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हिमाचल प्रदेश के लाहौल और स्पीति जनपद में लिंडूर गांव में आपदा के बाद जमीन में दरारें और धंसाव के प्रारंभिक अध्ययन पर एक नोट

टोपोशीट संख्या: 52 डी/14
(अतिरिक्त कार्य)
(मिशन - IV/ कार्यसत्र: 2023-24)

A NOTE ON PRELIMINARY POST-DISASTER STUDY OF GROUND CRACKS AND SUBSIDENCE IN LINDOOR VILLAGE, LAHAUL AND SPITI DISTRICT, HIMACHAL PRADESH

Toposheet Numbers Nos.: 52D/14
(ADDITIONAL WORK)
(Mission – IV/ Field Season: 2023-24)

द्वारा:
क्रिस्टी टॉम, भूवैज्ञानिक एवं सिद्धार्थ जंग थापा, भूवैज्ञानिक
भारतीय भूवैज्ञानिक सर्वेक्षण, उत्तरी क्षेत्र
By:
Christy Tom, Geologist and Siddhartha Jang Thapa, Geologist
Geological Survey of India, Northern Region

भारतीय भूवैज्ञानिक सर्वेक्षण, उत्तरी क्षेत्र / Geological Survey of India, Northern Region
राज्य इकाई: पंजाब, हरियाणा और हिमाचल प्रदेश/ State Unit: Punjab, Haryana & Himachal Pradesh
चंडीगढ़- 160020 /Chandigarh – 160020

दिसंबर/ December, 2023

A NOTE ON PRELIMINARY POST-DISASTER STUDY OF GROUND CRACKS AND SUBSIDENCE IN LINDOOR VILLAGE, LAHAUL AND SPITI DISTRICT, HIMACHAL PRADESH

(Toposheet No.: 52D/14)

By:

Christy Tom, Geologist and Siddhartha Jang Thapa, Geologist

Geological Survey of India, Northern Region

State Unit: Punjab, Haryana and H.P. Chandigarh - 160020 (U.T.)

1.1 BACKGROUND:

The incidence of ground cracks and subsidence was brought to the notice of Shri Jagat Singh Negi, Hon'ble Minister of Horticulture, Himachal Pradesh and Shri Ravi Thakur, MLA Lahaul and Spiti district, Himachal Pradesh, besides the District Administration through e-mail dated 07/08/2023 by Jan Chetna Samiti, Lahaul and Spiti district, Himachal Pradesh; following which, a letter from the Dy. Commissioner, DDMA, Lahaul and Spiti was received by the Director General, GSI, vide letter no. - 1663/DDMA, dt. 13/11/2023 requesting to carry out ground visit by GSI geologists in the affected area.

On 17/11/2023, the authors as per instructions received from the office of Shri N. V. Nitnaware, Additional Director General & HoD, GSI (Northern Region), Lucknow and Dr. Joyesh Bagchi, Dy. Director General, SU: P, H & HP, GSI, Chandigarh (In light of instructions received via GSI Mail dt. 16/11/2023), proceeded to Keylong (Administrative centre of Lahaul and Spiti district) for carrying out post-disaster studies of the incident. After reaching the Old Circuit House, Keylong on 17/11/2023, it was telephonically conveyed to GSI team from the Office of the Sub Divisional Magistrate that Mr. Hira Lal, Lindoor Village representative will be coordinating with the officers for carrying out post disaster risk assessment of Lindoor area. On 18/11/2023 and 19/11/2023, reconnoitory traverse was taken by the authors in the area affected by an incidence of damaged houses, ground cracks and ground subsidence in Lindoor village, Lahaul and Spiti District, Himachal Pradesh to ascertain the possible cause and suggest suitable preliminary remedial measures based on field traverse.

At a meeting with the villagers, Mr. Hira Lal briefed about the prevalence of cracks and the problems faced by the villagers. The GSI team was also informed that although cracks have been seen in the village area since 2000, the severity of the damage and landslides increased starting in August 2023 (following monsoon).

Mr. Naresh Kumar, Ward Panch, Mr. Hira Lal, Mr. Neel Chand Rashpa, and a few locals were also in the field assisting the team.

1.2 LOCATION OF THE STUDY AREA:

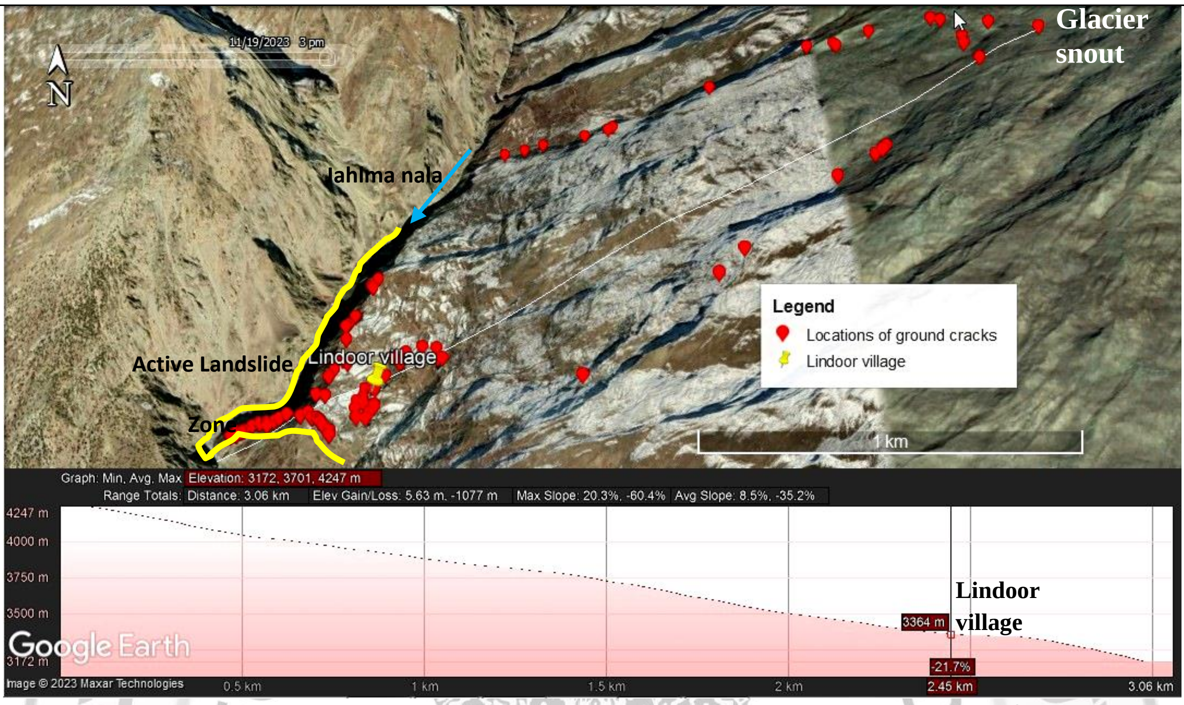


Fig.1: Google image showing location of Lindoor village along with the location of all the cracks recorded. Note that Lindoor village is situated on a slope and cracks have developed throughout the area with increase in concentration in downslope direction where the slides are active.

Lindoor village is situated along the left bank of Jahlma *nala* which is a tributary of Chandra Bhaga River. At the time of field investigation, the failure affected slope was noticed adjacent to the flowing *nala* as active as evidenced by minor/intermittent debris falls, loose mass slips, cracks in talus/debris materials etc.

The ground cracks and land subsidence affected area is located near Lindoor village [Lat: 32°38'56.20"N; Long: 76°52'38.17"E; Elevation: 3362 msl], Lahaul and Spiti district of Himachal Pradesh and falls in Survey of India (SoI) Toposheet No. 52D/14. Lindoor Village is 31 kilometres from Keylong Town and can be approached via SH-26. The actual affected area forms part of an old debris/talus deposit along left bank slopes of Jahlma *nala* which is a tributary of Chandra Bhaga River (Figure 1).

1.3 GENERAL GEOMORPHOLOGY AND GEOLOGY:

The Lindoor village and surrounding area forms a part of Great Himalayan ranges and exhibit a rugged topography with denudational and highly dissected hill slopes having altitude ranging between 3300 m and 4500 m msl. A few glaciers adorn the higher reaches of the village in the northern part and the area has a glacier sculptured landscape (Figure 1). The area is mainly drained by the glacier melt waters flowing as channelized *nalas* through the village. It was intimated by the villagers that the only source of water to the village is glacier melt water which runs through the village as channelized *nalas*.

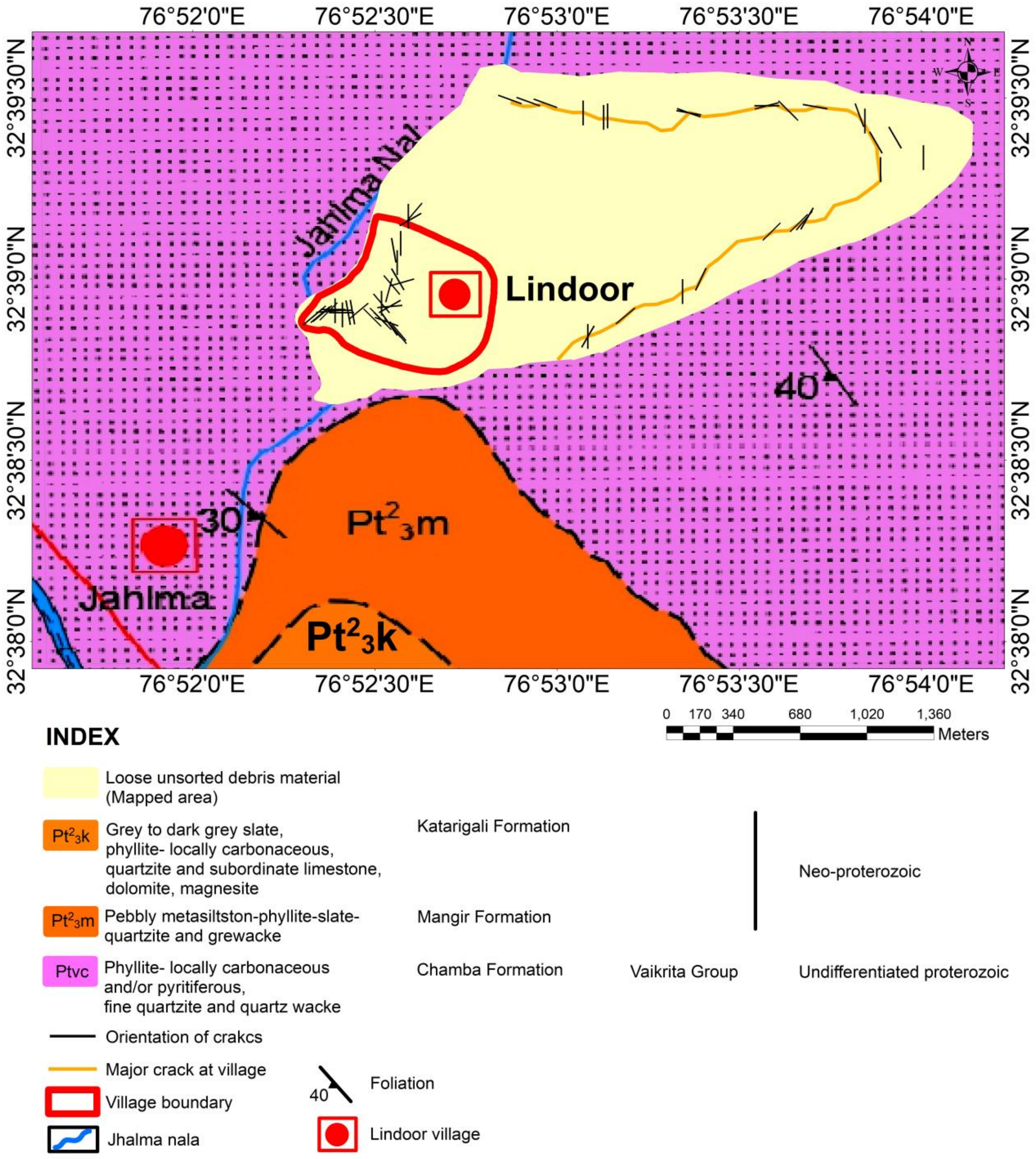


Fig. 2: Geological Map of Lindoor village and surrounding area (Part of SoI Toposheet No. 52D/14) (Source: Geoinformatics Division, GSI, Chandigarh).

Geologically, the area belongs to Vaikrita Group of rocks (Figure 2). Lindoor village and the surrounding area present in the left bank of Jahlma *nala* (Figure 1) is devoid of rock outcrops/exposures but floats of phyllite and quartzite are present throughout the area. The area to the right bank of Jahlma *nala* consists of intercalated sequence of quartzite and phyllite of Chamba Formation (Figure 2). Villages and some agriculture practices were seen nestled on gentler slopes with mean resultant direction of N267º (SW). The entire study area along the slopes is observed to be covered with debris/talus/slope wash material forming debris/talus cones and terraces which are observed to be relatively gentler and stable. Near the periphery of Jahlma *nala*, these debris/talus cones and terraces are deposited as relatively steeply inclined piles. Most of the slope forming materials in the study area is made up of loose, unsorted debris materials supported by clay matrix.

1.4 FIELD OBSERVATIONS:

The problem of instability as observed during field traverse is in the form of: ground cracks in the agricultural fields and slopes, horizontal-vertical-diagonal-step cracks in houses of village residences, ground subsidence and two active landslides ~300m to 250 m from the village area (Annexure 1 and 2). The entire study area is dissected by manmade gullies and *nalas* with flowing water from the glacier melts (Figure 4). Lindoor village and its surrounding area is setup on loose, unsorted debris materials supported by clay matrix and the soft nature of sediments composing the hill slopes makes them vulnerable to rapid soil erosion particularly during heavy precipitation. Besides this, offsetting of fences (Figure 14) and several tilted trees (Figure 23) were also observed with tilt towards the general slope direction i.e., SW.

The slope along the Jahlma *nala* is steep with mean resultant direction of N267º (SW) and two active slides (Slide 1 and 2) were observed during the time of visit where the SSW flowing Jahlma *nala* is taking a SE shift in its course (Figure 4). Loose materials were continuously sliding along these slopes at the time of visit (Figure 6). Majority of the cracks both transverse and longitudinal (Figure 8, 9 and 22), observed in the area are concentrated near to the active slides indicate the retrogressive and widening nature of the slide. The general trend of the transverse cracks as per field data collected is NNE-SSW which is also following the general trend of Jahlma *nala* (Figure 4). Several parallel sets of ground cracks have been recorded up slope from the active slide zones towards the glacier snout which are having similar trend with the ground cracks observed near the active slide zones (Figure 4 and 22).

Fig. 3: Panoramic view of Lindoor village, Lahaul and Spiti district, H.P.

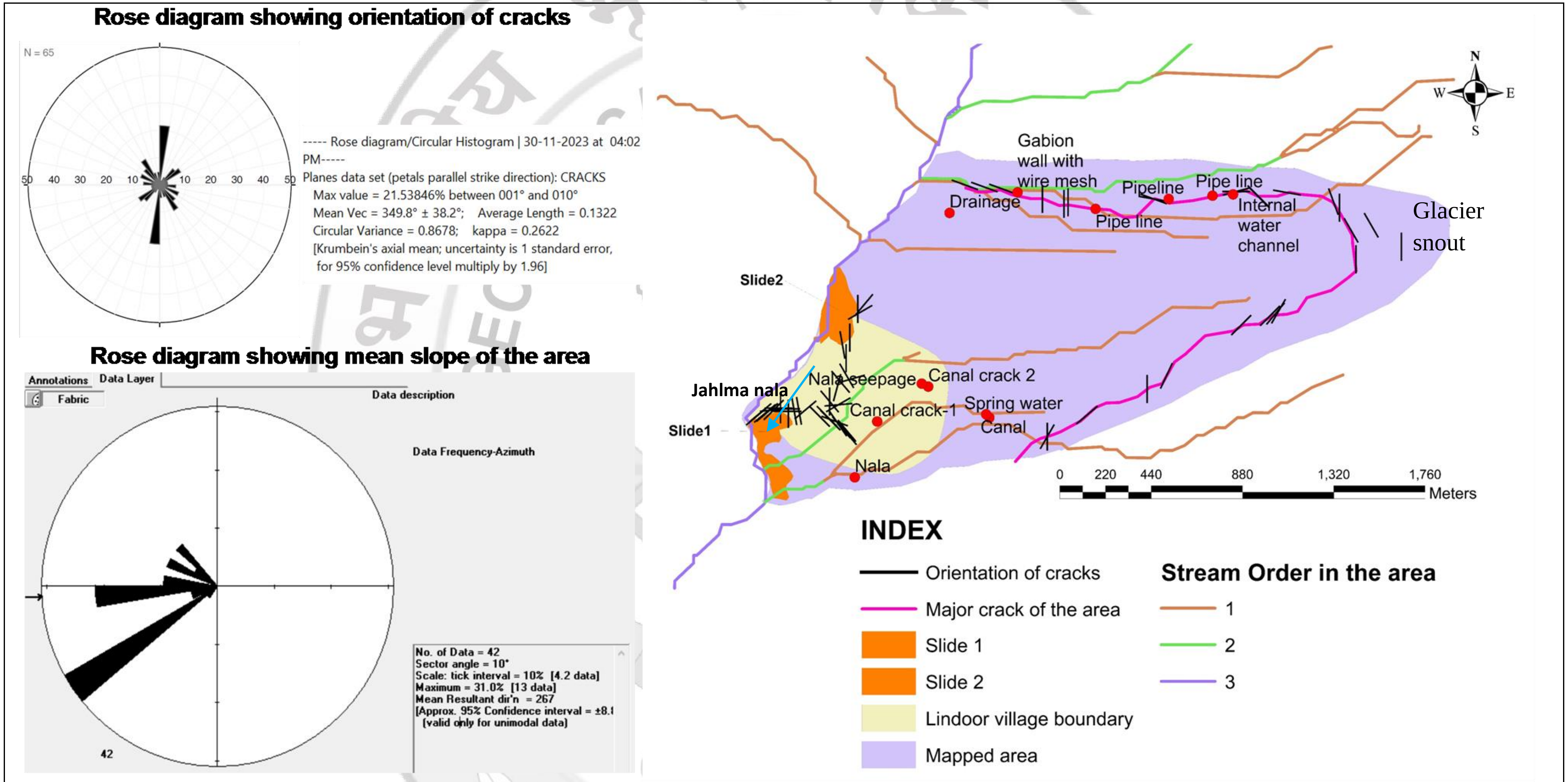


Fig. 4: Map showing the orientation of cracks in Lindoor village and its surrounding area along with rose diagrams.

Fig. 5: Active slide (slide 1) seen during the time of visit which is ~ 130 m from Lindoor village.

Fig. 6: Active slide (slide 2) with debris fall seen during the time of visit along the NNE-SSW trending Jahlma *nala*.

Fig. 7: Continuous water seepage observed along the slope towards the left bank of Jahlma *nala* where slide 2 is active.

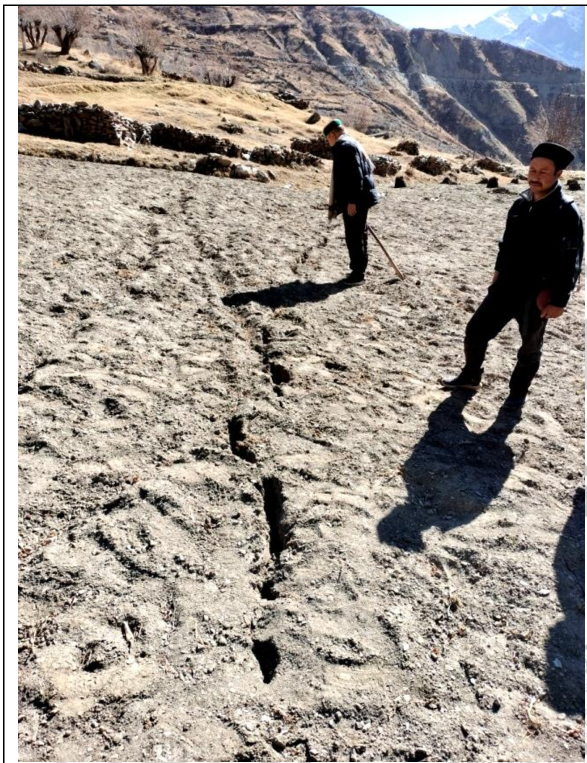


Fig. 8: NNE-SSW trending transverse cracks observed in agricultural fields near the periphery of the active slide 2.

Fig. 9: Vertical displacement seen in the NNE-SSW trending transverse cracks indicating subsidence of land near the crack zone.

The houses located in the study area are traced to be at distance of~300 m from slide 1 and ~250 m from slide 2. A total of 14 houses, 01 monastery, 01 primary school and 02 community centres are present in the village. It was intimated to the authors by the villagers that the ground cracks were common in the area from the year 2000 onwards but the intensity and damage was drastic this year after the heavy monsoon seasons during the month of August 2023. Majority of the houses in the village have been built using local rocks and mud with foundation upto 2 m depth (Figure 11, 12 and 13). As informed by the residents of houses visited, some mud houses are ~80 years old (Figure 12) and are observed to be having serious structural damage. However, in some cases it was found that the structural damages were caused by a combined effect of land subsidence, poor quality of construction materials (local rocks and mud), inadequate construction process and the age of house.

Mainly four types of fracture patterns were observed in the walls and floors of the houses– horizontal, vertical, diagonal, and step-like, at few locations they seemed connected (Figure 10, 11, 15, 16, 17, 18, 19 and 20). These fracture patterns are irregular with rough surfaces. Overall, the fracture pattern seen on the walls and floors of the houses have a similar trend to the trend of cracks observed in the ground, thus indicating the evidences of land subsidence and soil creep in area.

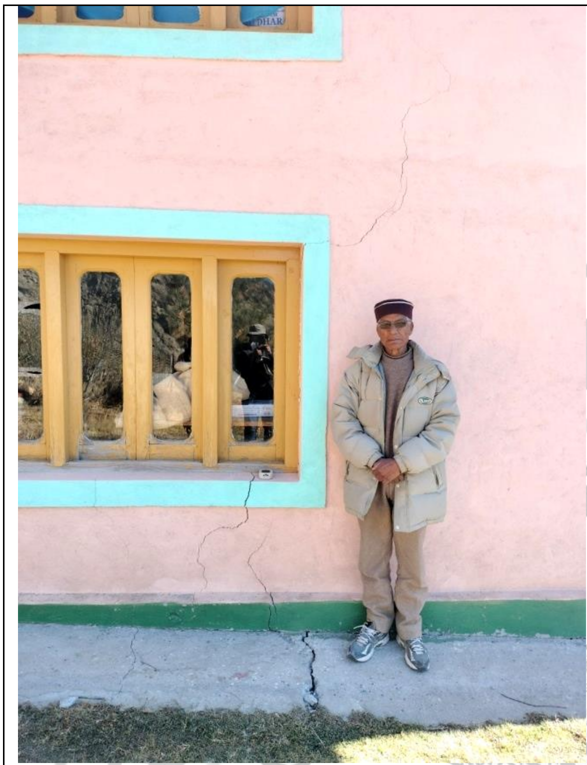


Fig. 10: Ground cracks continuing as diagonal cracks into the walls of a house.

Fig. 11: Horizontal and vertical cracks observed in a house with mud plastering.

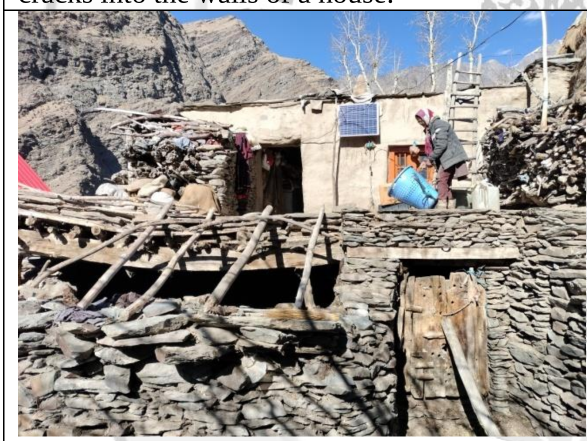


Fig. 12: 80 year old highly damaged mud house built on rock piles with no proper foundation.

Fig. 13: Two storeyed house made up of local rocks and mud as cementing materials.

Ground cracks are widely spread over the entire area surrounding the Lindoor village; however, its effects are more critical in the area near to the slides. Several continuous parallel sets of ground cracks seen in the area have continuity from fields to the houses in the villages. These cracks which got filled up partly at places at the time of field traverse (Figure 8), had aperture (opening) varying from about a few centimetres to about ~1.5 m maximum, as observed at select locations along its alignment. Signatures of stretching and breaking of roots [with average separation (wherever noticed) of ~1 to 5 cm] were also observed along the aperture of crack at places, indicating the phenomenon of widening of opening/aperture of ground crack.

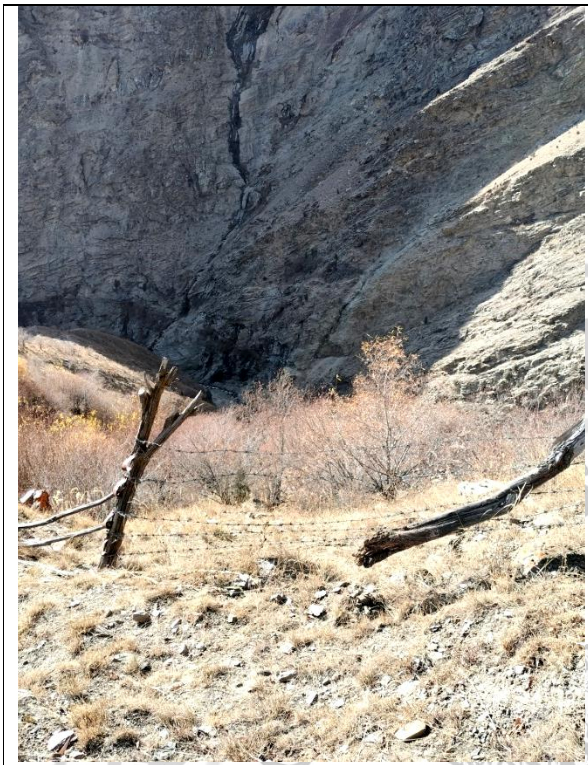


Fig. 14: Offsetting of fences seen near the crown portion of active slide 2.

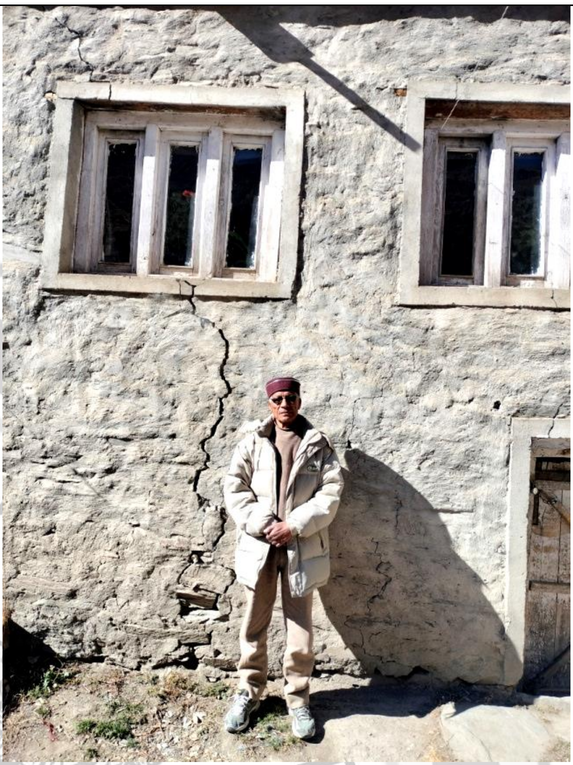


Fig. 15: Vertical cracks seen cutting across the all along with the wooden window frame.

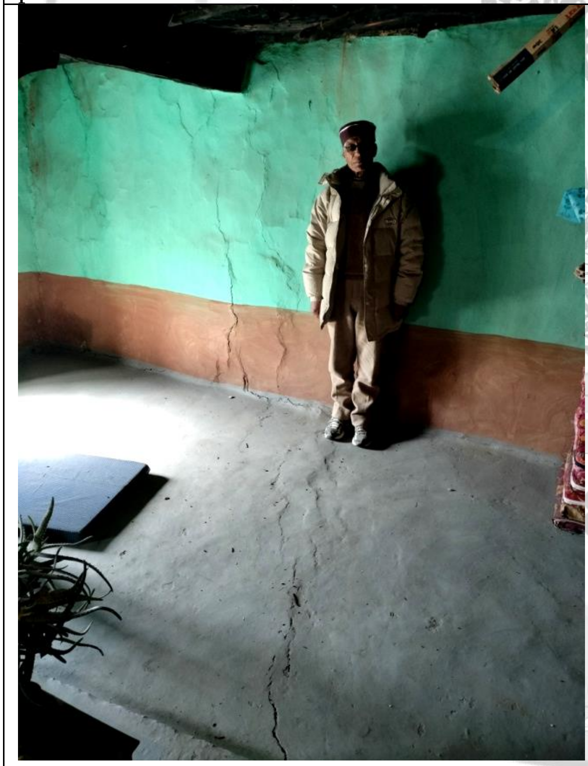


Fig. 16: Cracks on the floor of a mud house can be seen continuing towards the wall.

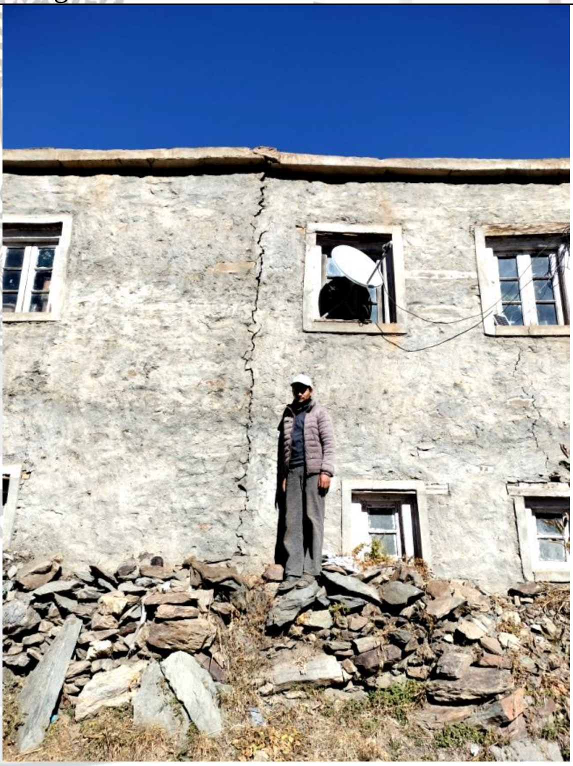


Fig. 17: Subsidence near the house has led to the formation of irregular vertical cracks.

Fig. 18: Step cracks with 2.6 cm opening seen in a mud house.

Fig. 19: Highly damaged and bulged wall of an old mud house (~80 years old).

Fig. 20: Ground cracks continuing into the walls of a community centre. Note that the trend of cracks on the wall and ground is same.

Fig. 21: Vertical cracks observed in a man-made channel with flowing water near a house leading to possible seepage of water to the ground.

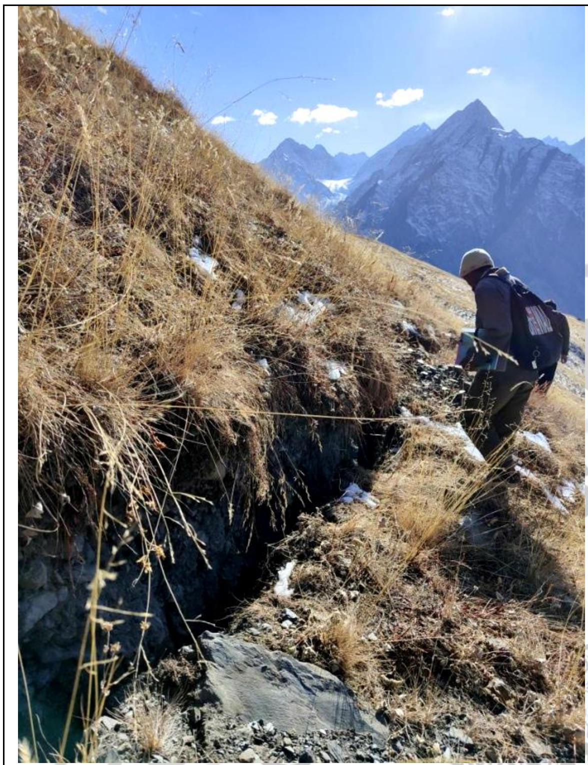
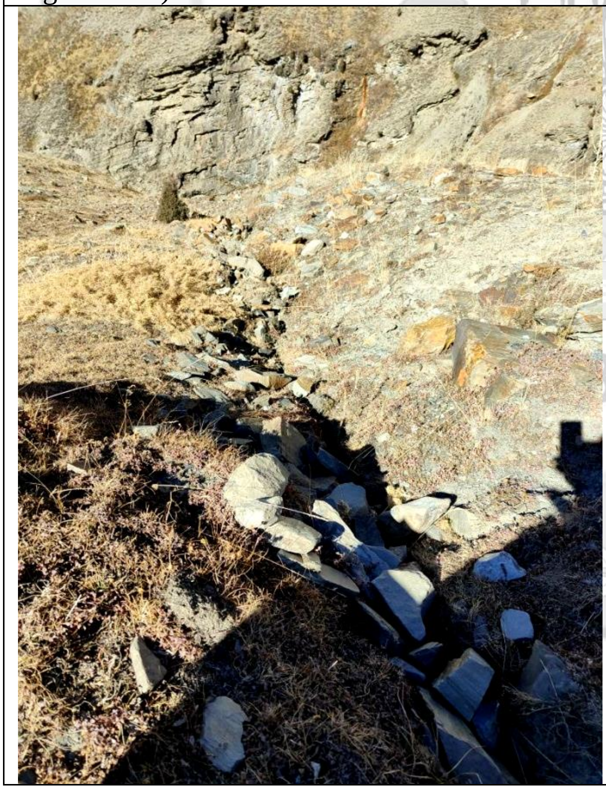


Fig. 22: Vertical displacement of ground and cracks observed near the glacier mouth towards the upper reaches of the area.

Fig. 23: Ground subsidence together with tilting of trees observed above the crown portion of active slide 1.

Some field photographs taken during field traverse surrounding the Lindoor village showing the major crack present in the area reaching up to the glacier present NE of Lindoor village (can be observed in Figure no. 4).



The depth of cracks, as observed in field is about few centimetres to about ~2 m, as recorded by visual estimation and by way of dipping a wooden stick by villagers at select locations. At few places vertical displacement of ~2.5 cm to 1.8 m was also observed indicating subsidence of land. Piping plays an important role in development of ground fissure and subsidence. Piping refers to erosive action of sub-surface flow of water, where sediments are removed by seepage forces, forming sub-surface conduits. Initiation of development of piping holes was observed at select locations near the landslide zones next to fringes of ground crack.

01 no. of soil sample has been submitted to the Geotechnical Laboratory, GSI, NR, Lucknow for the determination of various geotechnical parameters. However, results are awaited.

1.5 DISCUSSIONS AND INFERENCES:

Based on the media reports regarding micro-earthquakes in the area, earthquake data for the period since 1900 to Nov. 2023 was downloaded from USGS website (Figure 24 and Table 1) for an area within 50 km radius from Lindoor village. It was observed that 01 no. large earthquake (> M 7), 02 nos. Moderate earthquakes (> M 5), and 33 nos. Small earthquakes (5>M>3) have occurred in the area.

Lindoor village is situated on a gentle slope made up of loose unconsolidated debris/talus/slope wash material with no basement rock outcrop/exposure present. The depth of surface material to basement rock is not known. Considering the topography and location of Lindoor village, the ground cracks and land subsidence in the area are a resultant of two main factors – hydrogeological process and landslide effects.

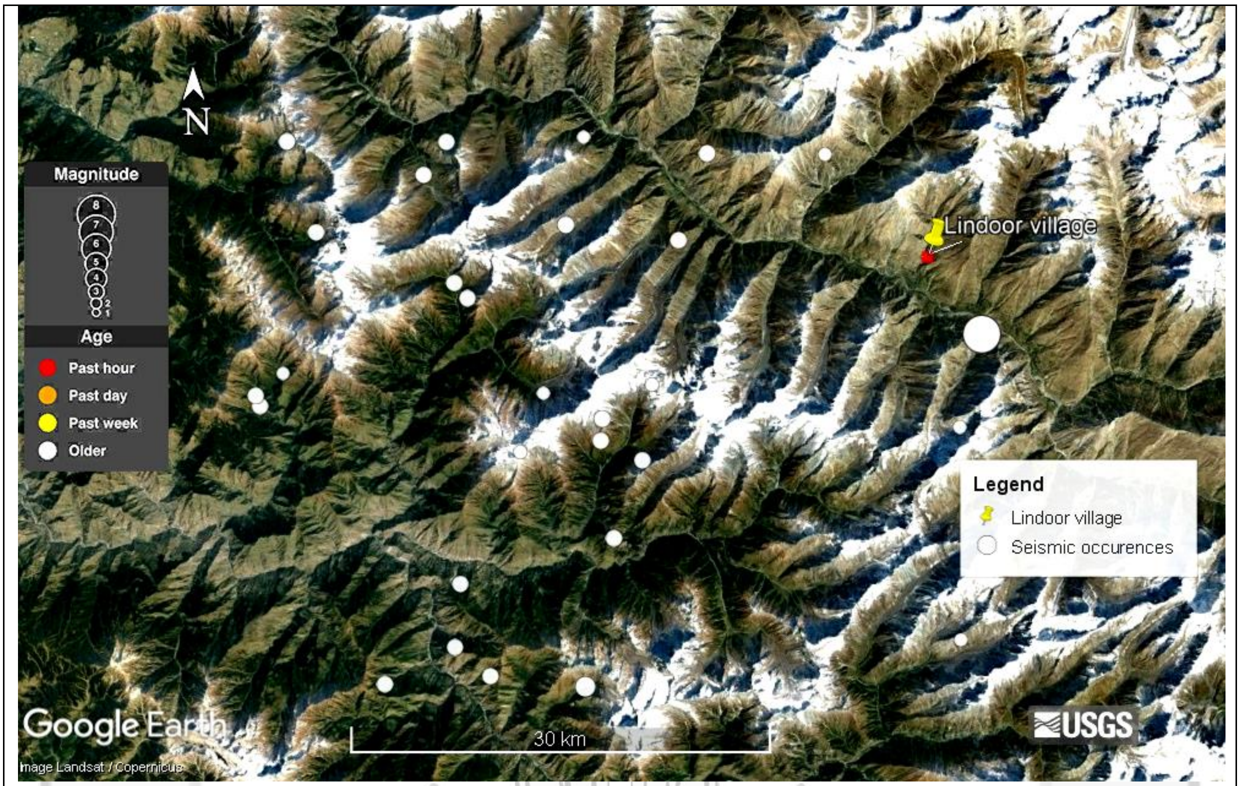


Fig. 24: Google image showing the earthquake events within 50km radius of Lindoor village from year 1900 onwards (Source: USGS).

Table 1: Details of earthquake events recorded within 50km radius of Lindoor village from year 1900 onwards (Source: USGS).

Sr. No.	Event Date	Latitude	Longitude	Richer Magnitude	Location
1	1905-04-04	32.597	76.916	7.9	10 km WNW of Keylong, India
2	1970-03-05	32.376	76.608	5.11	29 km N of Palampur, India
3	1975-09-16	32.379	76.454	4.6	21 km NE of Dharamsala, India
4	1976-04-10	32.727	76.511	4.5	40 km ENE of Chamba, India
5	1977-12-21	32.837	76.634	5.1	46 km NW of Keylong, India
6	1991-06-23	32.306	76.716	4.6	26 km NE of Palampur, India
7	1992-02-13	32.637	76.514	4.6	37 km ENE of Chamba, India
8	1996-05-23	32.707	76.492	4.2	38 km ENE of Chamba, India
9	1996-07-14	32.627	76.524	4.1	38 km ENE of Chamba, India
10	1996-12-23	32.403	76.892	3.8	22 km SSW of Keylong, India
11	2000-12-26	32.538	76.894	3.9	12 km WSW of Keylong, India
12	2001-04-25	32.713	76.798	3.9	26 km NW of Keylong, India
13	2003-04-27	32.874	76.761	4.1	41 km NW of Keylong, India
14	2003-12-21	32.548	76.626	4.2	37 km W of Keylong, India
15	2004-11-11	32.442	76.512	4.9	30 km NE of Dharamsala, India
16	2005-02-28	32.565	76.581	3.8	41 km W of Keylong, India
17	2005-02-28	32.534	76.624	4.8	37 km W of Keylong, India
18	2005-04-14	32.567	76.359	4.8	21 km E of Chamba, India
19	2005-04-18	32.671	76.41	4.1	29 km ENE of Chamba, India

20	2006-04-21	32.569	76.664	3.9	33 km W of Keylong, India
21	2006-05-09	32.661	76.686	4.4	33 km WNW of Keylong, India
22	2006-07-18	32.783	77.38	4.2	40 km NE of Keylong, India
23	2006-09-13	32.729	76.615	3.6	42 km WNW of Keylong, India
24	2008-09-14	32.581	76.381	3.9	24 km E of Chamba, India
25	2009-01-31	32.528	76.564	3.9	41 km NE of Dharamsala, India
26	2009-07-17	32.716	76.709	4.6	33 km WNW of Keylong, India
27	2011-04-28	33.047	76.817	4.2	46 km S of Padam, India
28	2011-08-23	33.095	76.858	5.1	41 km S of Padam, India
29	2012-10-02	32.401	76.507	4.6	26 km NE of Dharamsala, India
30	2012-10-02	32.471	76.632	4.8	38 km WSW of Keylong, India
31	2013-06-04	32.672	76.601	4.9	41 km WNW of Keylong, India
32	2013-07-13	32.383	76.535	4.4	27 km NE of Dharamsala, India
33	2018-06-14	32.5602	76.3615	4.5	22 km E of Chamba, India
34	2019-07-24	32.7286	76.3907	4.2	31 km NE of Chamba, India
35	2019-07-29	32.8856	76.7183	4.4	45 km NW of Keylong, India
36	2021-01-09	32.521	76.6552	4.5	35 km W of Keylong, India

Hydrogeological process leading to slope failures occur during heavy rainfall periods in combination with or shortly after snow melt. Sources of water contributing to slope instability in Lindoor village include: Continuous seepage from glacier melt waters, irrigation channels (Figure 21), rains during the monsoon and snow accumulation in slope during winters. Surface tension cracks are formed in soil slopes during the dry period after a prolonged wet and dry cycle (Freeze-Thaw). Subsequently surface waters infiltrate through the soil cracks and increase the moisture content in deeper layers through seepage and saturate the soil layers and thus reduce the matrix suction in soil. During triggering events like the case of high intensity rainfall especially during the months of July and August, combined with the glacier melt waters and surface irrigation water can lead to the oversaturation of soil, thus reducing the matrix suction of soil to a larger extend. The significant reduction of matrix suction causes the reduction of soil shear strength and thus leading to the formation of fissures and soil cracks. Any water head in the soil cracks further increases the infiltration rate above that of an un-cracked soil surface. As deeper layers receive more water this may reduce the soil shear strength and can cause slope failure/land subsidence. In Lindoor village these factors can be linked with several ground cracks observed in villages and near to the glacier points and especially in areas away from the active slide zones.

The slope along the Jahlma *nala* is steep and two active slides were observed during the time of visit, where the SSW flowing Jahlma *nala* is taking a SE shift in its course. Loose debris materials were continuously sliding along these slopes at the time of visit. Many cracks observed in the area were concentrated near to the slides indicating that the slide is active and retrogressive. Seepage of water was also observed along the scrap portions of the slide (Figure 7). The fact that the landslide is active during the time of visit i.e., non monsoon period indicates that seepage of glacier melt water and channelized *nala* for irrigation as contributing factor for the slide together with the type of slope forming material (unconsolidated debris/talus) where the village is situated.

After tracing the major crack (Figure 4) in the surrounding village area- developed during the year 2023, as per interactions with the villagers- it may be inferred that the whole mapped area falls under the same prominent slope/facet and the major crack can be correlated with the other cracks observed within the village premises (Figure 4). It was also observed that the major crack has subsequent parallel smaller cracks. Conclusion can be made that the whole mapped area (Figure 4) is a part of a single failure zone.

Further, it was found during the visit that many non-concrete and concrete *nala* (Figure 21) are passing through the vicinity of houses in the village; these *nalas* have flowing water which again in turn leads to water seepages directly or through cracks near the house. Many houses in the village are as old as ~80 years, one or two storied and are made up of local rocks and mud plastering with no proper foundation, and any instability in slope due to water seepage can cause these structures to collapse very quicky. Incidences of wall collapses in some mud houses have also been intimated to authors during their visit by the villagers. As per information received from villagers there was continuous blasting of rocks for laying down water pipes during the month of October 2023, on the right banks of Jahlma *nala* near to the location of active slides. This blasting activity further increased the damages to the houses.

The field observations and consultation of geological reports, maps and downloaded earthquake and rainfall data indicate the following causes of subsidence and related ground cracks in the area of study:

(1) Based on the long evolutionary history of cracks, direction of major crack orientations, the presence of tension cracks with displacement and occurrence of 36 nos. of earthquake events (since 1900) in the 50 km radial distance from the Lindoor village, it appears to indicate a tectonic control behind the subsidence related cracks in the area.

(2) The freeze-thaw cycles, melt-waters of glaciers located upslope, occasional flash flood followed by drying, and seepage of water due to water supply and irrigation drainage lines in the loose debris material also contribute to the ground subsidence and crack formation in the area.

(3) The available rainfall data (source: IMD) for the period from Jan 2005 to Dec 2022 (Annexure-III) has been analysed. The month-wise rainfall plot for the period is shown in Figure 25. The Annual rainfall (Figure 26) and Monsoonal rainfall ranges from 291.5 mm to 796.5 mm and from 35 mm to 212.9 mm (Figure 27) respectively. In the absence of data on ground deformation and its chronology, correlation of rainfall with ground deformation could not be carried out.

(4) However, detailed site-specific studies involving a bigger area surrounding Lindoor village may be undertaken to precisely evaluate the processes leading to the ground deformation and slope instability.

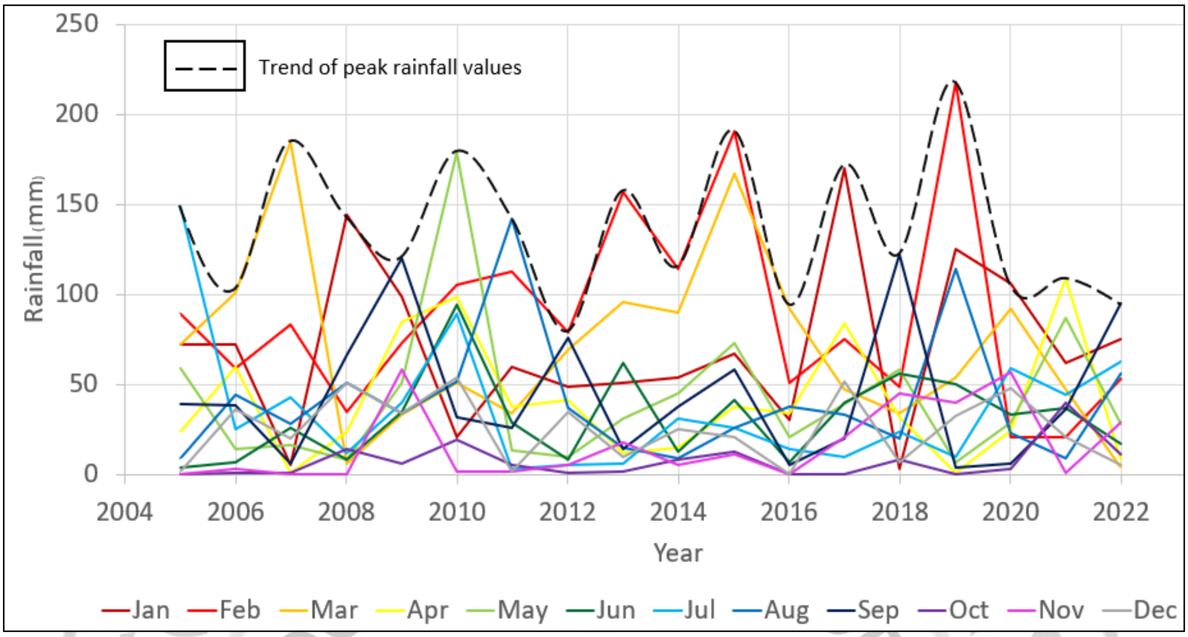


Fig.25: Total monthly rainfall data (mm) of Keylong, Lahaul & Spiti district, HP from 2005-2022.

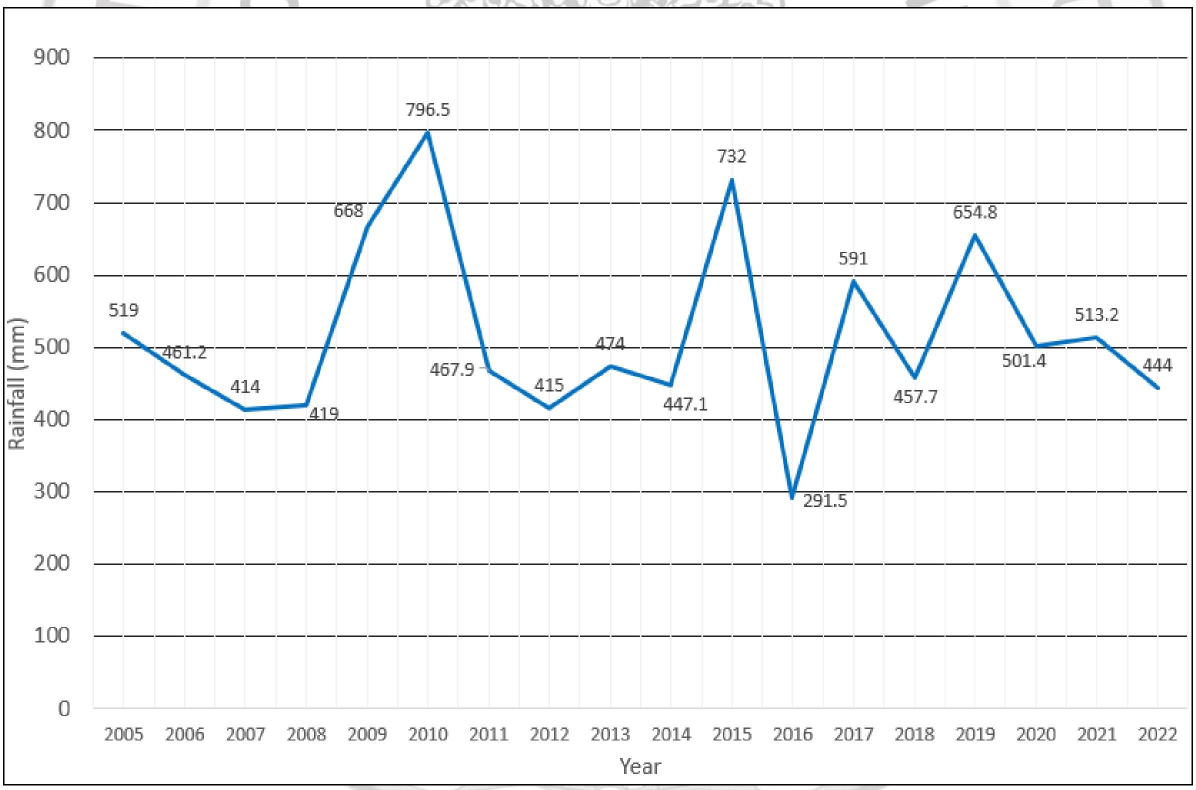


Fig.26: Total annual rainfall data (mm) of Keylong, Lahaul & Spiti district, HP from 2005-2022.

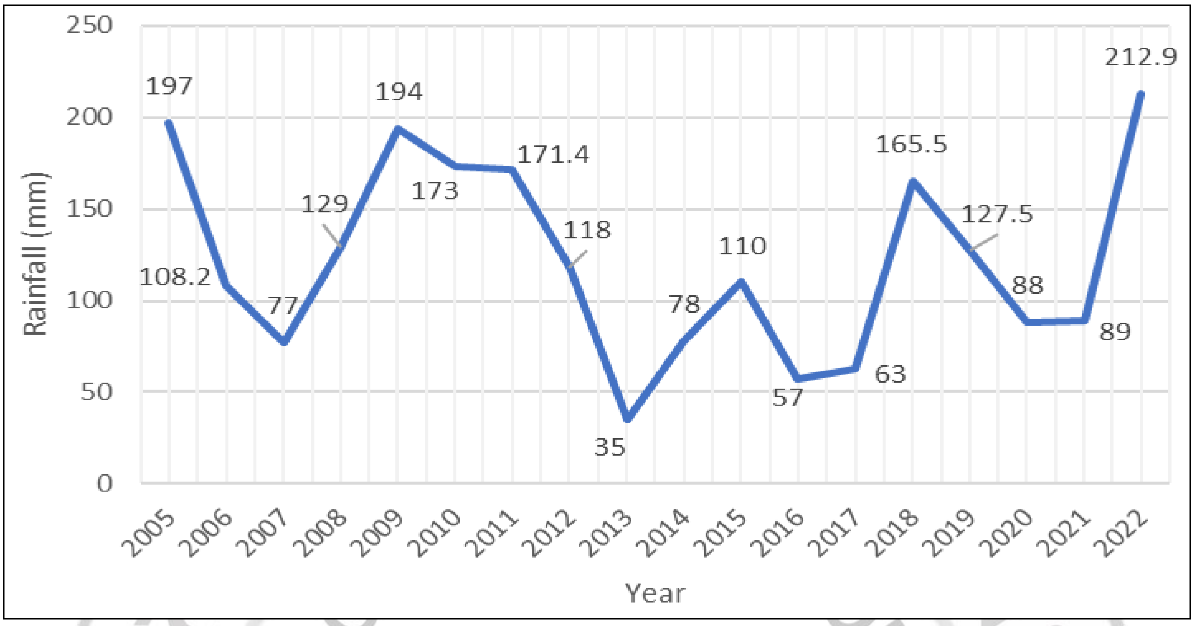


Fig.27: Total monsoonal rainfall data (mm) of Keylong, Lahaul & Spiti district, HP from 2005-2022.

1.6 SUGGESTIONS:

Based on the reconnaissance field visit at the site, following preliminary recommendations are suggested:

01) The entire Lindoor village is situated on an unconsolidated debris/talus material with multiple transverse and longitudinal cracks near the active slide zones and several other parallel crack sets towards the glacier snout zone indicating that the entire area is situated on an unstable slope and any triggering activity in the form of excessive glacier melt or cloud burst event, where, the ground becomes oversaturated, can lead to slope instability.

The houses which have suffered structural damage and the houses located adjacent to enlarging crown and widening portions of the landslides and located down slope of glacial snout should be shifted to safer locations. The rehabilitation of such houses to a safer place may be considered by the local stakeholders and the District Administration, with the initiative coming from the disaster management authorities of the state, taking into account the aforementioned criteria.

02) Temporary solutions are sealing of cracks by impervious material to avoid further enlarging/ ingress of water in debris/talus material at the earliest. Subsequently, crude monitoring/ vigil is a must in the affected and adjoining area regarding reoccurrence (after filling up of existing crack/subsidence affected area) or fresh occurrence of such incidences.

03) The re-occurrence and fresh occurrence of ground cracks and subsidence, may be brought to the notice of District Administration urgently. Real time ground deformation monitoring through InSAR, DGPS, and extensometer along with alarm system may be implemented, in order to have preparedness for the providence.

04) It must be noted that although the slumped debris mass near the toe of slide 1 and 2, is acting as a toe support for the failure, continuous pace of even smaller failures may induce instability to this mass with further scope of getting the same flown away by Jahlma *nala*. Therefore, it would be better if proper toe supports to this mass, as well as all along the debris/talus failure cone may be provided. This in turn, would prevent pressure of slush charged with water coming from Jhunda every year, especially in case of incessant rainfall spells/flash flood events during monsoon.

05) Appropriately designed retention structures/walls with stacks of crate walls may be provided all along the slumped mass along the left bank of Jahlma *nala* to retain the debris materials from further slipping.

06) Water seepage is the major problem in the area. Therefore, controlled channelling/piping of surface waters using appropriately designed water supply network instead of open *nalas*/channels for local use/irrigation would limit the over saturation of soil.

07) Continuous assessment and monitoring of glaciers runoffs near the Lindoor village and its proper record keeping should be done.

08) Considering the importance of water for agriculture and for survival and well being of the local population, surface water management by adopting practices such as drip irrigation, weather-based controllers, precision sprinklers, soil moisture monitoring, and crop water requirement calculations, farmers can optimize water usage. The details can be worked out with local stake-holders, agriculture scientists and civil engineers with initiative from disaster authorities of administration.

09) Attempts should be made to enquire whether or not; similar incidences of ground cracks and subsidence were experienced in nearby areas in past few years. The state government/district administration can probably be in the best position to collect such data. It is recommended that similar records should also be maintained in future so that any such disturbance can be better understood and monitored.

10) It was informed to the authors by the villagers that incidence of ground cracks and cracks in houses were a common phenomenon in the village from the year 2000 onwards. These incidences were never reported, but when the intensity of cracks increased this year after the monsoon and subsequent landslide events in other parts of Himachal Pradesh made the villagers panicked. This point to the need of an awareness programme among people on scientific reasons behind development of such ground cracks and subsidence and the dangerous consequent events associated with it, if left unchecked. These awareness programmes may be conducted under the guidance of appropriate organizations/departments. Such a programme will not only help in identifying landslide risk areas but also reduce the panic amongst the local population by ensuring co-operation from the residents while instrumentally monitoring such events in future.

11) Basic programmes on Slope instability and related issues and precautionary measures for slope stabilization may be framed by District Administration for various stake holders, students and local residents.

12) It must be noted that rainfall data recording, collection and maintaining of records are of utmost importance and installation of rain gauge stations at Taluka and Circle levels be initiated by District Administration and State Government for entire Himachal Pradesh. The rainfall data records generated can be very useful for various stakeholders including Administrative, Scientific, Academic and Local communities.

13) Detailed site-specific studies involving remote sensing, geological, geotechnical, geophysical, and hydrological components may be taken up to evaluate the causes of the subsidence and for implementation of remedial measures.

ANNEXURE-I

42-POINT DETAILED GEO-PARAMETRIC ATTRIBUTES FOR LINDOOR DEBRIS/TALUS SLIDE, LINDOOR VILLAGE, KEYLONG-UDAIPUR ROAD, SH-26, DIST. LAHAUL & SPITI, HIMACHAL PRADESH

No	Field	Description
1	Slide No. (LS. No.)	H.P./ Lahaul & Spiti/01/2023/Lindoor
2	State	Himachal Pradesh
3	District	Lahaul & Spiti
4	Toposheet	52D/14
5	Name of the slide	Lindoor slide 1
6	NH/SH/Locality	Lindoor
7	Latitude	$32^0$38’53.4”
8	Longitude	$76^0$52’23.1”
9	Length	~175.8 m
10	Width	~406 m
11	Height	~113 m
12	Area	~36512 m^2
13	Depth	>5 m
14	Volume	~4125856 m^3
15	Run out distance	~176 m
16	Type of Material	Debris (Clay-silt-sand with rock chunks and boulders of small to medium sizes)
17	Type of movement	Debris slide and associated subsidence
18	Rate of movement	Slow to Moderate
19	Activity	Active
20	Distribution	Retrogressive
21	Style	Successive
22	Failure mechanism	Deep rotational failure
23	History	Initiated during 2000s and reactivated during monsoon (Mid-August, 2023)
24	Geomorphology	Highly dissected and denudational hill slope
25	Geology	Vaikrita Group
26	Structure	The affected site comprises of Soil/Debris cone. However, in the right bank of Jahlma *nala* slopes/escarpments, weathered and jointed rock masses were observed. No rock is exposed along the left bank of Jahlma *nala* in the affected Lindoor village area.
27	Landuse/Landcover	Landuse: Agriculture/cultivation practice, civil structures; Land cover: Sparsely vegetated.
28	Hydrological condition	Wet conditions prevail in the landslide zone followed by recent development of *nala* on the left side of the landslide; Jahlma *nala* flows at the toe of the landslide as observed during field visit. The

		villagers have developed unlined channels (*kuhl/nalas*) for irrigation in the agriculture/cultivation fields which runs throughout the village area.
29	Triggering Factor	Rainfall
30	Death of persons	0
31	People affected	--
32	Livestock loss	--
33	Communication	--
34	Infrastructure	Cracks have been developed on houses as well as ground cracks have been developed on agriculture/cultivation fields
35	Agriculture/forest/Barren	Agriculture/Barren
36	Geo-scientific Causes	Thrust/pressure exerted on left bank slopes comprising of debris material and resultant toe erosion by Jahlma *nala*, increased pore-water pressure in debris/talus material possibly due to seepage of water (streamlet coming/flowing down) from upper slopes and *Kuhl/nala* passing all over the village areas used for water supply and irrigation purposes causing the ingress of water above the slide zone and due to moderately inclined hill slopes comprising of debris/talus material.
37	Remedial measures	1. Appropriately designed guide structures for toe support. 2. Immediate filling/protection of reported tension/ground cracks as reported in agriculture fields towards upslopes of the slope failure and observed tension/ground cracks in Lindoor village area. 3. Appropriately designed and placed checks along Jahlma *nala*.
38	Remarks, if any	--

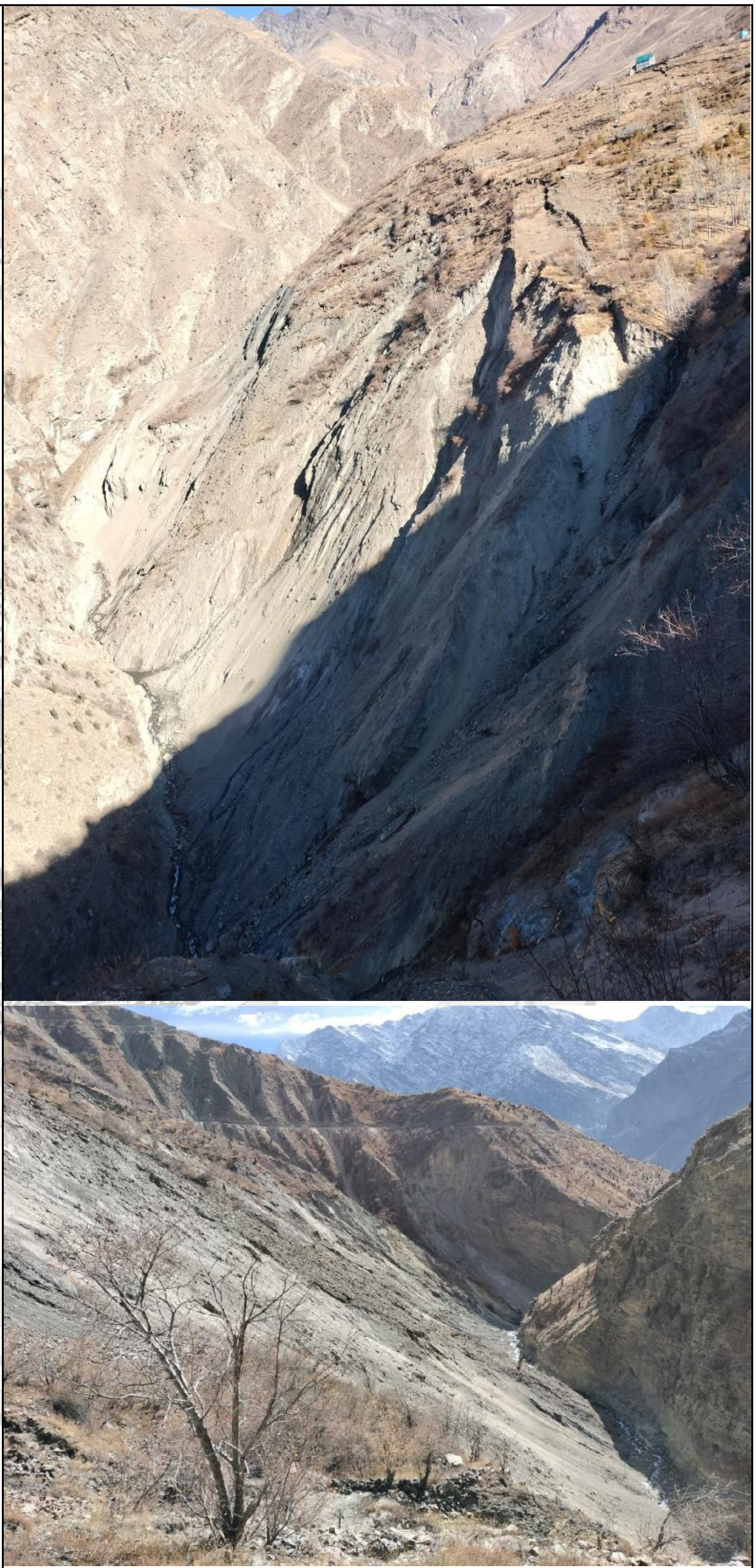
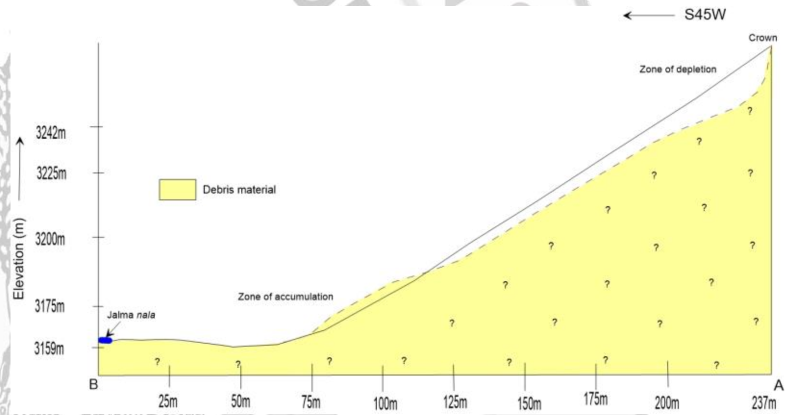
39	Photos. Sketch of Plan & section of the slide	 Fig.1 & 2: Distal view from right and left side of Lindoor Debris/Talus Slide 1, Lahaul & Spiti District.

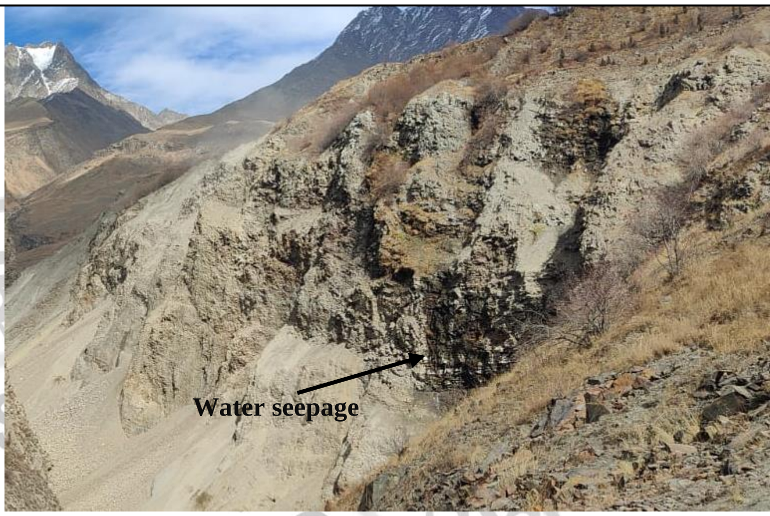
		 Fig.3: Crown of the Lindoor Debris/Talus Slide 1, Lahaul & Spiti District.  Fig.4: Schematic cross-section of Lindoor Debris/Talus Slide 1, Lahaul & Spiti District.
40	Summary/Abstract	As per the information from the villagers, the slide has been initiated somewhere near the year 2000. Since then, minor overburden sliding has been continuously been occurring but the slide has been majorly reactivated during the month of August 2023. As per media reports, 12 houses have developed cracks and fissures have also developed all over around 200 bighas of land. These reports were confirmed during the ground visit and found that these settlements are present ~300 m above the crown of the slide. The reasons could be attributed to the following: increased pore-water pressure in the debris/talus material possibly brought on by seepage of water (streamlet coming/flowing down) from upper slopes and *Kuhl/nala* passing all over the village areas used for water supply and irrigation purposes causing the ingress of water above the slide zone; or thrust/pressure exerted on left bank slopes comprising of debris material and resulting toe erosion by Jahlma *nala*.
41	Pdf	
42	Alert	II

ANNEXURE-II

42-POINT DETAILED GEO-PARAMETRIC ATTRIBUTES FOR LINDOOR DEBRIS/TALUS SLIDE, LINDOOR VILLAGE, KEYLONG-UDAIPUR ROAD, SH-26, DIST. LAHAUL & SPITI, HIMACHAL PRADESH

No	Field	Description
1	Slide No. (LS. No.)	H.P./ Lahaul & Spiti/01/2023/Lindoor
2	State	Himachal Pradesh
3	District	Lahaul & Spiti
4	Toposheet	52D/14
5	Name of the slide	Lindoor slide 2
6	NH/SH/Locality	Lindoor
7	Latitude	32^{0}39’04.6”
8	Longitude	76^{0}52’33.1”
9	Length	~130 m
10	Width	~339 m
11	Height	~78 m
12	Area	~37796 m^2
13	Depth	>5 m
14	Volume	~2948088 m^3
15	Run out distance	~130 m
16	Type of Material	Debris (Clay-silt-sand with rock chunks and boulders of small to medium sizes)
17	Type of movement	Debris slide and debris fall and associated subsidence
18	Rate of movement	Extremely Rapid
19	Activity	Active
20	Distribution	Retrogressive
21	Style	Successive
22	Failure mechanism	Deep rotational failure at place of debris slide
23	History	Initiated during 2000s and reactivated during monsoon (Mid-August, 2023)
24	Geomorphology	Highly dissected and denudational hill slope
25	Geology	Vaikrita Group
26	Structure	The affected site comprises of Soil/Debris. However, in the right bank of Jahlma *nala* slopes/escarpments, weathered and jointed rock masses were observed. No rock is exposed along the left bank of Jahlma *nala* in the affected Lindoor village area.
27	Landuse/Landcover	Landuse: Agriculture/cultivation practice, civil structures; Land cover: Sparsely vegetated.
28	Hydrological condition	Seepage of water can be observed at the scar face; Jahlma *nala* flows at the toe of the landslide as observed during field visit. The villagers have developed unlined channels (*kuhl/nala*) for

		irrigation in the agriculture/cultivation fields which runs throughout the village area.
29	Triggering Factor	Rainfall, blasting near the toe of the slide zone.
30	Death of persons	0
31	People affected	--
32	Livestock loss	--
33	Communication	--
34	Infrastructure	Cracks have been developed on houses as well as ground cracks have been developed on agriculture/cultivation fields
35	Agriculture/forest/Barren	Agriculture/Barren
36	Geo-scientific Causes	Thrust/pressure exerted on left bank slopes comprising of debris material and resultant toe erosion by Jahlma *nala*, increased pore-water pressure in debris/talus material possibly due to seepage of water (streamlet coming/flowing down) from upper slopes and *Kuhl/nala* passing all over the village areas used for water supply and irrigation purposes causing the ingress of water above the slide zone and due to steep hill slopes comprising of debris/talus material.
37	Remedial measures	1. Appropriately designed guide structures for toe support. 2. Immediate filling/protection of reported tension/ground cracks as reported in agriculture fields towards upslopes of the slope failure and observed tension/ground cracks in Lindoor village area. 3. Appropriately designed and placed checks along Jahlma *nala*.
38	Remarks, if any	--

39	Photos. Sketch of Plan & section of the slide	 Fig.1: Distal view from right side of Lindoor Debris/Talus Slide 2, Lahaul & Spiti District with seepage of water.  Fig.2: Active slide and fall of debris/talus material.

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		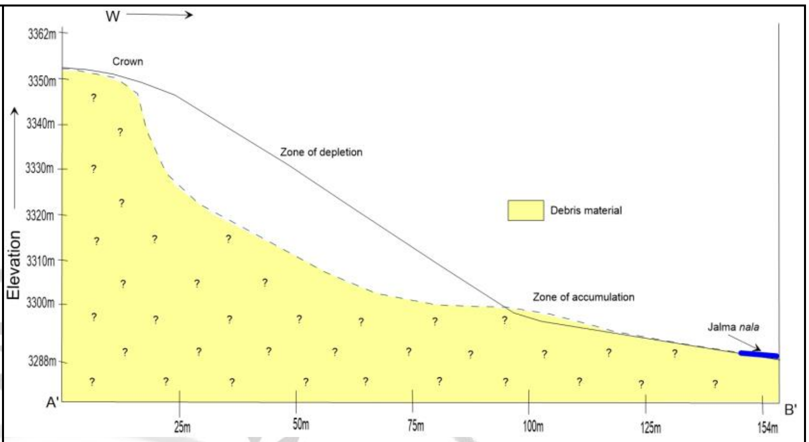 Fig.3: Schematic cross-section of Lindoor Debris/Talus Slide 2, Lahaul & Spiti District with seepage of water.
40	Summary/Abstract	As per the information from the villagers, the slide has been initiated somewhere near the year 2000. Since then, minor overburden sliding and fall has been continuously been occurring but the slide has been majorly reactivated during the month of August 2023. According to the villagers, blasting was carried out at the toe of the slide/fall zone for river water channelization by villagers of other villages. The blasting has been stopped after appeal by the villagers of Lindoor. As per media reports, 12 houses have developed cracks and fissures have also developed all over around 200 bighas of land. These reports were confirmed during the ground visit and found that these settlements are present ~250 m above the crown of the slide. The reasons could be attributed to the following: increased pore-water pressure in the debris/talus material possibly brought on by seepage of water (streamlet coming/flowing down) from upper slopes and *Kuhl/nala* passing all over the village areas used for water supply and irrigation purposes causing the ingress of water above the slide zone; or thrust/pressure exerted on left bank slopes comprising of debris material and resulting toe erosion by Jahlma *nala*.
41	Pdf	
42	Alert	II

ANNEXURE-III

MONTH WISE YEARLY RAINFALL DATA OF KEYLONG, LAHAUL & SPITI DISTRICT, HP (SOURCE: IMD)

Month	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	
Jan	72	72	5	**144**	99	21	60	49	51	54	67	30	**170**	3	125	**106.3**	62	75	**Rainfall (mm)**
Feb	89	59	83	35	73	105	113	79	**157**	**114**	**191**	51	75	49	**218**	20.6	21	53	
Mar	72	**101**	**185**	6	33	51	34	69	96	90	167	**92**	47	34	54	92	47	4	
Apr	24	60	1	24	85	99	38	41	12	15	38	34	84	32	1	24.5	**109**	8.4	
May	59	14	16	8	51	**178.5**	13.5	10	31	45	73	20.5	39	58.1	7	29	87	28	
Jun	4	7	26	8	35	94	29	8	62	13	41.5	7	40	56.1	50.1	33	37	17	
Jul	**149**	25	43	12	40	89	3.4	5	6	31	26	14	10	23.5	9.5	59	44	62.4	
Aug	9	44.5	28	51	34	52	**142**	37	15	9	26	38	33	20	114	23	9	55.7	
Sep	39	38.7	6	66	**120**	32	26	**76**	14	38	58	5	20	**122**	4	6	36	**94.8**	
Oct	0	1	1	14	6	19	5	1	2	8	12.5	0	0	8	0	3	39.7	11.4	
Nov	0	3	0	0	58	2	2	5	18	5.1	11	0	21	45	39.7	57	1	29.1	
Dec	2	36	20	51	34	54	2	35	10	25	21	0	52	7	32.5	48	20.5	5.2	