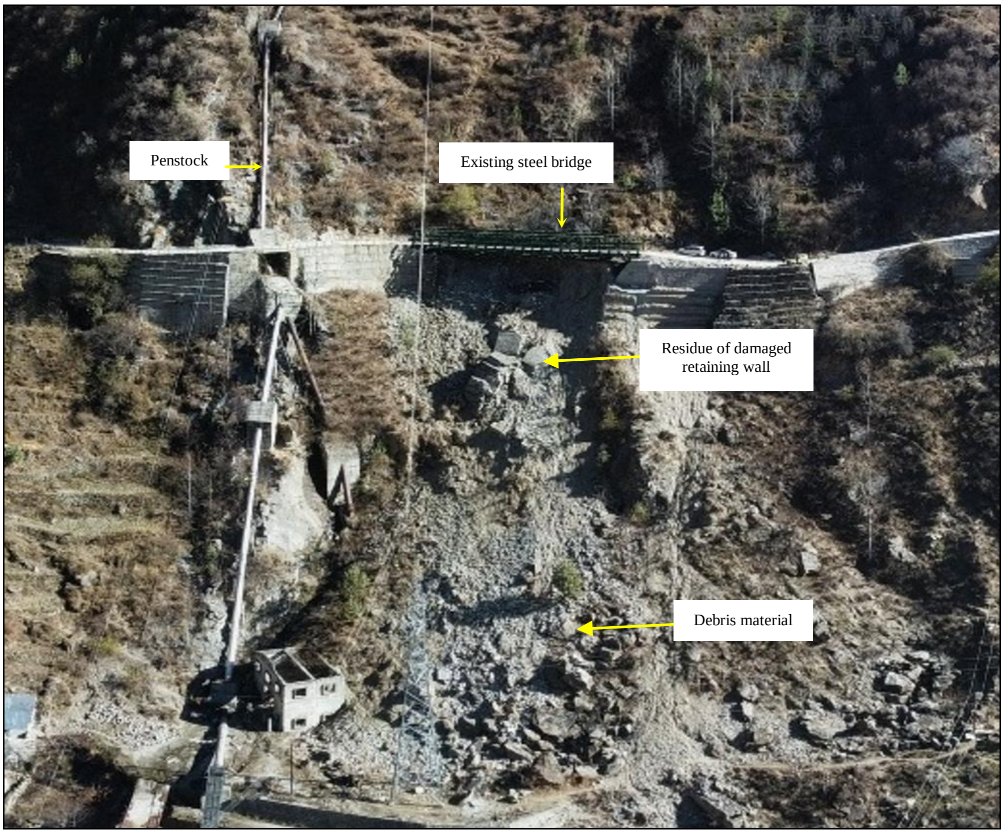


Fig. 27 Field photograph of Yangpa-I landslide, Kinnaur, HP

Fig. 28 Existing retaining structure at risk due to landslide occurrence

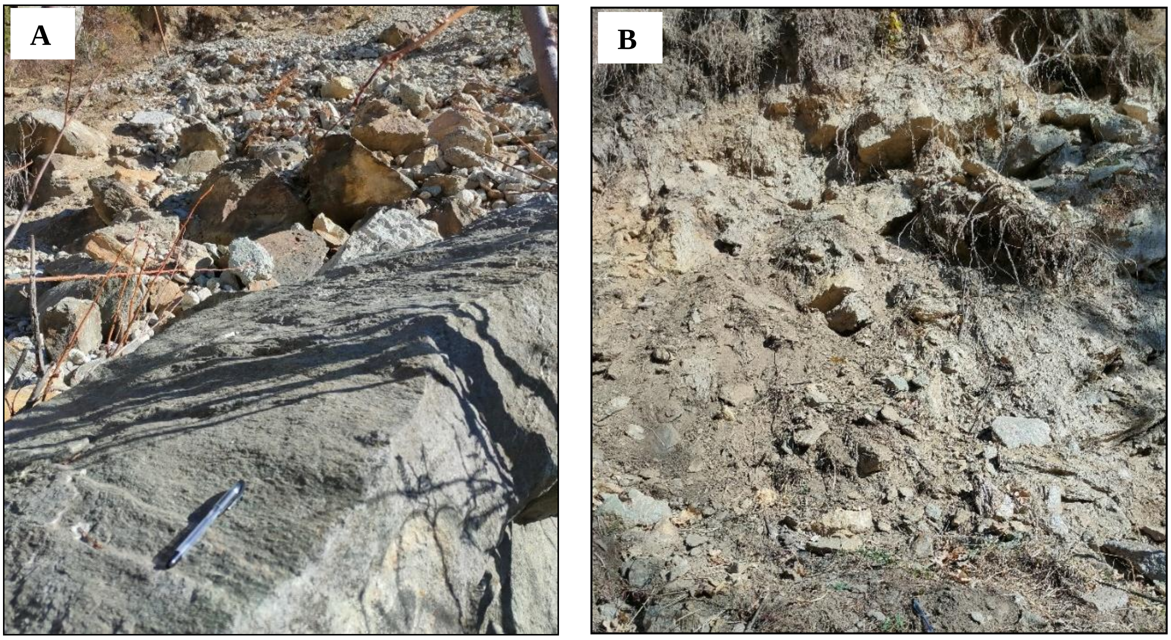


Fig. 29 Debris runout (A) and disintegrated rock mass (B)

Causative Factors

- Prolonged rainfall during the month of July, 2023 significantly increased the pore water pressure in a geologically unstable area, characterized by weathered and discontinuous rock mass, primarily gneisses, with extensive fracturing and disintegration.
- Excavation activities at the slope's toe for powerhouse construction and the possible impact of underground structures like pan stocks/tunnels, potentially widening existing fractures, might have destabilized the slope.
- The slope's steep angle (approximately 43°) and its orientation (250º N) coupled with the erosion caused by monsoon-induced flooding in Bhabha Khad, might have further enhanced the risk of landslide occurrence.

Short-Term Mitigation Measures

- The road has already been restored by the Himachal Pradesh Public works department as immediate solution.
- The retaining wall has also been constructed as indicated in the field photograph.

Long Term Mitigation Measures

- Employ temporary stabilization methods like installing wire mesh on the uphill of the slope and conducting selective rock bolting on exposed rock outcrops to prevent immediate rockfall or debris flow.
- Based on the catchment area analysis from the contour map, construct temporary culverts to manage water flow and reduce the risk of erosion and slope saturation.
- Comprehensive rock bolting and wire mesh installation on all critical rock outcrops and install wire mesh across the slope to prevent rockfall and debris flow.
- To safeguard the bridge at the Yangpa 1st landslide site, construct Reinforced Cement Concrete (RCC) piers, specifically engineered to anchor into the hard gneiss rock foundation. The design must account for the site's 43° slope angle, unique joint patterns in the gneiss, and local seismic conditions, ensuring resilience against landslide-induced forces.

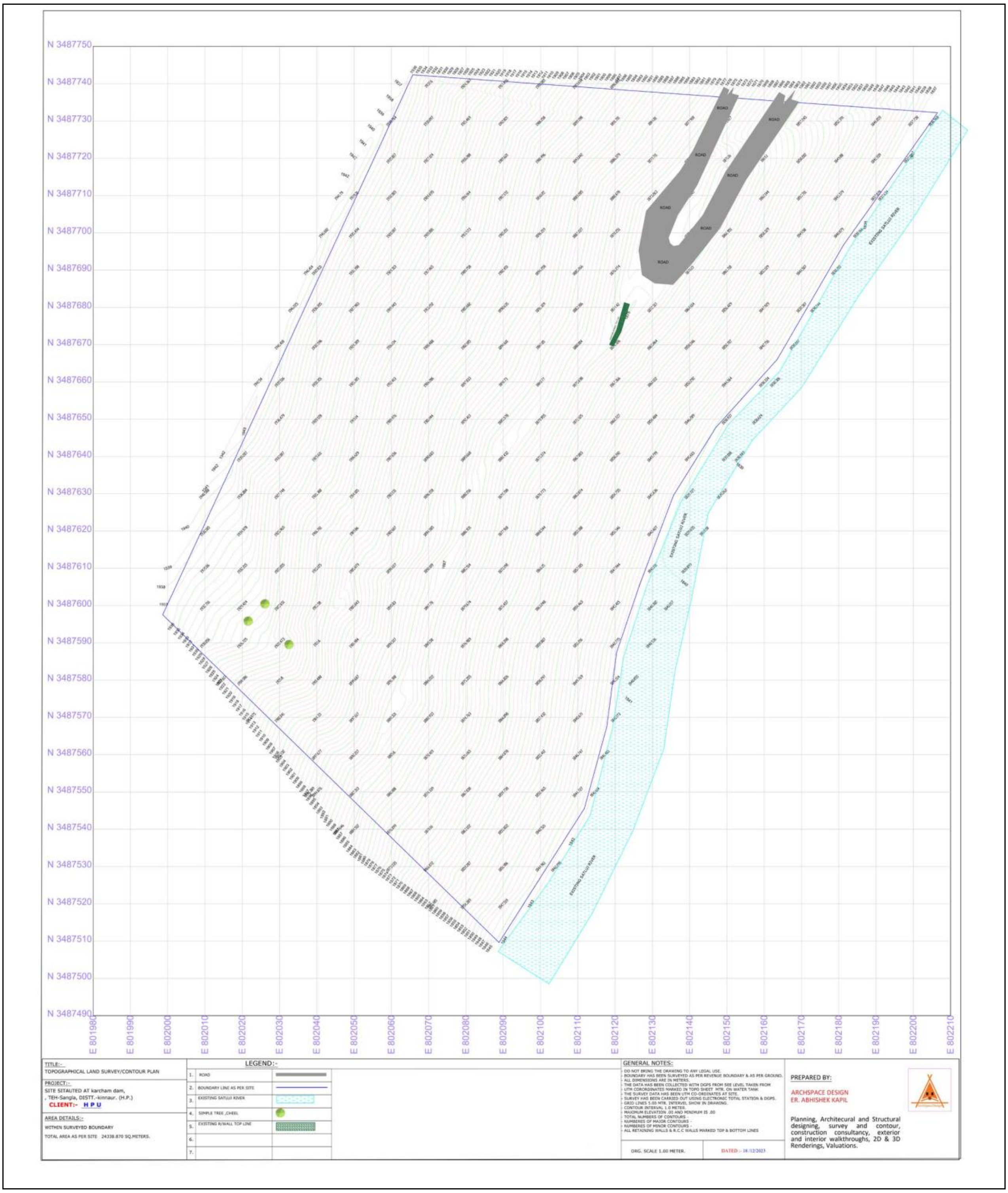
6.6 SAPNI LANDSLIDE

The Sapni landslide, located on the Karcham-Sangla route within the Sapni Panchayat, Kalpa Subdivision, Kinnaur District, Himachal Pradesh, is geographically positioned at 39°29'24" latitude and 78°10'57" longitude. **Fig. 30** presents the contour map of the Sapni landslide. The closely spaced contour lines prepared at 1m interval indicate a significant elevation gradient, consistent with a steep terrain. **Fig. 31** and **Fig. 32** illustrate the panoramic and the field photograph of the site respectively. The landscape's slope orientation is at 121°, with the dip direction and angles for joint sets J_0, J_1, and J_2 recorded as 234°/47°, 114°/43°, and 295°/74°, respectively. These features, combined with a volumetric joint count of 18 and the rough, unfilled nature of the joints, which exhibit persistence ranging from 20 cm to 3 m, underscore the site's complex geological structure. The primary trigger for the landslide has been identified as toe erosion by a stream, adversely impacting the road infrastructure located on the slope. This is visually supported by **Fig. 33**, which highlights the displacement of large rock blocks and the resultant debris runout.

Geological analysis reveals that the rocks in this vicinity are part of the Jeori-Wangtu Gneissic Complex (J-WGC), a constituent of the Lesser Himalayan Crystalline series. This complex is predominantly composed of various gneiss types—granitic, augen, migmatite and schistose gneisses—with garnetiferous mica schists notably present in the landslide-affected area. The Geological Survey of India's Bhukosh map further indicates the crossing of the Kullu and Jutogh Thrusts north of this region, adding to the geological complexity. The prominence of three joint sets (J_0, J_1, and J_2) at the site, with J_2 and J_3 forming wedges and J_1 presenting conditions conducive to planar failure, underscores the critical discontinuities contributing to the landslide. This is evidenced by the predominant planar mode of failure identified in the area through stereo plot (**Fig. 34**). Despite the slope's predominantly dry state, wet conditions at the toe, aggravated by regional thrusting, have led to deformation and increased susceptibility of the rock formations to failure. The ongoing deformation of the rock mass, coupled with rapid flooding events from the Baspa River, points to a dual causality of geological and climatic factors behind the landslide. The steep slope angle of 54° further accentuates the area's predisposition to such events.

Causative Factors

- The absence of an effective drainage system in the upslope area results in water accumulation and saturation during periods of excessive or incessant rainfall, such as that experienced in July 2023.This saturation reduces the shear strength of the slope materials, thereby increasing the likelihood of slope failure. Hydrostatic pressure build-up within the slope also enhances instability, particularly in geological formations prone to water infiltration.
- The erosional activity of the Baspa River at the base or toe of the slope undermines the structural integrity of the slope. This toe erosion removes support from the lower sections of the slope, leading to a decrease in resisting forces against gravitational pull. Continuous erosion by the river can create an over-steepened slope angle, precipitating slope failure.
- In the Sapni landslide area, the specific arrangement of joint sets and the composition of the Jeori-Wangtu Gneissic complex contribute to an adverse geological setup. The presence of weakened, fractured or sheared zones within the rock mass, along with the orientation of these geological features relative to the slope face, can significantly influence the slope's stability.



TITLE:-
TOPOGRAPHICAL LAND SURVEY/CONTOUR PLAN

PROJECT:-
SITE SITAUTED AT karcham dam,
, TEH-Sangla, DISTT.-kinnaur. (H.P.)
CLIENT:- H P U

AREA DETAILS:-
WITHIN SURVEYED BOUNDARY
TOTAL AREA AS PER SITE 24338.870 SQ.METERS.

1.	ROAD	▬
2.	BOUNDARY LINE AS PER SITE	—
3.	EXISTING SATLUJ RIVER	▨
4.	SIMPLE TREE ,CHEEL	●
5.	EXISTING R/WALL TOP LINE	▨
6.		
7.		

GENERAL NOTES:
- DO NOT BRING THE DRAWING TO ANY LEGAL USE.
- BOUNDARY HAS BEEN SURVEYED AS PER REVENUE BOUNDARY & AS PER GROUND.
- ALL DIMENSIONS ARE IN METERS.
- THE DATA HAS BEEN COLLECTED WITH DGPS FROM SEE LEVEL TAKEN FROM
- UTM CORORDINATES MARKED IN TOPO SHEET MTR. ON WATER TANK
- THE SURVEY DATA HAS BEEN UTM CO-ORDINATES AT SITE.
- SURVEY HAS BEEN CARRIED OUT USING ELECTRONIC TOTAL STATION & DGPS.
- GRID LINES 5.00 MTR. INTERVEL SHOW IN DRAWING.
- CONTOUR INTERVAL 1.0 METER.
- MAXIMUM ELEVATION .00 AND MINIMUM IS .00
- TOTAL NUMBERS OF CONTOURS -
- NUMBERES OF MAJOR CONTOURS -
- NUMBERES OF MINOR CONTOURS -
- ALL RETAINING WALLS & R.C.C WALLS MARKED TOP & BOTTOM LINES

ORG. SCALE 1.00 METER.

DATED :- 18/12/2023

PREPARED BY:

ARCHSPACE DESIGN
ER. ABHISHEK KAPIL

Planning, Architecural and Structural designing, survey and contour, construction consultancy, exterior and interior walkthroughs, 2D & 3D Renderings, Valuations.

Fig. 30 Contour map of the Sapni landslide, Kinnaur HP. The map is prepared based on a geodetic UAV survey.

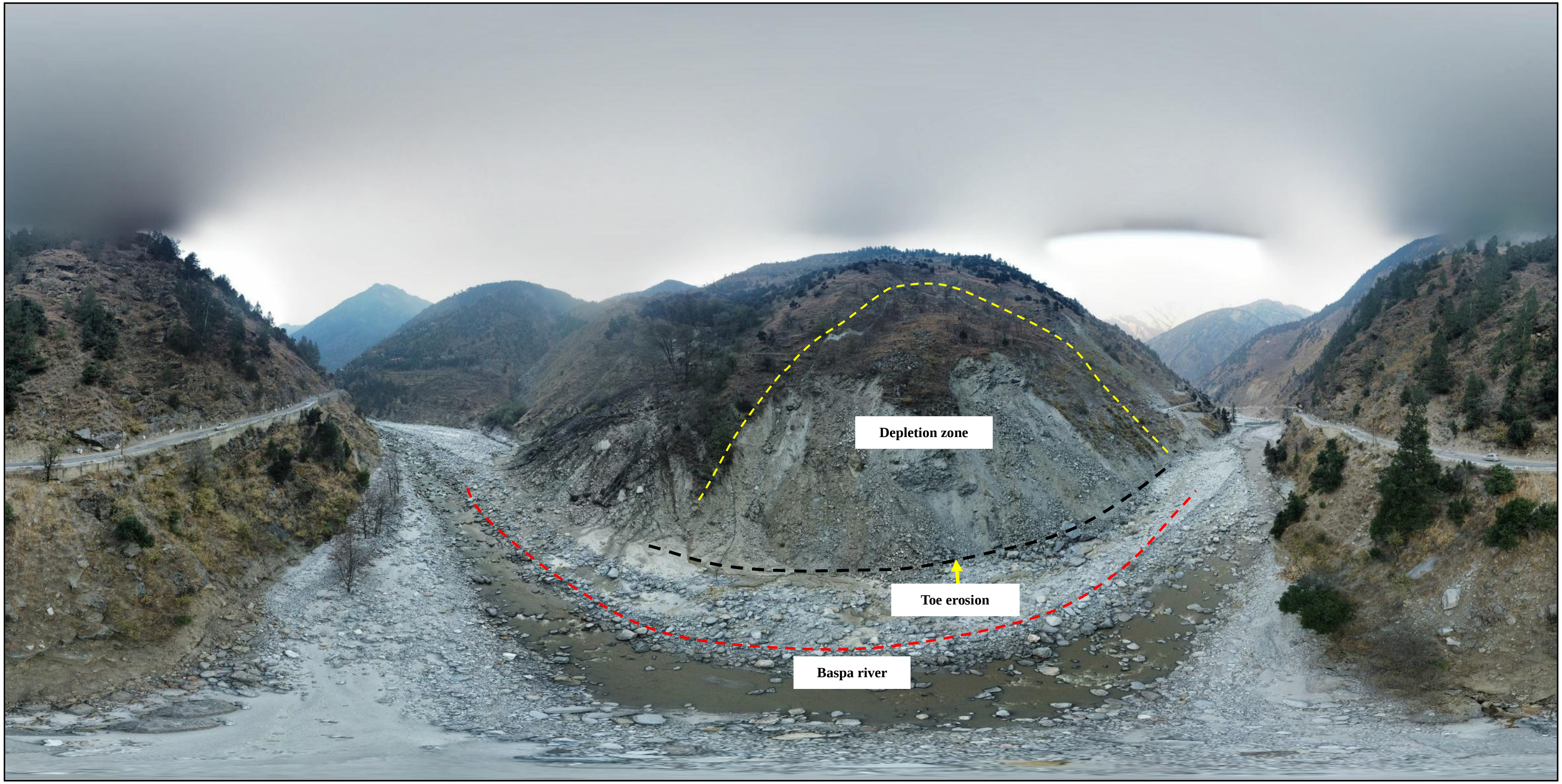


Fig. 31 A Panoramic view of Sapni landslide site at Kinnaur, HP

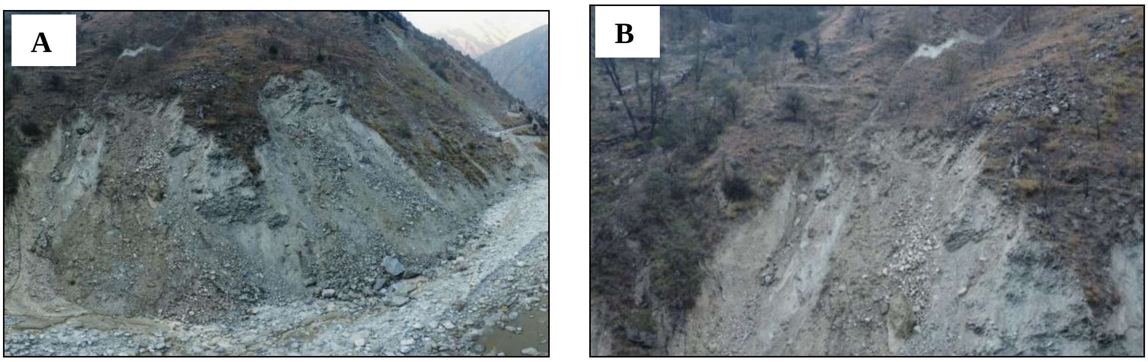


Fig. 32 Field photograph of Sapni Landslide, Kinnaur, HP

Fig. 33 Large size rock blocks and debris runout of the landslide

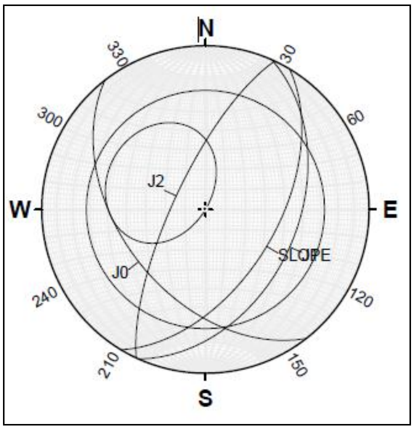


Fig. 34 Stereo-plot showing the planar failure along the discontinuous plane (J_1) at the Sapni landslide site.

Short Term Mitigation Measures

- Construction of a concrete wall at the toe of a landslide site ensuring it can adequately withstand the site-specific lateral and hydrostatic pressures. The construction process should commence with the excavation of a trench at the landslide's toe, extending down to stable ground. Upon this foundation, a reinforced concrete base is to be laid, designed for substantial load-bearing capacity. The wall, composed of reinforced concrete, ought to incorporate drainage features such as weep holes to effectively manage water pressures. For stability, the area behind the wall should be backfilled with materials conducive to drainage and compacted appropriately.
- Developing a drainage system that conforms to the local topography and geological conditions, ensuring efficient water channeling from the upslope areas to the Baspa River, thus reducing slope saturation.
- Implementing a trench system with wire mesh and rock bolts designed according to the specific joint orientations and rock conditions of the Sapni site, focusing on areas where the joint sets J_0, J_1, and J_2 are most problematic.

Long Term Mitigation Measures

- Construction of a geosynthetic reinforced gabion facia retaining wall by ensuring that foundation rests on an intact rock stratum for enhanced stability. High-strength geosynthetics are crucial in reinforcing the wall against dynamic soil and rock movements, countering the landslide risk. Furthermore, optimizing the gabion fill with locally sourced gneiss to ensure structural integrity and efficient drainage.
- Building a Gabion wall along the specific road sections passing through the landslide zone, designed to withstand the local slope conditions and the erosional forces of the Baspa River.
- Engaging with the Forest Department to identify local plant species that are most effective in soil retention for the specific soil and climatic conditions of the Sapni region, focusing on reforestation in the failure-affected zone.

Table 1: Geotechnical Properties of Soils

S. No.	Location	GRAIN SIZE ANALYSIS			LIQUID LIMIT (%)	PLASTIC LIMIT (%)	PLASTICITY INDEX (%)	MOISTURE CONTENT (%)	BULK DENSITY (GM/CC)	DRY DENSITY (GM/CC)	SPECIFIC GRAVITY	D60	D30	D10	SHEAR STRENGTH PARAMETERS			COEFF. OF PERMEABILITY (cm/s)
		GRAVEL (%)	SAND (%)	SILT (%)											TYPE OF TEST	COHESION C (t/sqm)	ANGLE OF FRICTION (DEGREE)	
1.	**Brua**	38	35.5	26.5	Non-Plastic			11.45	2.24	2.01	2.65	0.043	0.009	0.003	DST	0.07	34.62	_
2.	**Yulla Kenchi**	23	54	23	Non-Plastic			11.87	2.16	1.93	2.61	_	_	_	DST	0.15	36.14	_
3.	**Shilani**	32	45.5	22.5	Non-Plastic			11.01	2.206	1.98	2.64	0.043	0.009	0.003	DST	0.33	26.57	0.32×10^{-2}
4.	**Yangpa-I**	55.5	37.5	7	Non-Plastic			9.07	2.102	1.92	2.65	0.043	0.009	0.003	DST	0.096	33.03	0.51×10^{-1}

REFERENCES

Baruah S, Dey C, Sanoujam M (2023) Preliminary account on the 30th June 2022 Tupul, Manipur landslide of Northeast India. Landslides 20, 1547–1552. https://doi.org/10.1007/s10346-023-02074-y

Das S, Sarkar S, Kanungo DP (2022) Rainfall-induced landslide (RFIL) disaster in Dima Hasao, Assam, Northeast India. Landslides 19, 2801–2808. https://doi.org/10.1007/s10346-022-01962-z

Guzzetti F (2023) Landslide Early Warning Systems: Resources or Problems?. In E3S Web of Conferences (Vol. 415, pp. 03010). EDP Sciences. https://doi.org/10.1051/e3sconf/202341503010

Martha TR, Roy P, Govindharaj KB et al. (2015) Landslides triggered by the June 2013 extreme rainfall event in parts of Uttarakhand state, India. Landslides 12, 135–146. https://doi.org/10.1007/s10346-014-0540-7

National Disaster Management Authority (2023) Report *on Post Disaster Needs Assessment Himachal Pradesh Monsoon-2023: Floods, Cloudbursts & Landslides*. Ministry of Home Affairs, Government of India, New Delhi.

NDMA (2019) Compendium of Task Force Sub Group Reports on National Landslide Risk Management Strategy. A publication of the National Disaster Management Authority, Government of India, September 2019, New Delhi.

Pradhan SP, Panda SD, Roul AR et al. (2019) Insights into the recent Kotropi landslide of August 2017, India: a geological investigation and slope stability analysis. Landslides 16, 1529–1537. https://doi.org/10.1007/s10346-019-01186-8

Sarkar S, Pandit K, Sharma M, Pippal A (2018) Risk assessment and stability analysis of a recent landslide at Vishnuprayag on the Rishikesh–Badrinath highway, Uttarakhand, India. Curr Sci 1527-1533. DOI: 10.18520/cs/v114/i07/1527-1533

Sharma A, Prakash C, Nautiyal A (2022) Recent landslide news of Himachal Pradesh, India. Landslides 19, 221–224. https://doi.org/10.1007/s10346-021-01802-6