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हिमाचल प्रदेश के हमीरपुर जनपद के हिस्सों में ढ़लान अस्थायित्व तथा संबन्धित घटनाओं का भूवैज्ञानिक आंकलन

(भा. स. वि. टोपोशीट सँख्या: 53ए/6, 53ए/10 एवं 53ए/11)
[मिशन - 4/ क्षेत्र कार्य-वर्ष 2023-24: अतिरिक्त कार्य]
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GEOLOGICAL ASSESSMENT OF SLOPE INSTABILITY AND ASSOCIATED PHENOMENA IN PARTS OF HAMIRPUR DISTRICT, HIMACHAL PRADESH

(Sol Toposheet Nos.: 53A/6, 53A/10 and 53A/11)
[Mission - IV/ Field Season: 2023-24: Addl. Work]
[Under Item No.: M4EGG/C/NR/SU-PHP/2023/45658]

द्वारा:
हरीश बहुगुणा[1], अतुल कोहली[2], प्रशान्त त. इलामकर[3]
1: उपमहानिदेशक, मि4ए (भू-तकनीकी एवं भू-आपदा प्रबन्धन), भा. भू. स. (के. मु.), कोलकाता (प. बं.)
2, 3: निदेशक (भू.), मि-4, रा. इ.-पं., ह. एवं हि. प्र., भा. भू. स. (उ. क्षे.), चण्डीगढ़ (के. शा. प्र.)
भारतीय भूवैज्ञानिक सर्वेक्षण, उत्तरी क्षेत्र

By:
Harish Bahuguna[1], Atul Kohli[2], Prashant T. Ilamkar[3]
1: DDG, M4A (Geotechnical and Geohazards Management), GSI (CHQ), Kolkata (W.B.)
2, 3: Director, M-IV, SU-PHHP, GSI (N.R.), Chandigarh (U.T.)

भारतीय भूवैज्ञानिक सर्वेक्षण, उत्तरी क्षेत्र / Geological Survey of India, Northern Region
राज्य इकाई: पंजाब, हरियाणा तथा हि. प्र./ State Unit: Punjab, Haryana and H.P.
चण्डीगढ़ - 160 020 (के. शा. प्र.) / Chandigarh - 160 020 (U.T.)

दिसम्बर /December, 2023

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[Sol Toposheet Nos.: 53A/6, 53A/10 and 53A/11]

[Mission - IV/ F.S.: 2023-24: 05-07/11/2023]

By:

Harish Bahuguna[1], Atul Kohli[2], Prashant T. Ilamkar[3],

1: DDG, M4A (Geotechnical and Geohazards Management), GSI (CHQ), Kolkata (W.B.)

2, 3: Director, M-IV, SU-PHHP, GSI (NR), Chandigarh - 160020 (U.T.)

1.1 THE BACKDROP:

In the ongoing Field Season 2023-24, a Brain Storming Workshop (BSWS) on Geological Hazards particularly Earthquakes and Landslides in Northwestern Himalayas was conducted by the Himachal Pradesh Council for Science, Technology and Environment (HIMCOSTE) in association with Himachal Pradesh State Disaster Management Authority (HPSDMA), Govt. of Himachal Pradesh, during 05-06/10/2023 at Shimla, the Capital to the state of Himachal Pradesh. During the BSWS, Hon'ble Chief Minister of the State has expressed the desire to study the unusual activity at Bara Gaon area near Barsar in Himachal Pradesh by GSI. Subsequently, in light of Letter No. Rev. (DMC)(F)(1)1-3//2019-Meeting-1182, Dt. 16/10/2023 from H.P. State Disaster Management Authority (HPSDMA) addressed to DG-GSI and further instructions from competent authorities in GSI as conveyed vide OCBIS Mail dt. 31/10/23 (A/N) from Mr. A. K. Talwar, Director TC, SU-PHHP, GSI (NR), Chandigarh instructing to attend the same. The field studies were carried out during 05-07/11/23.

Although as per above BSWS and HPSDMA's letter, request was made to GSI for geological assessment of the unusual phenomena related to slope instability/landslide activity in Barsar area (Bara Gaon), after reaching at Barsar, the team was also requested for geological assessment of slope instability/landslide activity at two more locations viz. Jabal-Khairian and Samthana villages. Accordingly, the present reconnoitory geological assessment of slope instability and associated phenomena at above locations was carried out during 05-07/11/2023..

On 05/11/23, the authors carried out field visit to Bara Gaon and Jabal-Khairian Villages and carried out reconnoitory assessment of the slope instability and associated phenomena. Subsequently, on 06/11/23, the 2nd and 3rd authors of this Note continued field studies in parts of Bara Gaon and Samthana Villages area, and, likewise, they carried out field studies in parts of Jabbal-Kherian Villages on 07/11/23 to study the above phenomena. During 1st day i.e. 05/11/23, Dr. Rohit Sharma, SDM and Mr. Suram Singh, Tehsildar, Barsar joined the GSI Team, in addition to Gram Sabha Officials and local residents. Similarly, during 06 and 07/11/23, Mr. Suram Singh continued with GSI Team, in addition to Tehsil and Gram Sabha Officials and local residents. There was, however, no Official present from District Disaster Management Authority (DDMA), Hamirpur. Although no loss to life was conveyed by the District Administration, Gram Sabha Officials and Local Residents to GSI team, they have conveyed about the damage in the area due to above incidences including damage to civil properties. The District Administration Officials have also conveyed that for a few affected families, rehabilitation/relocation process is underway. The observations, findings and general suggestions with a view to reduce risk to life and property were conveyed to Dr. Sharma, Mr. Singh and Tehsil Officials at SDM Office, Barsar at the end of this study.

1.2 LOCATION AND ACCESSIBILITY:

Hamirpur is a sparsely populated, centrally located district of Himachal Pradesh State. It is bounded on the east by Mandi district, on the northwest Kangra district, on the south and southwest by Bilaspur and Una districts respectively (CGWB, 2013) (Fig. 01). In all, 3 areas affected by slope instability phenomena were reconnoitored. The Bara Gaon and Jabal-Khairian villages form part of Barsar Tehsil while Samthana village forms part of Bijhri Tehsil of Hamirpur district. The Bara Gaon village [Coordinates: N31°27'54.306" (N31.465); E76°36'31.598" (E76.609)] is located immediately on right bank slopes of Sukar *Khad* and falls in Survey of India (SoI) Toposheet No. 53A/10. The Jabal-Khairian village [Coordinates:

Jabal: N31°30'34.268" (N31.509); E76°27'0.198" (E76.450); Khairian: N31°30'25.114" (N31.507); E76°27'0.299" (E76.450)] fall in SoI Toposheet No.53A/6. Likewise, the Samthana village [Coordinates: N31°32'51.370" (N31.548); E76°34'55.153" (E76.582)] is located along uphill sides of left bank slopes of Sukar Khad and falls in SoI Toposheet No. 53A/11 (Fig. 01). The study area can be accessed from Barsar Tehsil headquarters and Hamirpur District headquarters through all weather roads. Similarly, the study area can be accessed from Chandigarh via Chandigarh-Sri Anandpur Sahib-Nangal-Una-Hamirpur Road. The nearest main broad gauge railway station and Airport are located at Una (H.P.) and Chandigarh (U.T.), connecting the study area with rest of the nation.

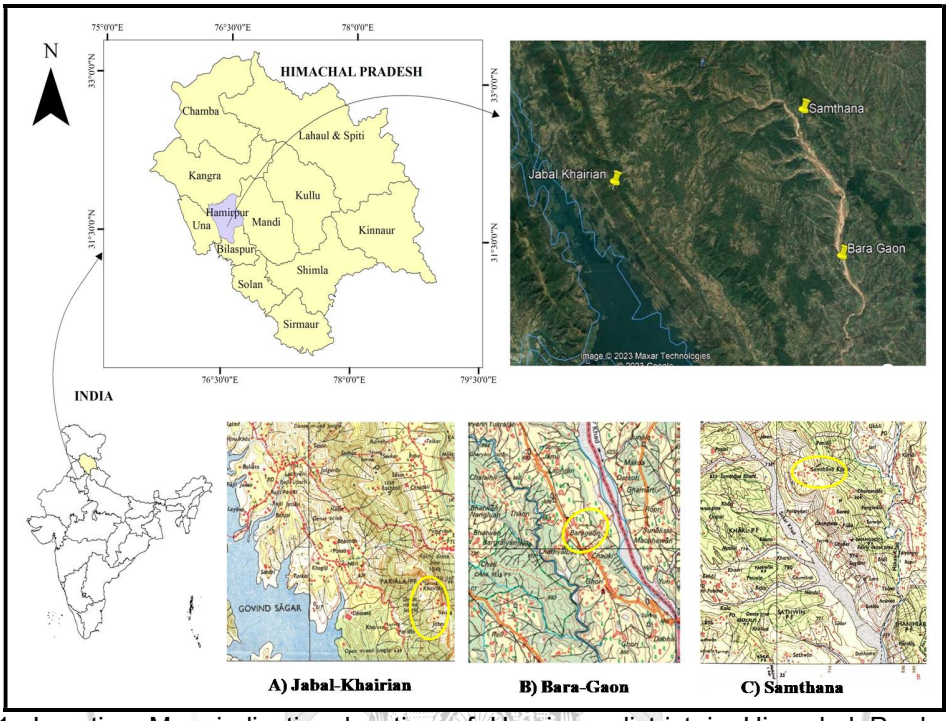

Fig. 01: Location Map indicating location of Hamirpur district in Himachal Pradesh and showing A) Jabal-Khairian, B) Bara Gaon and C) Samthana villages falling in parts of Survey of India (SoI) Toposheet Nos. 53A/6, 53A/10 and 53A/11 respectively (Note the Yellow Ovals) [Source: Google Earth; Survey of India (SoI) Toposheets].

1.3 GEOMORPHOLOGY AND GEOLOGY:

The Hamirpur district forms a part of Changer Belt, which is an acute water scarcity area of the State and experiences severe drought conditions. The terrain of the district is mostly hilly and undulating. The surface elevation ranges in the district varies from 400m to 1145m above MSL. Deep gulleys and gorges are formed in the northeastern parts of the district. The river/ *Khad* valleys are broad in the southern parts of the district (CGWB, 2013). Broadly, four geomorphic units can be identified in this district viz. moderately steep to very steep low hills and valleys of Siwaliks, the fluvial valley of the Beas river, fluvial terrace and structural valleys. Drainage in the upper reaches is dendritic but streams (*Khads*) preserve trellis pattern, controlled by the structure of the rocks. (GSI, 2002) (Fig. 01).

The district lies in the foothill ranges of the Outer Himalaya and is covered by the rocks of Siwalik Group of Middle Miocene, Plio-Pleistocene Age (GSI, 2002). The Siwalik belt around Hamirpur, H.P. is a part of the Gambhar-Sarkaghat fault block. Three main litho-units belonging to Lower, Middle and Upper Siwalik Formations are decipherable in the area on gross lithologies and physical characters of the sediments (Verma, 1979). The Siwalik Group comprises grey to light green colour, thickly bedded sandstone with salt and pepper texture, intercalations of light red, brown or greenish grey clay and boulder conglomerate. Quaternary sediments are represented by the newer alluvium and boulder conglomerate. Quaternary sediments are represented by the newer alluvium along the river and streams (*Khads*). The Barsar thrust, Gambhar thrust and Changar talai anticline are three major structures in the area. Soft to moderately hard sedimentaries constitute geotechnical province of the district

which has low to moderately high permeability, wide ranging bearing capacity/compressive strength and poor/fair foundation characteristics (GSI, 2002; GSI) (Fig. 01, 02).

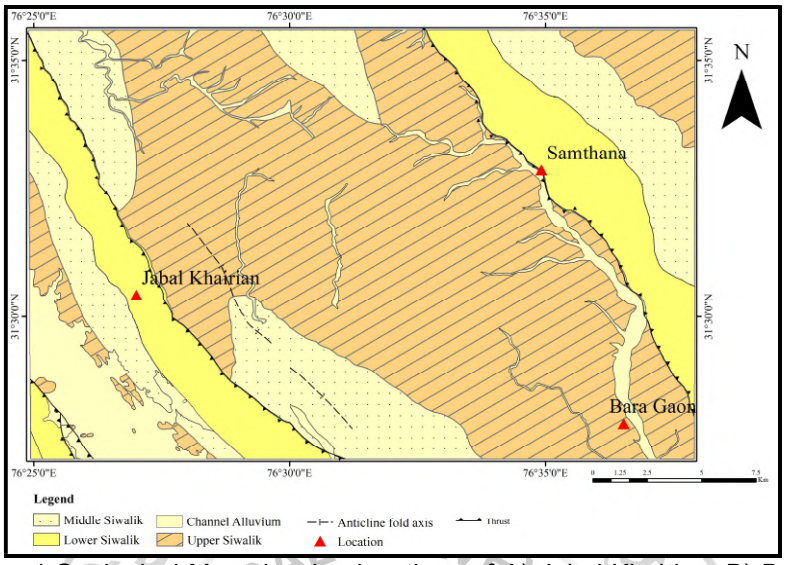

Fig. 02: Regional Geological Map showing locations of A) Jabal-Khairian, B) Bara Gaon and C) Samthana villages [Source: Geoinformatics Division, GSI, Chandigarh].

1.4 HAZARD PROFILE:

The Hamirpur district is vulnerable to multi-hazards viz. earthquakes, road accidents, forest fires, urban fires, floods, landslides, hailstorms, dam burst, drought but particularly earthquake. The district falls in the highest seismic risk zones of the country i.e. Zone V and IV. The 90.9% area of the district is situated in Zone V and rest 9.1% of area falls in Zone IV (HPSDMA, 2017; BMPTPC 2019) (Fig. 03).

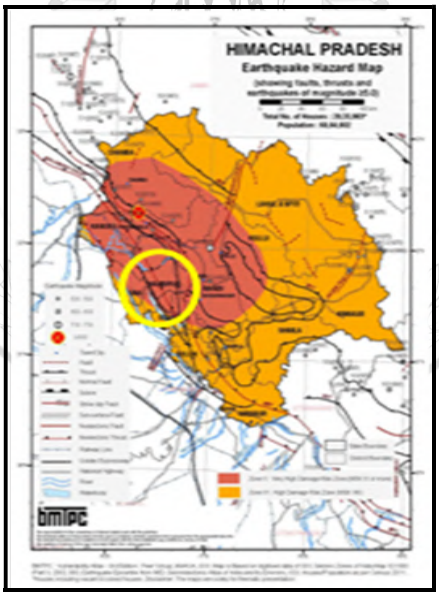

Fig. 03: Location of Hamirpur District falling in Seismic Zones IV and V (BMTPC, 2019) (Note the Yellow Circle).

From landslide/slope instability point of view, high, moderate and low susceptible zones have been identified in parts of Hamirpur district based on Macro Scale (1:50,000) landslide susceptibility mapping (LSM) studies linked with GSI's flagship National Landslide Susceptibility Mapping (NLSM) Programme. For the above studies, all the major factors that induce landslide have been used for landslide susceptibility mapping along with landslide inventory preparation and recognizing the main causes of instability (Mandal et al., 2019; Nabiyal and Ganguly, 2019 and Kumar et al., 2019).

1.5 FIELD OBSERVATIONS AND RECONNOITORY SLOPE STABILITY ASSESSMENT:

1.5.1 Bara Gaon:

The Bara Gaon is located off Barsar-Bhota Road along right bank slopes of Sukar *Khad*, a tributary of Satluj River and is flowing in N-S direction. The area can be accessed by all weather road followed by some trekking along available foot tracks. The dwelling units in the settlement are located above ~08-15m thick overburden/ river borne material (RBM) of quaternary deposits. The sizes of the pebbles comprising the section vary from fine clay, layers of silty sand and pebbles to cobbles of varying sizes (Fig. 04 to 09).

From slope instability point of view, gullies were observed in above stated overburden/RBM column. The major gully (with general orientation N160° to N210°) was observed in upstream starting from rock mass exposed along right bank of Sukar *Khad* (Fig. 04 to 09). While, it's downstream end was observed at a distance of about ~100m, opening in overburden/RBM. Due to presence of rock mass in upstream side and overburden/RBM in downstream side, the aperture of major gully was observed relatively less in upstream side as compared to downstream side, where the same was relatively wider.

Fig. 04: Proximal view of the major gully (~ N160° to N210°), as observed along right bank of Sukar *Khad* (Note the partially damaged civil structure along right bank).

Fig. 05: Proximal view (as observed in d/s side) of the major gully, as observed along right bank of Sukar *Khad* (Note the partially damaged civil structure along right bank).

Fig. 06: Proximal view (as observed in u/s side) of the major gully (with general orientation N160° to N210°), as observed along right bank of Sukar *Khad*.

Fig. 07: About 08-15m thick succession of Quaternary sediments as observed exposed along the sides/walls of major gully.

Fig. 08: Thick succession of Quaternary sediments as observed exposed along the sides/walls of the major gully.

Fig. 09: Quaternary sediments as observed exposed along the right bank of Sukar *Khad* (towards downstream of the major gully) (Note the Yellow oval).

While approaching from Sukar *Khad* Side, weathered and jointed rock mass comprising clay stone/siltstone was observed along right bank. Mainly three sets of joints were observed in the rock mass viz. J_1 (S0): 24°/N354°, J_2: 60°/N060° and J_3: 86°/N164°. Quaternary deposits were also observed along open joints/fractures along the outcrop (Fig. 10 to 13).

Fig. 10: Weathered and jointed rock mass outcrop exposed towards u/s end of the major gully, as observed along right bank of Sukar *Khad* (Note the Yellow oval).


Fig. 11: Weathered and jointed rock mass exposed towards u/s end of the major gully, as observed along right bank of Sukar *Khad*.


Fig. 12: Weathered and jointed rock mass and widened joint(s) towards u/s end of major gully, as observed along right bank of Sukar *Khad*.


Fig. 13: Quaternary deposits as observed along open joints/fractures in weathered rock mass, as observed along right bank of Sukar *Khad*.

As per local residents, agriculture practices through terraced agriculture have been followed since a long time which is also observed from the available SoI Toposheet (Fig. 01; 15). As observed during field studies, river bank erosion processes and associated slope instability were observed clearly along major gully on right bank of Sukar *Khad*. This has led to development of several instability signatures like ground cracks, differential settlement, bulging, gullying with occasional piping activity in overlying overburden/RMB material.

Coming to the settlement, a few cracks were observed in a house that was located in immediate vicinity of the major gully along right bank of Suker *Khad*. The general trend of the cracks was also observed almost N-S during field studies, which was broadly near similar to that of the major gully. At places, they were observed zig-zag. The aperture of these cracks was relatively less varying from about few mm to few centimetres. Along the right bank of Sukar *Khad*, retention structures that were provided for river bank protection. The same were tilted and damaged reportedly during SW Monsoon of 2021 and 23 (Fig. 14). However, it is to state that neither the major gully nor the instability signatures such as subsidence, ground cracks etc. are visible in available satellite imageries (Fig. 15).

Fig. 14: Partly tilted and damaged retention structures seen along right bank of Sukar *Khad*. .

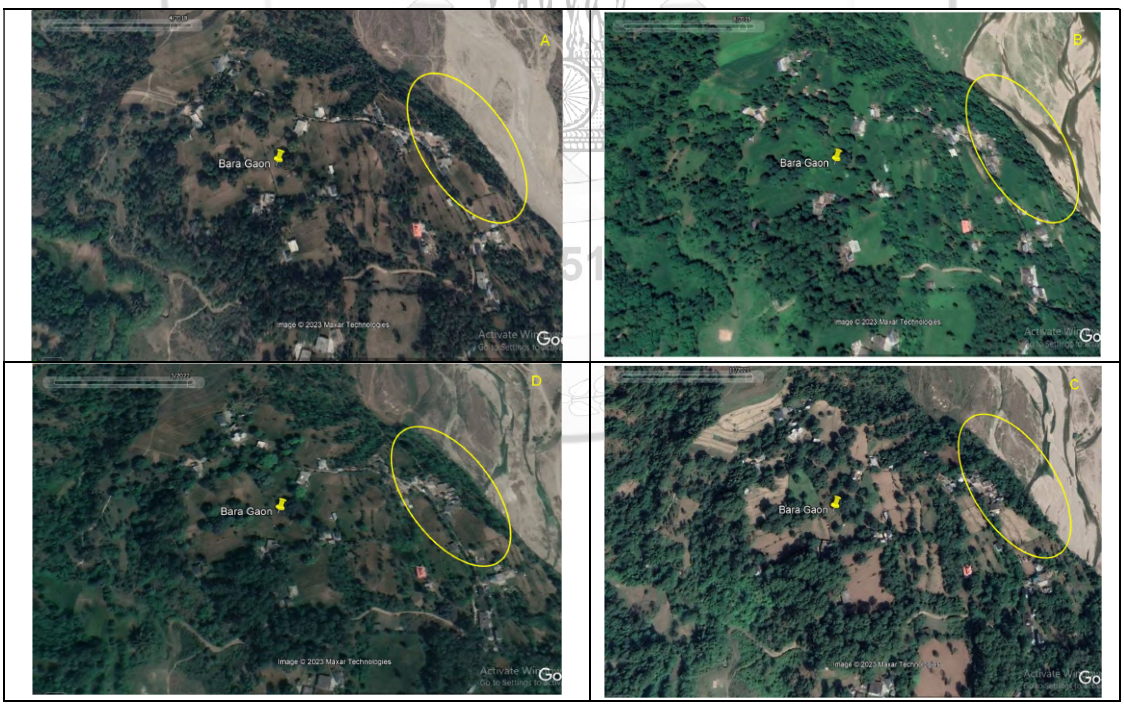

Fig. 15: Time series view of Bada Gaon area including incision/slope instability affected area (indicated by a yellow oval), as discernible in 2018, 2019, 2021 and 2022 (Clockwise: A, B, C, and D respectively: Note the yellow ovals) (Source: Google Earth).

From risk perception point of view, the house(s) that are located towards extreme outer end of the settlement are having possible risk of further damages to the agricultural land and civil

structures here; which may also involve possible risk to life. On account of roundness of its constituents and relatively poor degree of cohesion, the RBM material is often vulnerable for the slope failure.

Based on field traverses and discernible features, following possible causes are observed:

01) Based on field observations, it is said that from immediate upstream side of the village, a splay/branch of Sukar *Khad* has entered/breached through the open fractures/joints exposed in the weathered and jointed rock mass towards exposed along right bank of the *Khad*. During spells of rainfall and perennial ingress of *Khad* water through above open fractures, the river borne material forming the bank slopes got completely wet and oversaturated (Refer 1.3; Fig. 10 to 13).
02) Due to perennial ingress/breach of *Khad* water and oversaturation of the riverine material, the pore water pressure has developed that has further exceeded and caused failing of the river borne material and associated slope instability/failures .
03) The above processess is likely to be enhanced due to agriculture water that was used by local residents for irrigation of agriculture fields nestled above right bank slopes at the affected locations.
04) Steeper local slope accompanied with heavy water discharge of water deduced to have aggravated the pace of erosion activity at the location, which has gradually eroded away the relatively softer sediments of the material forming the local slope along river bank and formed relatively wider gullies as can be seen towards middle and downstream side, finally merging with Sukar *Khad* along its right bank in downstream direction.

1.5.2 Jabal-Kharian Village:

It's a twin village i.e. Jabbal and Kharian, locally called as Jabbal-Kharian, with their Gram Panchayat being Barsar in Barsar *Tehsil* of the district. During the site visit, a total of six slope instability affected spots in this twin village were shown by the Tehsil Officers to the GSI Team: two and three spots in Jabbal and Kharian areas respectively. These spots are located along gentle to moderately inclined slopes with sparse vegetation and agriculture practices. Almost all of these spots are overlooking the tail part of Bhakra (Gobind Sagar) Reservoir and their slope direction, in general, varies from N160° to N240°. The slope instability phenomena at all of the above locations are mostly development of ground cracks with or without differential settlement, creep movement and minor slope failure incidences.

1.5.2.1 Jabal Village:

In this village, following 2 locations were shown to the authors of this Report:

Location-1-A: Mahila Mandal Building and adjoining areas: The location [Coordinates: N31°30'25.114" (N31.507); E76°27'0.298" (E76.450); Elv: ±831] is located along Mahila Mandal Building Complex, where a few instability signatures viz. intermittent/discontinuous ground cracks, bulging/minor failures of skirt/bund/retaining walls etc. were observed within the premises and sporadic spots in continuity with terraces located in adjoining area (Fig. 16, 17 and 18). Some of these intermittent/discontinuous cracks were observed to have finer to medium aperture while a few were observed to have a few mm wide aperture and the later observed as discontinuous/intermittent and though zig-zag yet following the gentler slope's overall orientation.

Fig. 16: Instability signatures (damage to skirt wall: Note the right portion of the Fig.) as observed in Mahila Mandal Complex, Jabbal Village.

Fig. 17: Instability signatures (damage to dry stone wall and foot track) as observed in Mahila Mandal Complex, Jabbal Village.

Fig. 18: A minor bund failure in bund wall of agriculture terraces at some distance away from Mahila Mandal Complex (Note the yellow oval).

It is to state here that the drainage arrangement in Mahila Mandal Building Complex and in adjacent terraces was extremely poor. The slope material observed was mainly fine to coarse grained soil. Intermittent ground cracks were also observed in agriculture field area during the time of field studies. It is crucial to state that there was no crack in other civil structures located a few meter away from the affected spot. As per the local residents, these instability features have also observed starting during Southwest monsoon 2023.

Location-1-B: Slope failure located a few meters away in strike continuity of Location-1-A: This location [Coordinates: N31°30'25.114" (N31.507); E76°27'0.298" (E76.450); Elv: ±831] is located at a few meters away from the Location-1 along the same slope only and overlook the tail part of Bhakra (Gobind Sagar) Reservoir. As per the local residents, it was intimated that they were previously residing in Location-1 area but due to development of intermittent ground cracks, associated minor subsidence and minor failures (Fig. 18, 19, 20 and 21) and in light of partial damage to their house, they've shifted to this new spot (Fig. 21). Nonetheless, an incidence of slope failure was observed at this location immediate next to the house building, which as per the local residents took place towards the end of Southwest Monsoon of 2023 (Fig. 21).

However, based on the geological assessment carried out, it is imperative to state here that no proper arrangement for channelization of domestic and natural drainage was present in the area. The surface and rain water thus flown freely on natural surface This had resulted into prolonged ingress into ground/slope material (mostly overburden) and further downwards. This has probably caused for the development of instability features such as viz. ground crack(s) (seen intermittent/discontinuous), minor slope failure(s) etc. that took place here (Figs. 18, 19, 20 and 21). Possibilities can't be ruled out regarding removal of less competent layer of mudstone layer immediate below the sandstone rock mass, as seen sporadically at one or two locations in the area, which is a known process in Siwaliks (Fig. 20). Nevertheless, again in strike continuity of this location, the slope failure indicated above can be attributed due to absent drainage network and free flow of domestic water on the same slope in front of house leading to minor slope failure incidence (Fig. 21).

Fig. 19: Traces of ground cracks (next to temporary drain) as observed in strike continuity of Mahila Mandal Complex at Jabbal Village.

Fig. 20: Traces of ground crack below a sandstone rock mass outcrop (?) as observed in strike continuity of Mahila Mandal Complex at Jabbal Village.

Fig. 21: Minor slope failure that took place in further strike continuity of Mahila Mandal Complex.

1.5.2.2 Khairian Village:

A total of 3 locations were shown by Tehsil Officials on 07/11/23 in Khairian village, another village of Jabbal-Khairian twin village. These are as follows.

Location-2-A: Road Subsidence and Cracks in adjoining areas: The location [Coordinates: N31°31'1.804" (N31.5172); E76°26'45.394" (E76.446); Elv: ±797] is affected by a relatively smaller road subsidence incidence (Fig. 22), which according to the local residents took place during the Southwest monsoon of 2023. Nonetheless, during the field observations, a valley side seasonal *nala* was observed with a few house(s) constructed along its left bank on valley side. Although no damage was observed to the above house(s) on account of a guide wall placed immediate behind them along left bank of above seasonal *nala*, possibilities of risk/damage to the civil structure(s) cannot be ruled out in case of extreme weather events/high intensity rainfall spells.

Fig. 22: A relatively smaller subsidence incidence as observed along approach road of Khairian Village.

It is to further state that a few meters away from right bank of above *nala*, cracks, bulging in bund walls and other similar instability signatures were observed in a house located amidst terraced agriculture fields (Fig. 23, 24).

Fig. 23: Crack observed along one wall of a house, located along the agriculture terraces built up within house premises.

Fig. 24: Agriculture terraces (at least 5 to 7) developed within a house premises with bulging observed in bund wall of the terraces/fields, likely due to pore water pressure build-up.

The poor drainage management for water in terraced agriculture fields and of course for water coming from hill side during rainfall spells were prima facie considered as triggering factors for developing pore water pressure in slope material that has led to such instability signatures, which probably have taken more time in their development, as compared to what was reported/intimated by the local residents. At this location, at least 5-6 levels of artificial terraces made for agriculture were observed protected with a bund sort of wall but no proper drainage network.

Location-2-B: Minor instability features in a house complex and its immediate surroundings, located at a few meters away in strike continuity of Location 2-A: Here at this location [Coordinates: N31°31'0.267" (N31.517); E76°26'42.96" (E76.445); Elv: ±893], some instability signatures were shown to the authors viz. minor bulging in the wall of raised platform on which the house is constructed and a few minor cracks in the building of the house. As per the local residents there is some minor creep type movement observed since last few years along this relatively gentler slope (Fig. 25) that has caused removal, transportation and deposition of some soil a few meters away towards reservoir side. However, except very minor subsidence, common in such terraces, neither specific/clear instability signatures were observed nor shown by the District Administration personnel and local residents. Prima facie, there appear issues related to surface water drainage management. Here at this location, a few levels of agriculture terraces were observed but with near absent management for surface water drainage.

Fig. 25: Agriculture terraces/fields located in the vicinity of Location 2-B, where reportedly minor creep type movement is reported as per local residents.

Location-2-C: Instability features in the premises of another house near Village's Bowri (Pond), located a few meters away from Location 2-B: Here at this location [Coordinates: N31°30'52.71" (N31.515); E76°26'43.42" (E76.445); Elv: ±832] also, some instability signatures were shown to the authors viz. traces/imprints of a few ground cracks that were not clearly discernible in their fresh form. As per the local residents a few years back, relatively larger cracks were formed in their agriculture field located immediate next to the house and that has caused them to take decision of shifting their house a little behind i.e. towards hill side while the cracks were artificially filled up with soil brought artificially from outside. However, no clearly discernible traces/imprints of such cracks were seen on ground on the day of field work as stated above (Fig. 25). At this location also hardly any proper drainage network was observed to drain out surface water properly. Here again, prima facie, there appears issues related to surface water drainage management in terraced slopes with relatively thicker column of overburden soil/slope material comprising mostly fine grained soil as seen during site visit (Fig. 25).

A natural spring was shown by local residents along the gentler terraced slopes towards road/hill side (Fig. 26) stating occurrence of reported instability signatures in agriculture fields/terraces area in the immediate vicinity due to above spring. However, in the immediate vicinity, no appropriate slope failure incidence/ instability incidences were shown either by District administration people/ local residents except intermittent traces of some old minor incidences that most likely occurred due to poor drainage network reported perennial rainfall spells etc.

Fig. 26: A natural spring renovated with construction of civil structure/shade around it. Reported minor subsidence within/immediate next to spring premises.

1.5.3 Samthana Village:

This village is located off Barsar-Bhota Road along left bank slopes of Sukar *Khad*, a tributary of Satluj River and is flowing in NW-SE direction. As conveyed by the local residents a slope failure incidence took place during SW Monsoon of 2023 (Fig. 27). The area can be accessed by all weather road followed by some trekking along available foot tracks. The dwelling units in the settlement are located along ~30-35°/N250° slope looking towards Sukar *Khad*. The slope forming material here is shallow debris comprising fine silty clay and soil, bottomed by weathered and jointed sandstone rock mass.

Few outcrops of weathered and jointed sandstone rock mass were observed towards right fringe of the failure (Fig. 28). The rock mass was relatively jointed and weathered with at least 3 sets of joints as stated above. Three sets of joints were observed in the rock mass viz. J_1 (S0): 24°/N354°, J_2: 60°/N060° and J_3: 86°/N164°.

Fig. 27: Proximal view of Samthana Slope failure incidence

Fig. 28: Outcrops of weathered and jointed sandstone rock mass were observed towards right fringe of the failure.

From slope instability point of view, the above stated slope failure incidence was observed along a southwesterly slope with its crown located just below a house which is constructed just at the valley side fringe of a seasonal *nala* depression. The general dimensions viz. length, height and width of the slope failure is approx. ~20m, ~20m and ~30m. However, the flow path of the failure appeared to be ~100 to 150m or so, part of which was visible. The material involved in the failure was mainly soil and debris comprising fine to medium grained fractions. Besides, the valley side failed slope was having few instability signatures viz. intermittent ground cracks and transverse cracks with or without associated minor differential settlement/subsidence, bulging/damage to crate/skirt wall erected on valley side of agriculture fields/terraces through which the failure took place, tilted tree trunks, cracks in a few houses located along immediate upslope/above crown area etc. (Fig. 27, 29, 30, 31 and 32). The agriculture fields/terraces and the skirt/crate wall were developed by the local residents about a decade before by the local residents, as conveyed by them during the site visit. The general trend of the contour parallel and transverse cracks was observed as about N130°-140° to N230°-250°.

From the causative point of view, it is to state that neither in house(s) upslope nor along agriculture fields/terraces, any proper drainage network was seen to channelize/divert the domestic water, agriculture water, surface runoff and rain water. As per the local residents, the water was being allowed to drain towards valley side slopes including agriculture fields/terraces which were in turn protected by skirt/crate walls on their valley side. This scenario most likely has developed the pore water pressure which further prolonged over the time and led to development of aforementioned slope instability signatures and slope failure.

Fig. 29: Presence of ground cracks within failure zone (Indicated by Yellow oval)

Fig. 30: Proximal view of traces of ground cracks within failure zone.

Fig. 31: Tilted tree trunks in the failure zone (Note the yellow oval).

Fig. 32: Presence of crack in house(s) located on valley side, in the immediate upslope of Samthana slope failure.

From risk perception point of view, the house(s) that are located towards *nala* fringe on valley side are having possible risk of further damages to the agricultural land and civil structures here; which may also involve possible risk to life.

1.6 SUGGESTIONS AND RECOMMENDATIONS:

On the basis of present reconnoitory slope instability assessment, following suggestions can be enumerated with a view to reduce risk to life and property:

1.6.1 Bara Gaon:

Based on the present reconnoitory traverses, following are suggestions with a view to reduce risk to life and property:

01) Channelisation of water of Suker *Khad* along right bank and thereby preventing its further ingress through fractures/open joints in the rock mass exposed in upstream side from where the incision is actually took place.
02) Appropriately designed lining all along the major gully with its gradient downstream side to channelize surface water and seepage, if any, towards Suker *Khad*.
03) Immediate sealing of ground cracks, wherever present including agriculture field area, with appropriate impervious material.
04) Treatment for cracks developed in civil structures including walls and floors of the house(s) as observed/noticed by the local residents.
05) No further construction of heavy concrete structures, particularly in and immediate vicinity of the major gully/incision and slopes.
06) As a long term measure, with a view to avoid possible risk to life and property, residents may be shifted at appropriately identified location(s). It is advised to carry out proper site suitability studies for the location(s), if already identified.

1.6.2 Jabal-Khairian Village:

In all**,** a total of 5 locations were shown to GSI team in Jabal-Khairian twin villages on 06 and 08/11/23. It is to further state that 2 locations were shown in Jabal Vallage while 3 locations were shown in Khairian village.

1.6.2.1 Jabal Village:

01) Immediate sealing of ground cracks (with appropriate impervious material), mostly present in agriculture field area(s) located between Mahila Mandal and the last house shown to GSI team on 06 and 08/11/23 respectively, with appropriate impervious material.
02) Appropriate treatment for cracks and/or damages developed in civil structures including walls and floors of the house(s) as observed/noticed by the local residents.
03) Provision of appropriately designed contour parallel drainlets all along the terraces in aforesaid field areas.
04) Appropriate treatment/ retention structure for bund failures, as observed at a few places along foot track connecting Mahila Mandal and the last house stated above.
05) Proper surface drainage management practices be followed, especially as observed along few houses where minor failures took place due to direct discharge of domestic water to the filled up slopes/minor uplifted terrace prepared for house construction.

1.6.2.2 Khairian Village.

01) Immediate sealing of ground cracks (with appropriate impervious material), mostly present in agriculture field area(s) at 3 different spots, as shown to GSI team on 08/11/23, with appropriate impervious material.
02) Treatment for cracks and/or damages developed in civil structures including walls and floors of the house(s) as observed/noticed by the local residents.
03) Provision of appropriately designed contour parallel drainlets all along the terraces in aforesaid field areas.
04) Appropriate treatment/ retention structure for bund failures, as observed at a few places in agriculture terraces.
05) Proper surface drainage management practices be followed and direct discharge of domestic water on slopes may be avoided.

1.6.3: Samantha Village:

01) Immediate sealing of ground cracks (with appropriate impervious material), mostly present in agriculture field area(s) that are located on valley side slope (Ref. 1.5.3).
02) Treatment for cracks and/or damages developed in civil structures including walls and floors of the house(s) as observed/noticed by the local residents.
03) Provision of appropriately designed contour parallel drainlets all along the terraces in field areas on valley side.
04) Proper surface drainage management practices be followed, especially as observed along house(s) located at just above the crown portion of the failure, where direct discharge of domestic water on valley side was discernible and reportedly contusing since long time back (Ref. 1.5.3).
05) Provision of appropriately designed retention structure at appropriately identified location(s) all along the valley side slope, as the old retention structure provided on valley side was observed completely damaged/collapsed due to the slope failure.
06) No further construction of heavy concrete structures, particularly in and immediate vicinity of the major slope failure and *nala* courses.
07) As a long term measure, with a view to avoid possible risk to life and property, residents may be shifted at appropriately identified location(s). It is advised to carry out proper site suitability studies for the location(s), if already identified.

1.6.4: Long Term/ General Suggestions:

The present reconnoitory geological assessment of above sites, particularly at Bara Gaon area, was carried out on request from State Government. Accordingly, based on the present field study, select set of suggestions/recommendations were planned with a view to reduce risk to life and property as enumerated above. Nonetheless, as long term/ general suggestions, both with a view to reduce risk to life and property in long term and for better understanding of such issues, a few more long term/general suggestions are outlined below.

01) Vigil by local residents toward identification of slope instability signatures, especially during rainy seasons, and their timely intimation to concerned authorities. This may be done by way of forming Self Help Groups (SHGs) at local levels.
02) Identification of safer location(s) (from possible risk of slope instability and extreme weather conditions to life and property) in nearby areas for stay of local residents affected or likely to be affected by slope instability or related phenomenon, especially during rainy seasons.
03) Identification of vulnerable/risky inhabited hill slopes in the area and possible appropriate suggestions based on geological assessment.
04) The above stated areas and/or nearby such areas may be considered for slope monitoring and/or allied studies as a long term measure for better understanding of such phenomena in the area.
05) From the point of view of capacity building of district administration personnel and local residents, tailor made programmes may be formulated, for which specific requests may be placed to Geological Survey of India Training Institute (GSITI), Hyderabad (T.S.)
06) Community based Disaster Management practices be followed.

As stated above Barsar and Gambhar thrusts are passing through the area (Refer 1.3). Tectonics has also governed long-term subsidence and accumulation within the foreland basin, depending on the distance from the thrust front and the complex topography of the underlying Indian Craton, while active faults affect river courses in places (Sinha et al., 2012). Nevertheless, based on the present reconnoitory geological assessment, no surface manifestations and associated signatures were observed at any of the three localities and in their vicinity, particularly in Bara Gaon area. Also, no thrust induced instabilities or continuance of above stated slope instability features were observed in and around respective localities as seen during present field study. The local residents have also neither reported nor conveyed any such instability in and around their respective locations. The District administration people present during site visits have also not conveyed any of such incidences in and around respective locations. The geo-scientific causes assessed based on present field visit for aforesaid incidences/locations/spots and related instabilities viz. bank erosion/incision, slope failure, ground cracks etc. were fairly localised in nature and either natural and at times anthropogenic ones, as seen in field. Based on the present geological assessment of aforementioned three localities, appropriate suggestions/recommendations are also enumerated above.

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Sd/-	Sd/-	Sd/-
Harish Bahuguna	**Atul Kohli**	**Prashant T. Ilamkar**
Dy. Director General (G)	Director (G)	Director (G)

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