STUDY OF GROUND SUBSIDENCE IN JOSHIMATH FOLLOWING THE EVENTS OF JANUARY 2023

Submitted by

WADIA INSTITUTE OF HIMALAYAN GEOLOGY

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to

Uttarakhand State Disaster Management Authority

Government of Uttarakhand

INTRODUCTION

In light of the recent observations of accelerated development of cracks in houses and ground in Joshimath, and eruption of new water channels, Wadia Institute of Himalayan Geology, Dehradun has been directed by USDMA to conduct the following scientific studies.

Geophysical investigations to understand the sub-strata and seismic monitoring of the region.

(a) Seismological Monitoring using a close seismic network

(b) Magneto-Telluric (MT) and Electrical Resistivity Tomography (ETR)

(c) LiDAR Data Acquisition, creation of high-resolution of DEM and topographic maps

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set out for field on 10 January 2023 and conducted the field work, installation of stations and surveys for acquisition of required data. The LiDAR survey was initiated on 23 February 2023.

GEOLOGICAL AND STRUCTURAL STUDY

Wadia Institute of Himalayan Geology, Dehradun has taken up the transact from Pipalkoti to Tapovan to understand the geological and structural setup, temporal evolution of the deformation kinematics, signatures of active tectonics, geomorphology and slope stability in vulnerable regions.

Faults, fractures and joints were mapped in details along the Pipalkoti-Joshimath-Tapovan transect along with the penetrative structures.

Results of the study is expected to answer long-term structural deformation along with the process of landform evolution and their subsequent modification during the Quaternary time scale that probably led to land subsidence in the area.

The objectives of the survey is:

1) the characterization of the structural aspects of the Joshimath town with respect to the faults and fractures

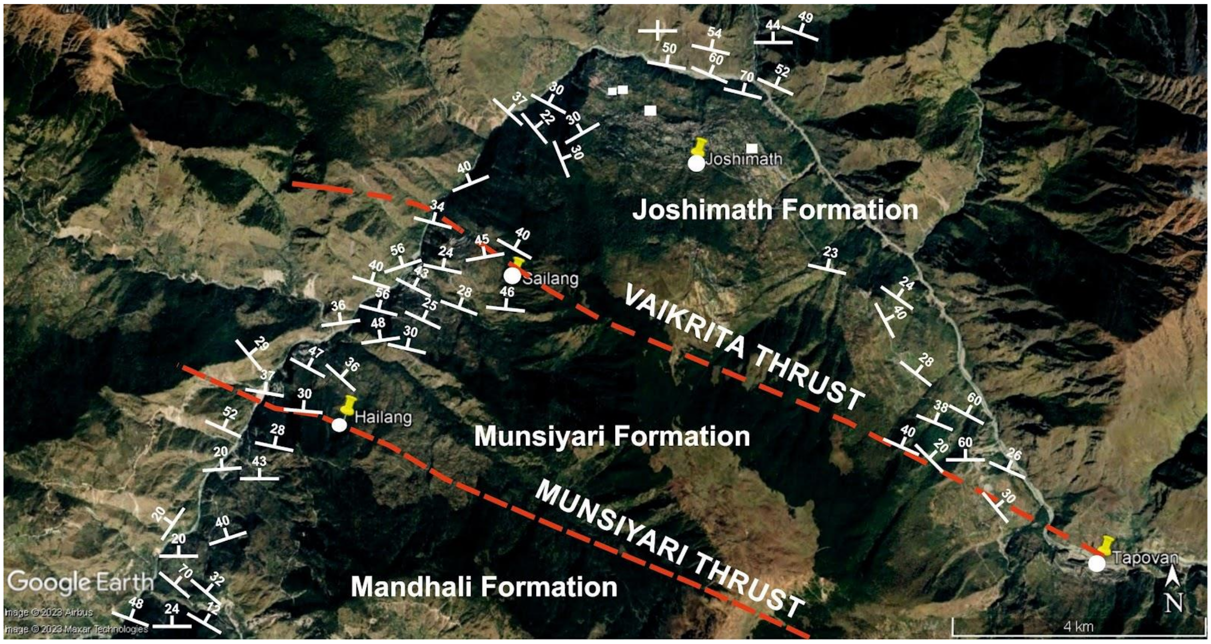
2) Temporal evolution of the debris as it is reported already that the town is situated on unconsolidated to semi-consolidated debris

3) Stability analyses of vulnerable slopes in and around Joshimath

The preliminary observations from the field work are the following:

1. Penetrative structures, faults and fractures:

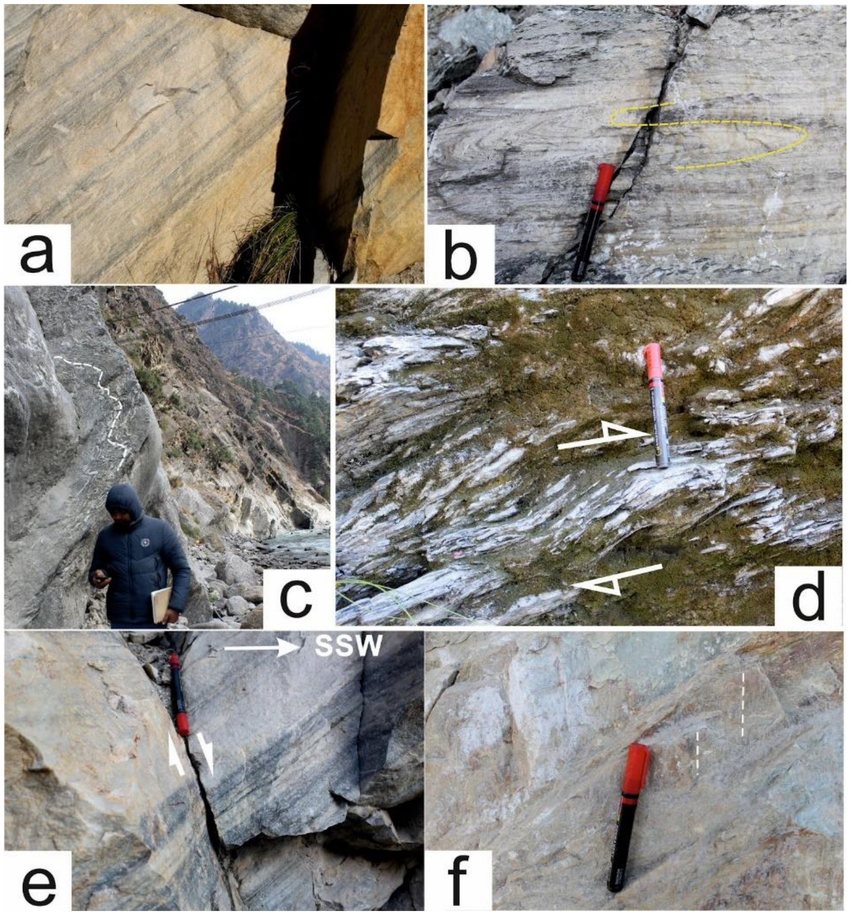
The penetrative planar fabric or foliation in the area is a gneissic segregation between quartz-rich and micaceous layers consisting of both muscovite and biotite (Fig. 4a). Occasionally, significant increase in mica-content gives a schistose appearance to these rocks resulting in the intercalated occurrence of high grade schists within the gneisses. Tight to isoclinal folds (Fig. 4b) are commonly observed both on the gneissic segregation as well as the schistose foliation. Often these folds are overturned (Fig. 4c) with both limbs dipping towards



north or north-east. Immediately north of the Joshimath town, recumbent folds occur in the Garnet-bearing gneisses of the Joshimath formation. Overturned antiform with wavelength of about 30-40 metres with subhorizontal hinge is detected on the northern bank of the Dhauliganga River in

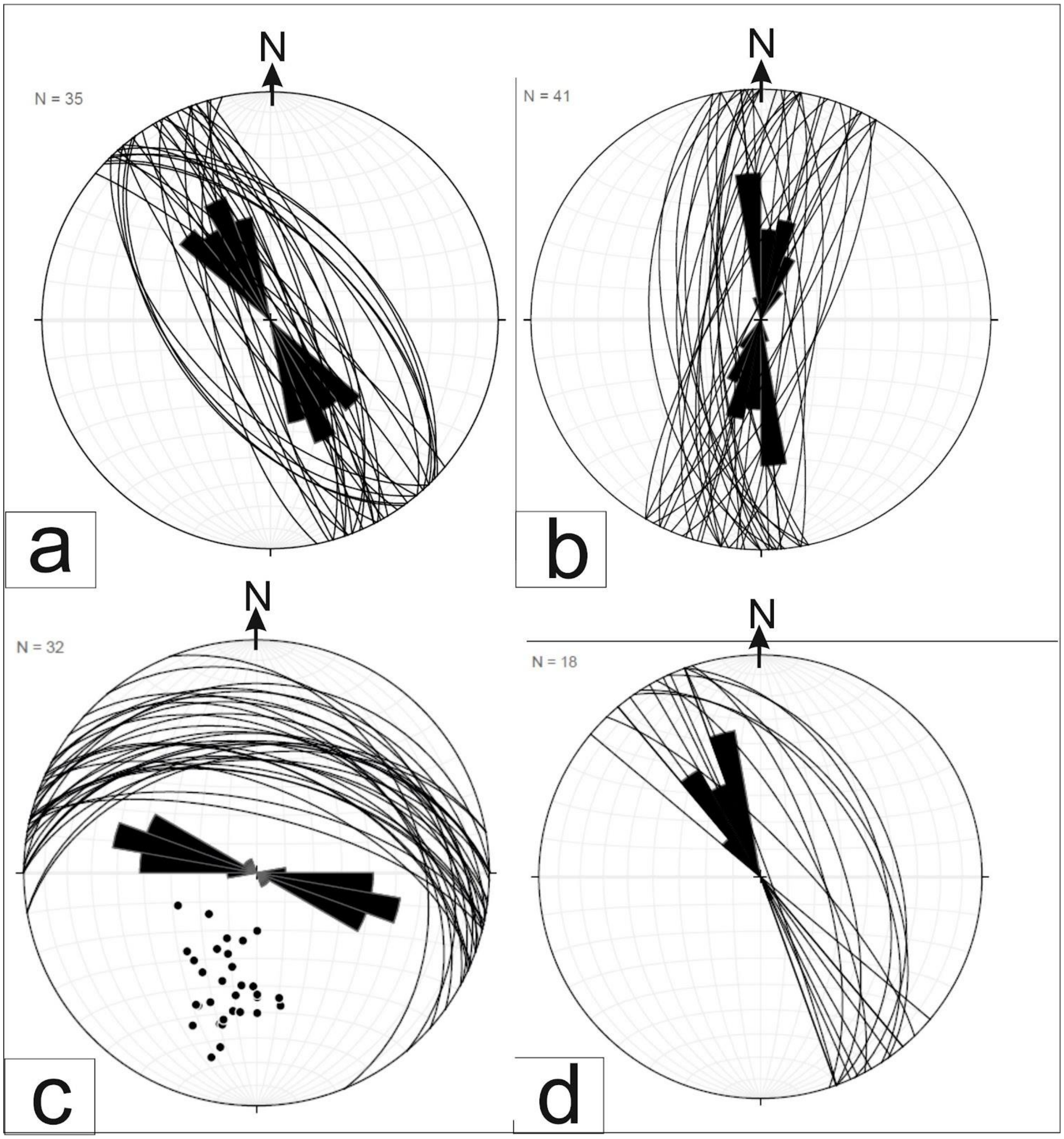
Vishnuprayag. Smaller scale drag folds occur on the limb of this overturned antiform with hinges having attitude similar to the larger-scale fold (Fig. 4c). Consistent occurrence of consecutive overturned antiformal and synformal structure on the gneissic and schistose foliation is observed across the area. However, the wavelength of folds vary in accordance with the competency contrasts between the layers that define the segregation as well as with the thickness and spacing between the layers. Similar attitudes of the fold hinges suggest that these folds with varying wavelengths were formed in the ductile regime during the same deformation. S-C fabrics (Fig. 4d) occur in the MCT zone and also in zones of strain localization to its north with prominent top-to-the-southwest or reverse sense kinematics (Fig. 4d) along north-easterly dipping mylonitic foliation. The mylonitic foliation in the MCT is also defined by alternate quartz-rich and micaceous layers, similar to the penetrative foliation on which the folds described above, occur consistently. Quartz-rich domains of the mylonitic foliation often exhibit prominent asymmetry with reverse kinematics. On the surface of the foliation a down-dip lineation is detected in these zones of mylonitization.

The penetrative gneissic and schistose foliation are often truncated against faults and fractures that displace the penetrative banding (Fig. 4e) or exhibit striations on their surfaces (Fig. 4f). So far, three sets of faults and fractures that are regionally consistent, have been characterized. One of these constitutes fractures that strike NW-SE to NNW-SSE and dips steeply towards both east and west (Fig. 5a). Prominent normal-sense of displacement has been observed for the easterly dipping fault that transects the gneissic foliation in the last in-situ exposure, immediately south of the slope on which Joshimath is situated. Faults and fractures with orientation similar to this fault plane occur in areas around Joshimath. The other fracture set comprises of fractures that strike N-S to NNE-SSW and are subvertical or have very steep dips (Fig. 5b). The third fracture set is parallel to the gneissic foliation in the studied area and the mylonitic foliation in the MCT zone (Fig. 5c). It appears that Joshimath sits on the debris that is located on the hanging wall of the NW-SE to NNW-SSE striking, easterly dipping normal fault. Moreover, the N-S to NNE-SSW striking faults also occur on the western and eastern parts of the slope on which Joshimath is situated. The continuation of the cracks on the central part of the slope cannot be confirmed due to the absence of in situ rocks.



2. Cracks on roads and walls of houses:

The orientations of some recent cracks that came up on the roads and walls of the houses on the slope (Fig. 6a) in Joshimath were also acquired in course of this study (Figs. 6b-d). Study of the cracks revealed that most of the cracks have similar geometries i.e., narrowing downward geometry (Figs. 6b and d) implying that the cracks propagated or are still propagating from top to bottom. The top portions of the cracks being wider than the bottom portion suggest a major component of tension involved in the formation of these cracks. Nevertheless, there are domainal variations in the orientation of each crack (Fig. 6d) although a gross average orientation can be understood (Figs. 6b and d). It is observed that the orientations of 18 cracks (Fig. 5d) are similar to the normal faults observed on the last in situ rock immediately south of the slope on which Joshimath is situated and also in the area around Joshimath (Fig. 5a). The statistics of the rose diagrams (Figs. 5a and c) particularly in context of the mean vectors are strikingly similar.



N
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a
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b
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c
N
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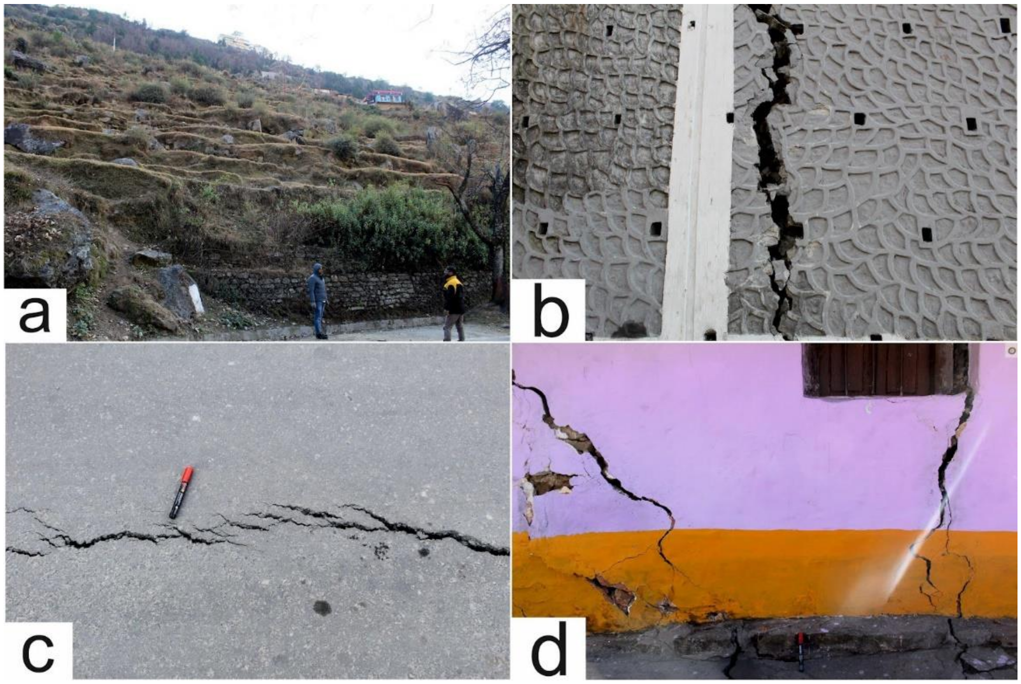


3. Discussion

- On the basis of the present study a detailed map showing the different formations and their penetrative structures have been prepared for the area from Helang to Joshimath, in and around Joshimath and the Joshimath-Tapovan transect.
- The Joshimath town is situated on a slope on which no in situ rock has been observed so far. Rather the slope consists of loose boulders of varying sizes and soil material, the boulders being composed of garnet-bearing gneisses of the Joshimath formation belonging to the lower part of the Greater Himalayan Sequence (GHS) in the area.
- The slope comprising of loose boulders and soil occur on the hanging wall of the NNW-SSE striking, easterly dipping fault set (Fig. 5a) that cuts across the penetrative gneissic foliation. Moreover, the area is traversed by steep ESE-ward or WNW-ward dipping or subvertical faults and fractures. A set of fractures parallel to the gneissic foliation and the mylonitic foliation in the MCT has also been detected in course of the present study.
- There is striking similarity observed between the NNW-SSE striking fault set (Fig. 5a) and some of the recent cracks (Fig. 5d) that came up on the roads and walls of the houses in different locations of the Joshimath town.

Further study:

- Reactivation potential of the faults and fractures with respect to the contemporary stress-field needs to be determined for delineating the fault/s that stand the best chance of reactivation in view of the current subsidence phenomenon.
- Pits were excavated along the eastern as well as the western sections of the identified subsidence zone, particularly in localities where some damage was detected (for example, Figs. 6b-d). Detrital charcoal and bulk soil samples were collected from these pits to understand the timing of deposition of the paleo-landslide material and to understand the phenomenon of landform evolution in the area. Results are awaited.
- Collection of geotechnical data for slope failure analysis have been undertaken to understand the phenomenon of land subsidence in Joshimath. Data pertaining to slope parameters (such as slope height, slope angle variation, and slope orientation), material property, and various discontinuities were obtained in course of the field work. Data pertaining to the physical condition of slope surface, weathering and erosion effect, more critical locations and representative samples were obtained from the pits for the purpose of Rock Mass Characterization and their classification.

RESISTIVITY INVESTIGATIONS IN AND AROUND JOSHIMATH

As a part of resistivity investigations in Joshimath region, the first phase of data acquisition for electrical resistivity tomography (ERT) is completed on 23rd January. 5 channel ARES 2 with 48 electrodes being utilised for the data collection.

The objective of resistivity measurements are:-

- To characterise the subsurface in terms of resistivity variations. These variations can be correlated with lithology.
- Estimation of the thickness of overburden along the profiles.
- To Identify the shear zones

Total 7 ERT profiles at following places have been acquired.

1. Parsari
2. Manohar Bagh (2 profiles)
3. Singhdhar
4. JP Colony
5. Sunil village
6. Marwari (Below JP Colony)

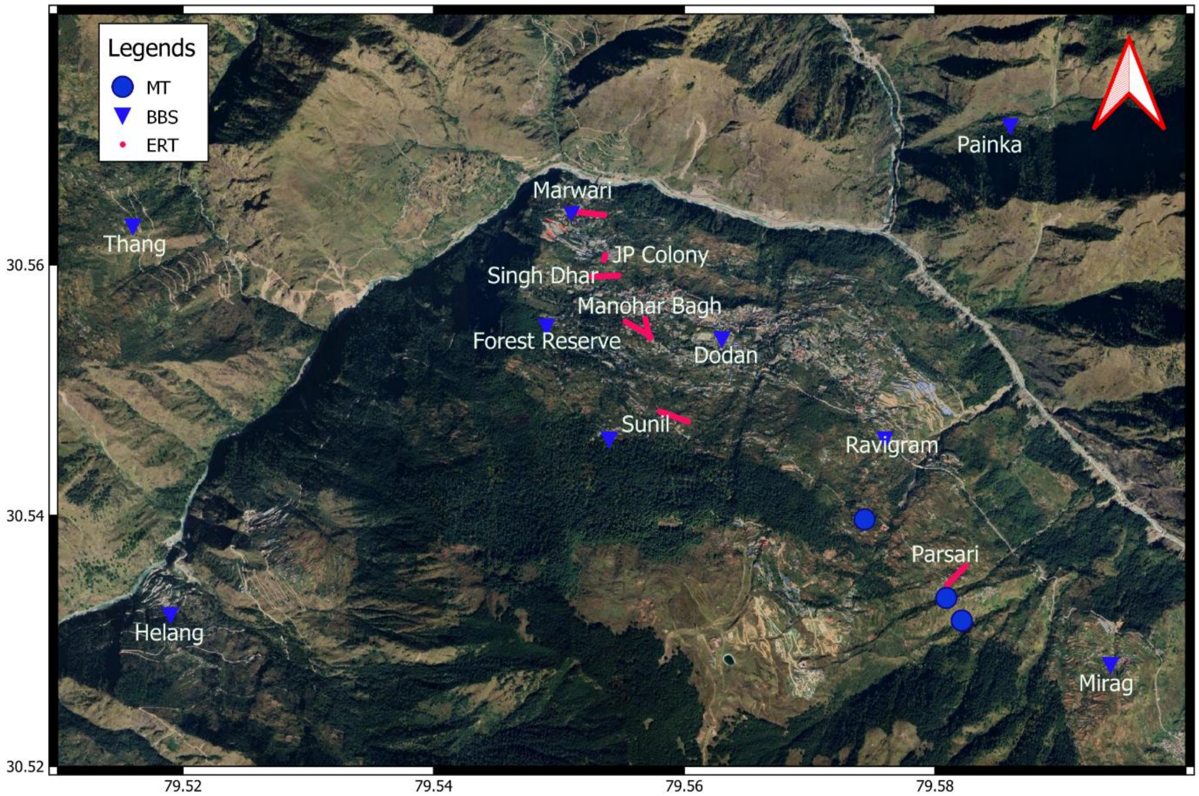


Figure 1: ERT profile location map

1. Parsari

Parsari village is located toward South - East of Joshimath. An ERT profile orienting SW-NE is taken (Fig 1). The length of the profile is 235 m. Total 48 electrodes are used at a spacing of 5 m. Schulmberger Wenner Configuration is used to measure potential difference across different combinations of electrodes. These measured potential differences are modelled for subsurface resistivity variations. Figure 2 is the subsurface resistivity section beneath the profile.

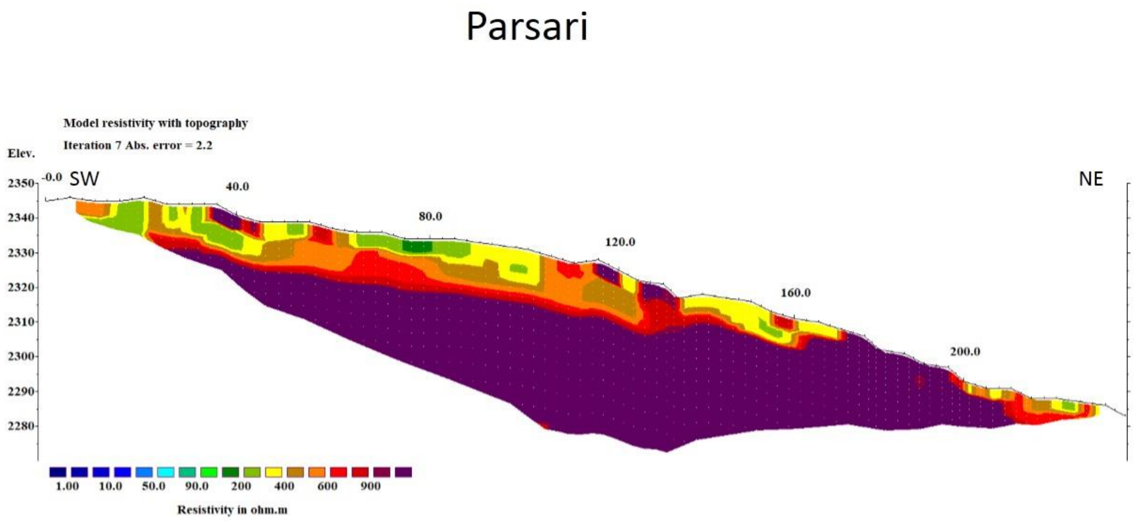


Figure 2: Resistivity variation beneath the Parsari

Resistivity variations at the Parsari profile indicate two distinct horizontal layerings. The bottom layer beneath the depth level of 15 m has resistivity above 1000 ohm-m indicating the presence of hard rock. Resistivity variations from surface to 15 m depth range are moderate and vary from 100 to 1000 ohm-m.

2. Sunil

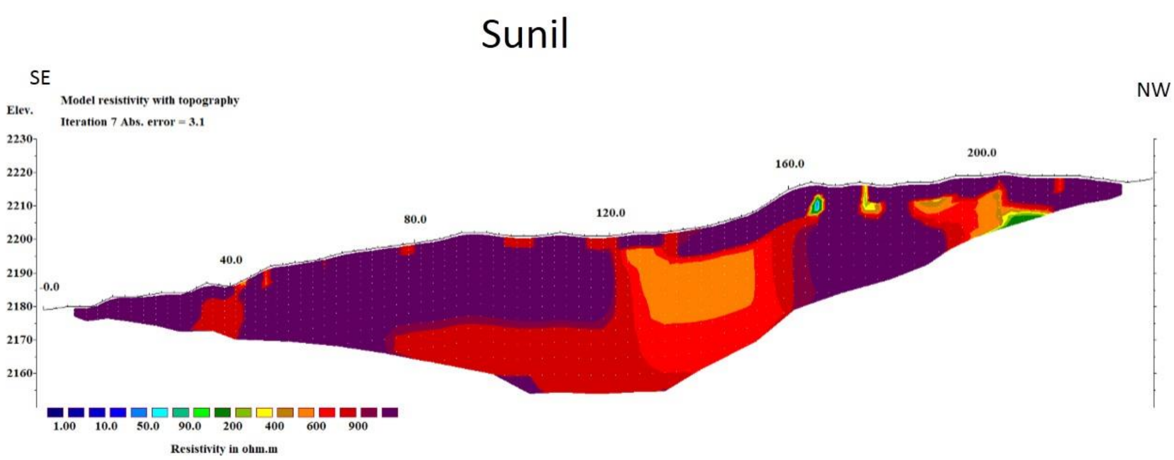


Figure 2: Resistivity variation beneath the Sunil

The profile length at the Sunil village is 235 m with 5 m electrode spacing. Total 48 electrodes are used in the ERT at the Sunil Village with Wenner Schulmberger configuration of electrodes. Resistivity variations beneath the Sunil village (Fig 3) have lateral variations. The high resistive feature is embedded with many moderately resistive and high resistive blocks. The bottom section throughout the profile is moderately resistive.

3. Manohar Bagh

There are two ERT profiles at the Manohar Bagh. The first profile is along the slope and the length of this ERT profile is 188 m with 4 m electrode spacing. The length of the profile is governed by the availability of linear space for stretching the electric cable.

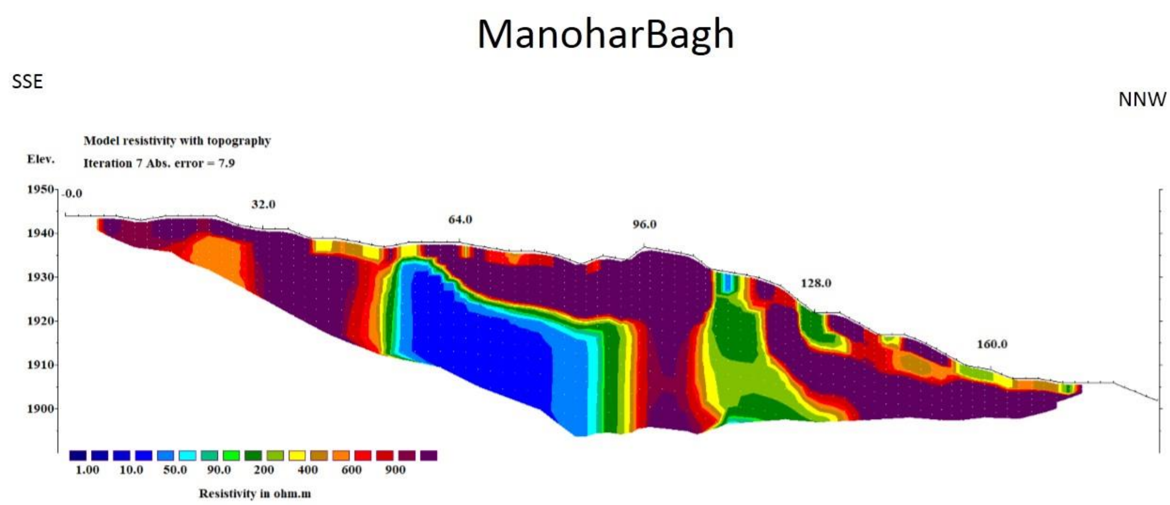


Figure 4: Resistivity variation beneath Manohar Bagh 1

Significant lateral variations are observed in the resistivity variations beneath this ERT profile. The important feature in this section is presence of high conductive zones. The presence of ground cracks above these zones are significant. The high conductivity of these zone indicates highly saturated sediments or fracture zone filled with water.

Another profile at the Manohar Bagh is oriented approximately perpendicular to the above profile and across the slope of hill. The length of this profile is 235 m with 5 m electrode spacing. Interestingly the conductive feature is present beneath entire profile. This layer emerges to surface at 135 m from the depth of 10 m at 10 m. The important observation along this profile is widening of ground cracks toward the second half of profile.

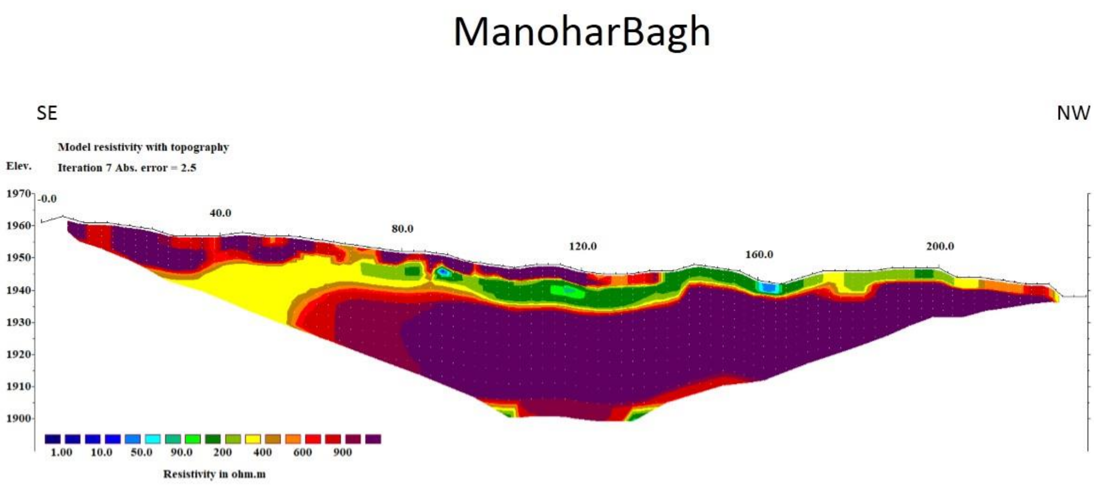


Figure 5: Resistivity variation beneath Manohar Bagh 2

Significant resistivity variations are observed in profile along downslope at shallow depth, whereas smooth variations are observed when profile is oriented approximately across the slope. Low resistivity features signifying the saturation /aquifer is observed. Interpretation of resistivity section is in progress and will be completed after modelling of all profiles.

4. Singhdhar

The length of the profile at the Singhdhar is 235 m and the orientation of profile is approximately across the slope. The electrode spacing is 5 m and Wenner Schulmberger configuration is used for measuring potential differences across appropriate combination of electrodes. The resistivity variations beneath the profile (Fig 6) is having moderate to high resistivity except the two blocks of low resistivity. One beneath the distance mark of 80 m and one beneath the distance mark of 170 m to 195 m. Ground cracks are observed at the horizontal distance of 77 m is above the low resistive zone.

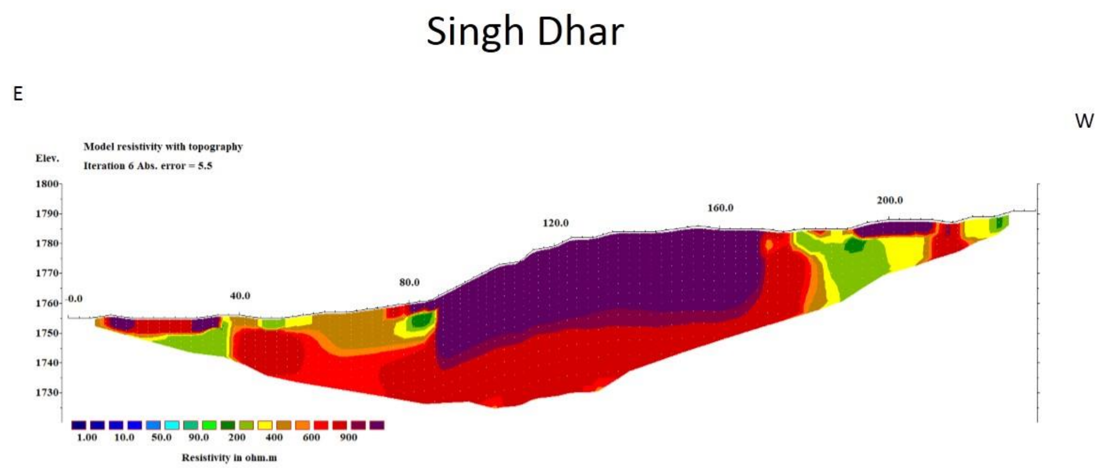


Figure 6: Resistivity variation beneath Singhdhar

5. JP Colony

The ERT profile inside JP Colony is all along the down slope and follow the orientation of Nala above Badminton court. The length of the profile is 47 m. After this distance the ground is cemented and it is not possible to extend the profile linearly. The 1m electrode spacing is used in the ERT at this place. The resistivity variations are shown in figure 7. As can be seen, the most of the part of ground imaged is covered with low resistivity to moderate resistivity indicating the percolation of water from surface to depth of 9 m. The low resistivity at depth of 1-2 m indicate the presence of water, which is gushing out near JP Colony gate.

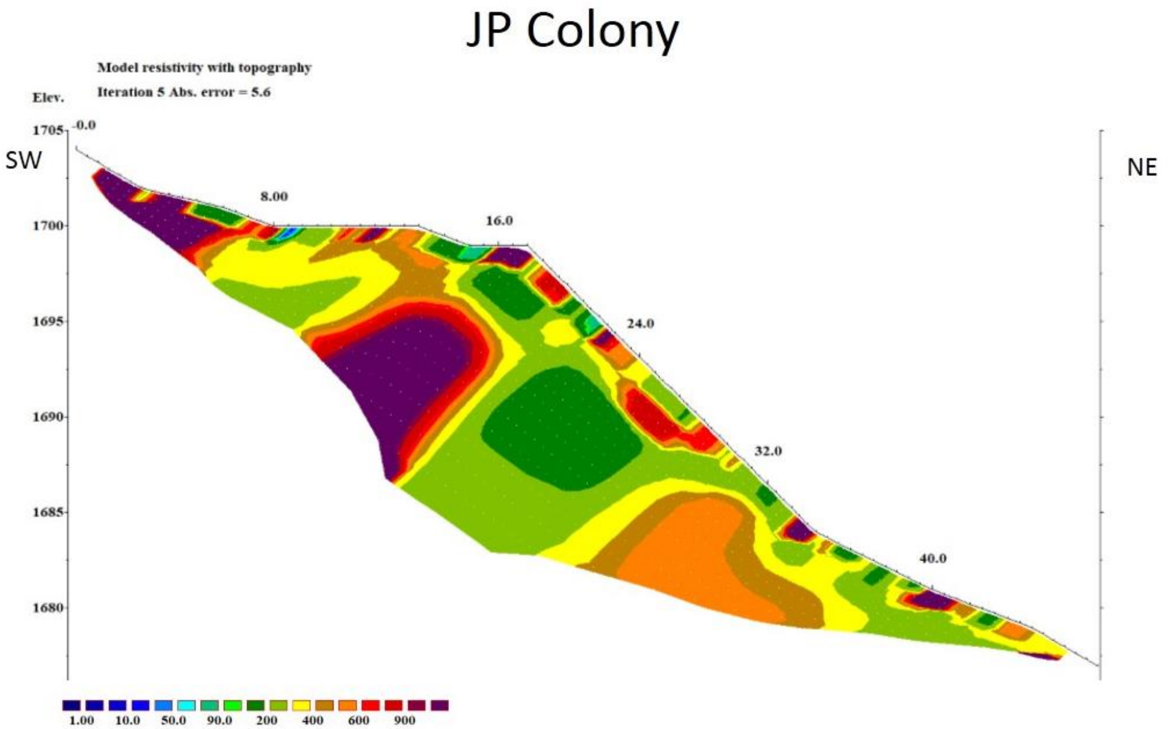


Figure 7: Resistivity variation beneath JP Colony

6. Marwari (Below JP Colony)

The length of the profile at the Marwari is 235 m and the orientation of profile is approximately across the slope. The electrode spacing is 5 m and Wenner Schulmberger configuration is used for measuring potential differences across appropriate combination of electrodes. The entire profile (Fig 8) is covered with moderate resistivity feature.

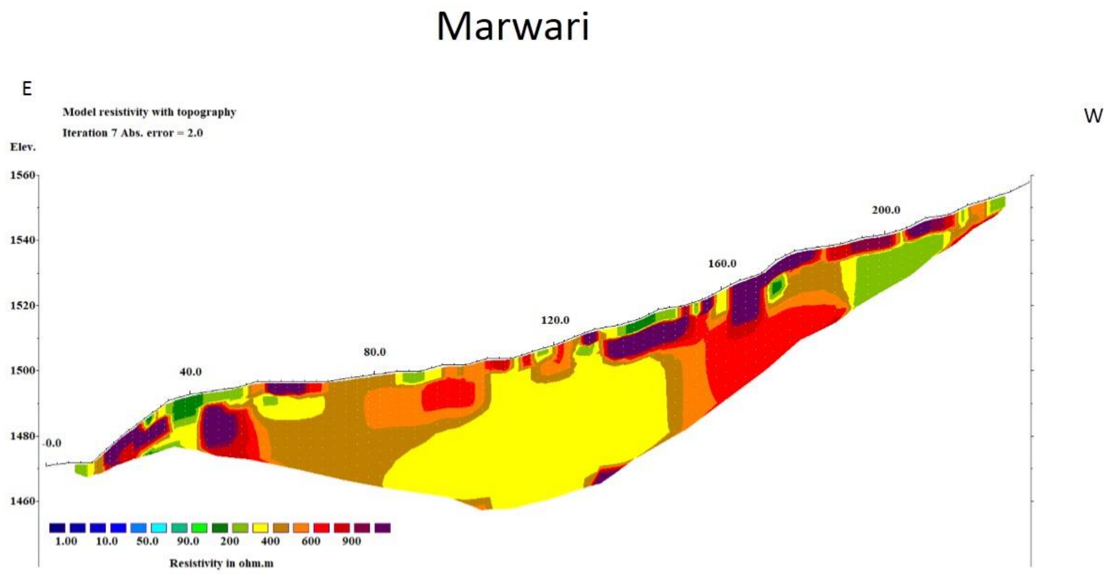


Figure 8: Resistivity variation beneath Marwari

Conclusion:

1) At Parsari resistivity shows that a consistent bedrock layer is present at a depth of 15 m. There is no signature of water seepage.

2) At Sunil, presence of sub-surface boulders are seen. There is no significance seepage zones in the section covered.

3) At Manohar Bagh 1, one Resistivity Section was covered from Auli Road towards northwest near Tower 1. Here, **highly water saturated zone** is observed at a depth from 5 m to 35 m (maximum observation depth) dipping along the slope.

4) In another profile in Manohar Bagh (2), parallel to the Auli Road (SE to NW), signature of water seepage is observed all along the profile at a depth of 5-10 m.

5) In Singdhar, isolated patches of water seepage is present along the profile. A big boulder is present in the middle of the section upto a depth of 25 m.

6) At Jaypee Colony, water seepage is clearly observed at least up to a depth of 10 m (maximum observation depth) along the profile. Presence of sub-surface boulder is seen.

7) In Marwari, signature of water seepage is seen in isolated patches, but at very shallow depth of 4-5 m.

From the resistivity variations in different sections, it can be said that the seepage water is natural and is not affected by anthropogenic activities.

SEISMICITY MONITORING AND SUBSURFACE IMAGING FROM A CLOSE SEISMOLOGICAL NETWORK

Wadia Institute of Himalayan Geology (WIHG), Dehradun, Uttrakhand has established a closely spaced Seismological Network of 11 stations for monitoring of microseismic activity in and around Joshimath area (Figure). The installation of the stations was completed by 20 January 2023. The data of the stations till 19 January 2023 is being processed. For realtime monitoring of earthquake activity in the area, GPRS modules are being installed to transmit waveform data from BBS sites to the central recording Station at WIHG, Dehradun.

Objectives:

- Seismological monitoring to observe the seismic activity to micro-earthquake level. Making it feasible for detecting lower than 1.0 magnitude earthquakes
- Monitoring of blasting activity
- Temporal assessment of Seismic noise

Table: Locations of the seismological stations installed by WIHG in and around Joshimath:

Sl. No.	Station Name	Latitude	Longitude
1	Painka	30.571	79.586
2	Auli Rd., Sunil	30.546	79.554
3	Marwari	30.564	79.551
4	Bhauna, Sunil	30.555	79.549
5	Helang	30.532	79.519
6	Merag	30.528	79.594
7	Thang	30.563	79.516
8	Ravigram	30.546	79.576
9	Dadon, Upper Bazar	30.554	79.563
10	Tapovan	30.496	79.611
11	Garurganga	30.464	79.441

Joshimath region of Uttrakhand falls within the highest seismic zone of India where the recent surface subsidence and cracks in roads have been reported recently. The epicenter of the 1999 Chamoli earthquake of magnitude 6.6 is close and to and south of Joshimath. Seismic activity is high where the Himalayan seismic belt passes through the region. The Main Himalayan Thrust within the upper crust is the major tectonic fault driving the seismic activity. The past seismicity of ~50 years indicates high seismicity of small magnitude earthquakes along the epicenter of the Chamoli earthquake (Figure 1). Wadia Institute of Himalayan Geology (WIHG), Dehradun established a local seismic network in and around Joshimath (Figure 1) in January 2023 to monitor the ongoing seismicity of micro-earthquake with magnitude threshold of ~1.0. The seismic stations are connected online to extract the continuance seismic data at Central Recording station Dehradun. The continuance seismic data is monitored on daily basis to extract the earthquake events and obtain the earthquake source parameters.

During January 13 to April 12, the seismic network recorded 16 micro-earthquakes of maximum magnitude ~1.5 within a distance of 50 km from the Joshimath. Hypocentes are within uppermost crust of 10 km depth. Epicenters are mainly to the south and south-west of the Joshimath where Vakrita Thrsut (VT) and Munsiary Thrust (MT) tectonic faults exists. The present and past seismic activity has similar trend on increasing seismicity to the south and southwest mainly concentrated around the epicenter of Chamoli earthquake. Therefore, this seismic activity of very small micro-earthquake size is normal in this region. However, some light and higher magnitude earthquakes are recorded within a distance of 100 km around the Joshumath which is on slightly higher scale compared to adjoining pats of the Himalaya. The highest magnitude earthquake is 5.4 occurred 0n 24 January 2023 within western part of Nepal with a distance of ~100 km from Joshimath located to its southeast.

We also processed the continuance data of each seismic stations to investigate the anomalous signature in the waveform data. The background noise is observed on daily basis to assess the temporal change in background noise. The analysis is also performed for the day time and night time data where the culture noise is less in the night time. It is observed that noise was slightly higher on the Marwari station which is located close to the Japee colony. Sometimes sudden changes are noticed which are on very higher magnitude compared to the background noise level. These changes are in all three component records with simple increasing and decreasing trends in the vertical component. These changes are mainly noticed in the data of Marwari and Ravigram stations. The amplitude and frequency of occurrence is on higher side in the data of Marwari station. The Marwari station was installed first with temporary installation in the basement of Hotel on January 11. Therefore, we are able to record long continuance records of this station. On January 16, the station was shifted in a seismic hut which is very close built on bedrock. The other seismic stations were installed before January 20, 2023.

An example of anomalous change in the background noise at Marwari station is shown in Figure 2 for raw data record of 1 hour. It indicates a very clear signal in all three components.

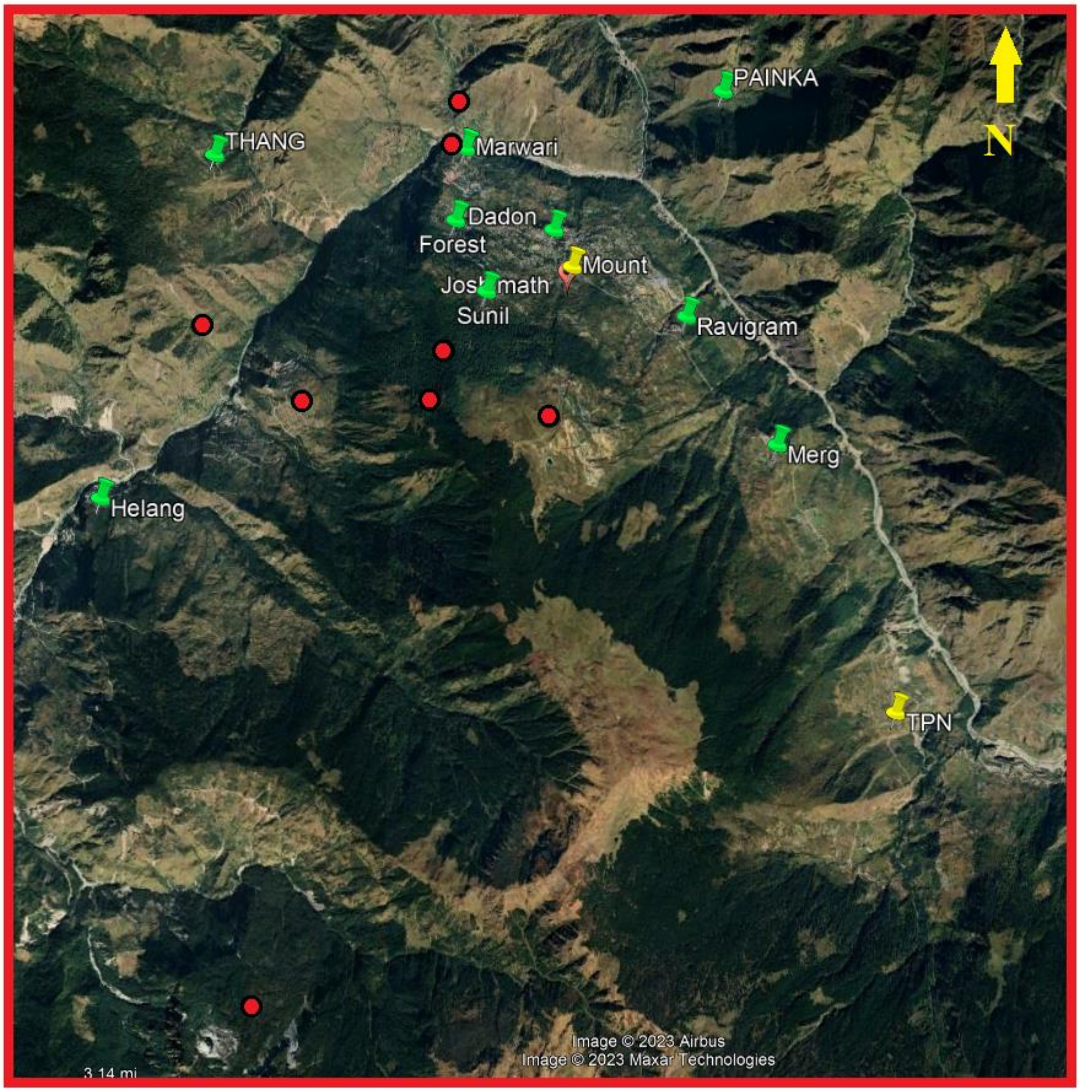


Figure 1: Seismic stations of the online WIHG seismic network of Joshimath.

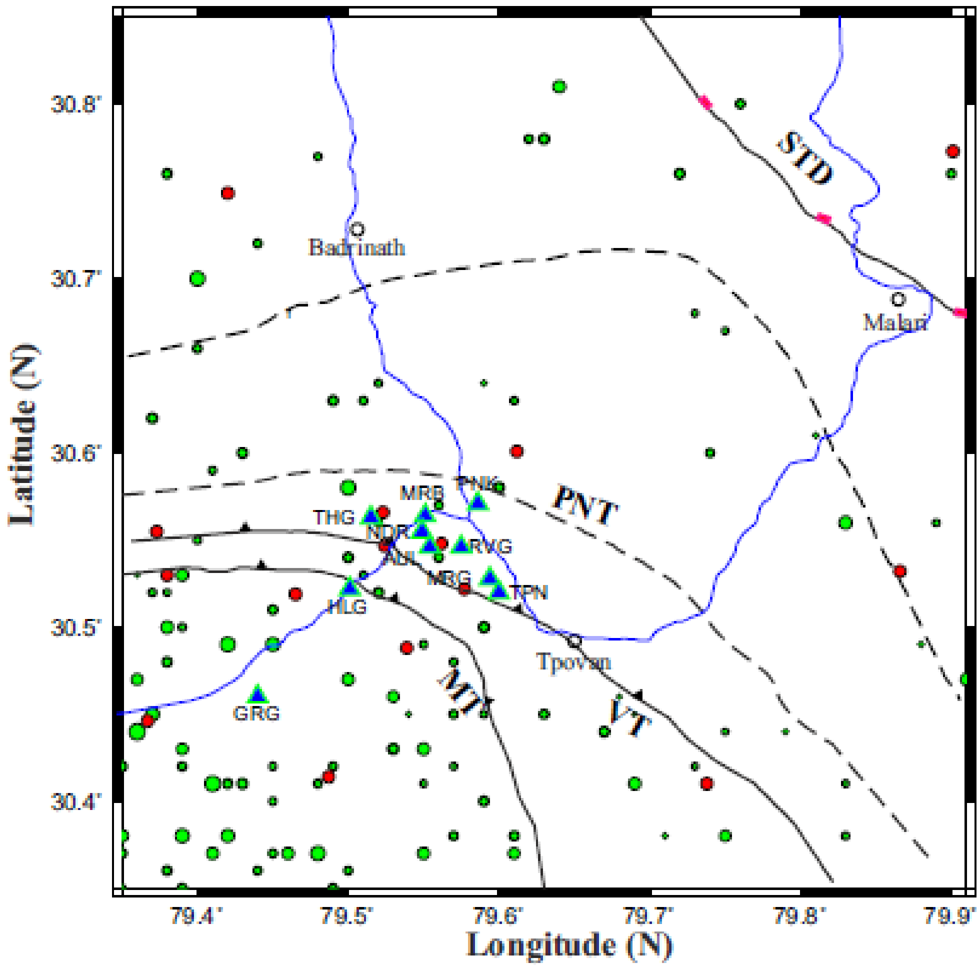


Figure 2: Local recent and background seismicity in and around Joshimath. Blue triangles represent the seismic stations of WIHG, Dehradun, red circles recent seismicity, green circles past seismicity.

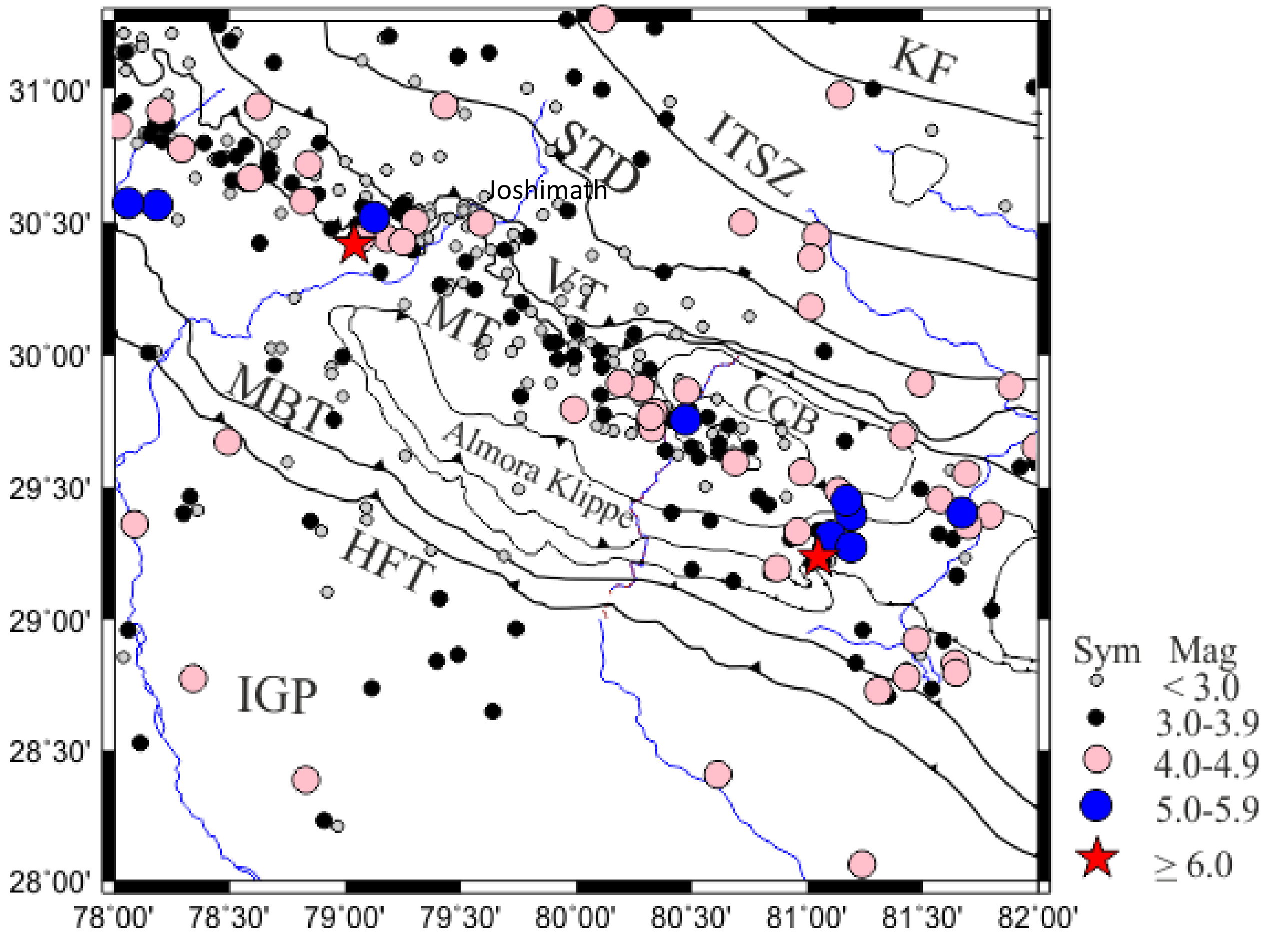


Figure 3: Past background seismicity around Joshimath. Red star near Joshimath is the epicenter location of the M6.6 Chamoli earthquake of 1999.

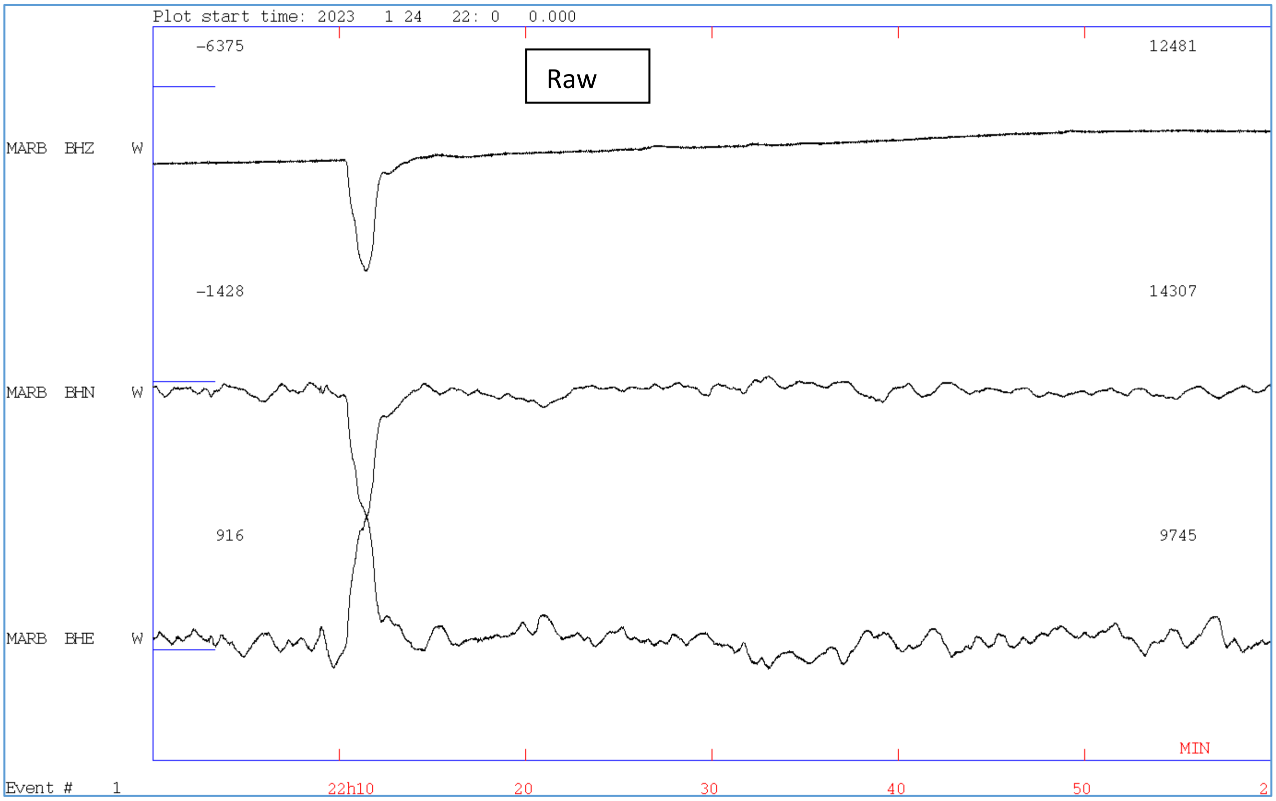
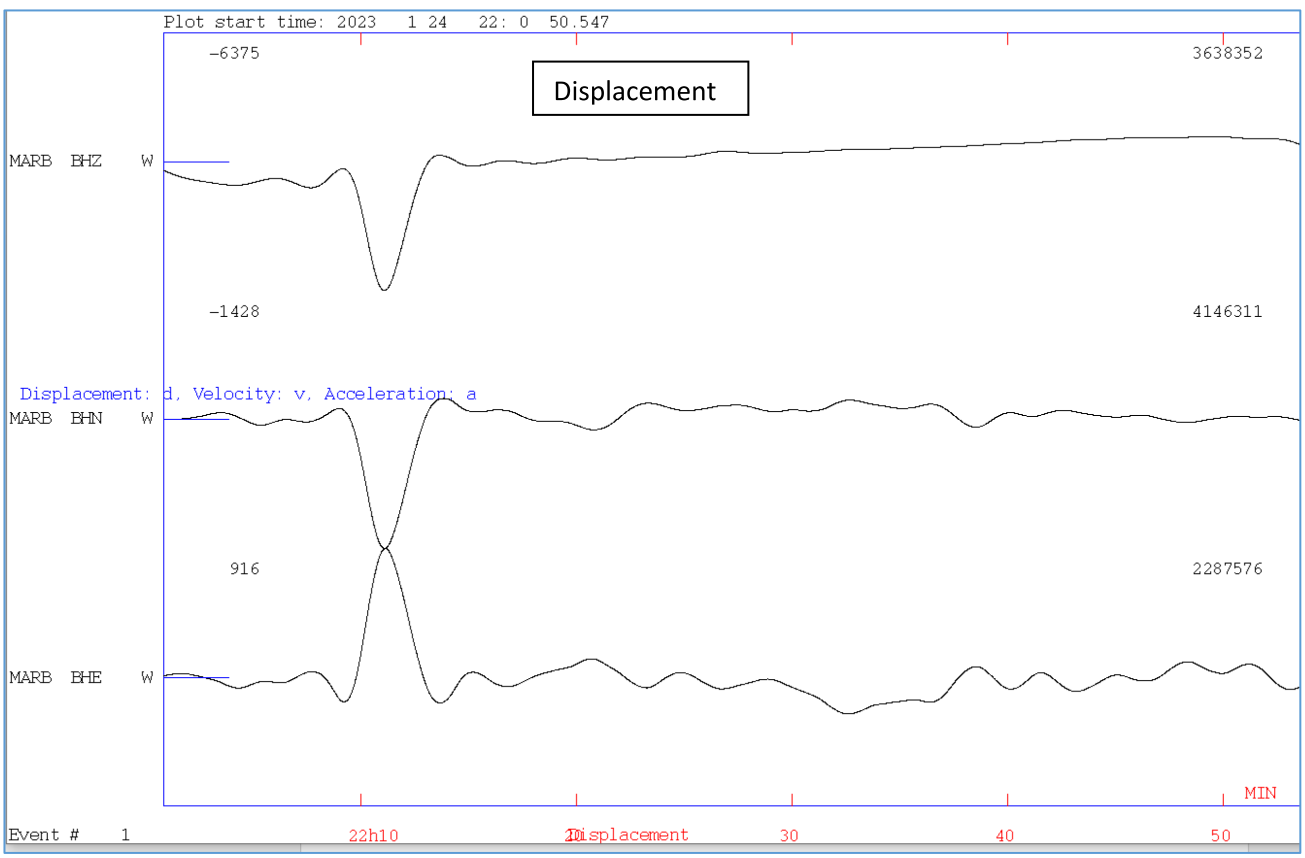


Figure 4: Anomalous signature observed in the waveform on 24 January, 2023.



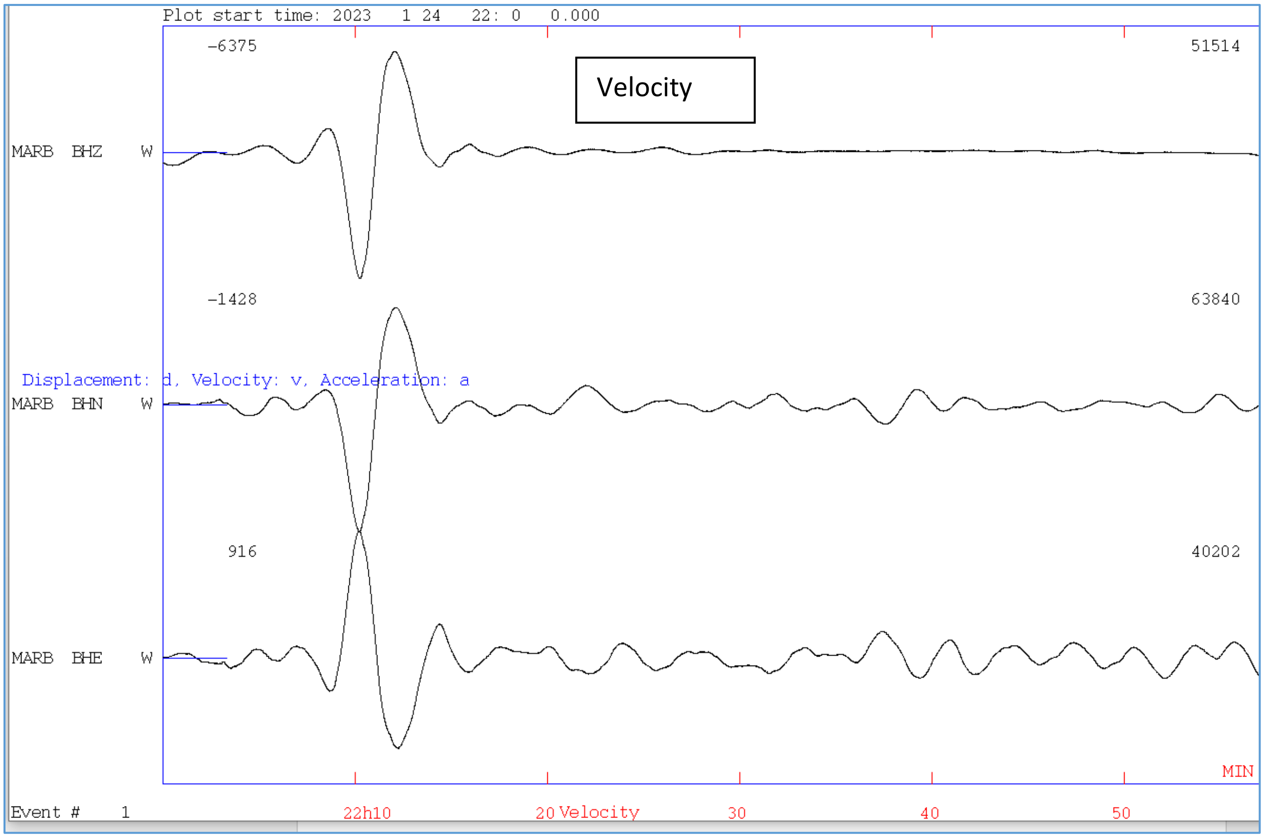


Figure 5: Anomalous signature observed in the waveform on 24 January, 2023.

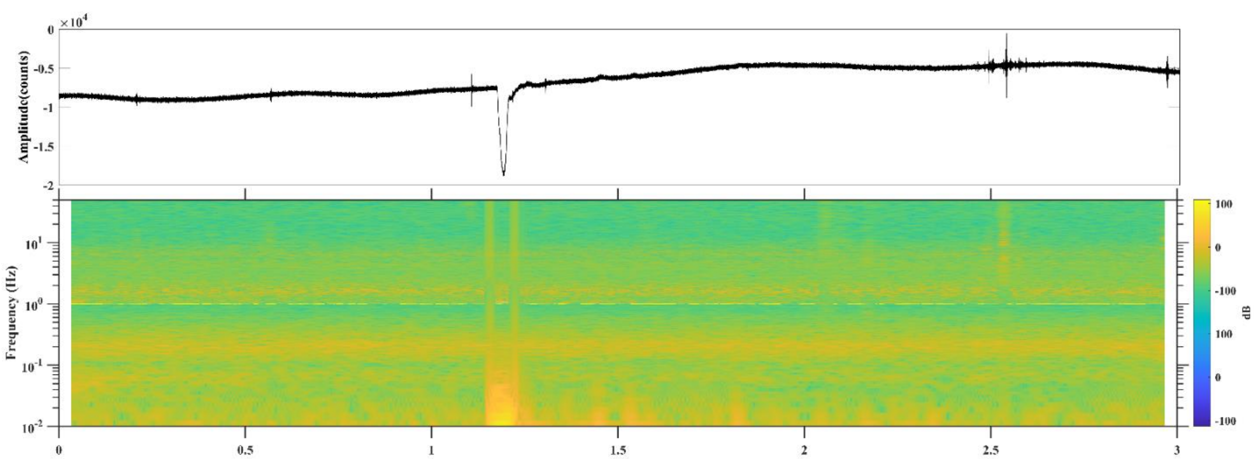


Figure 5: Waveform records of anomalous change along with corresponding spectrogram of Marwari records on 24 January, 2023.

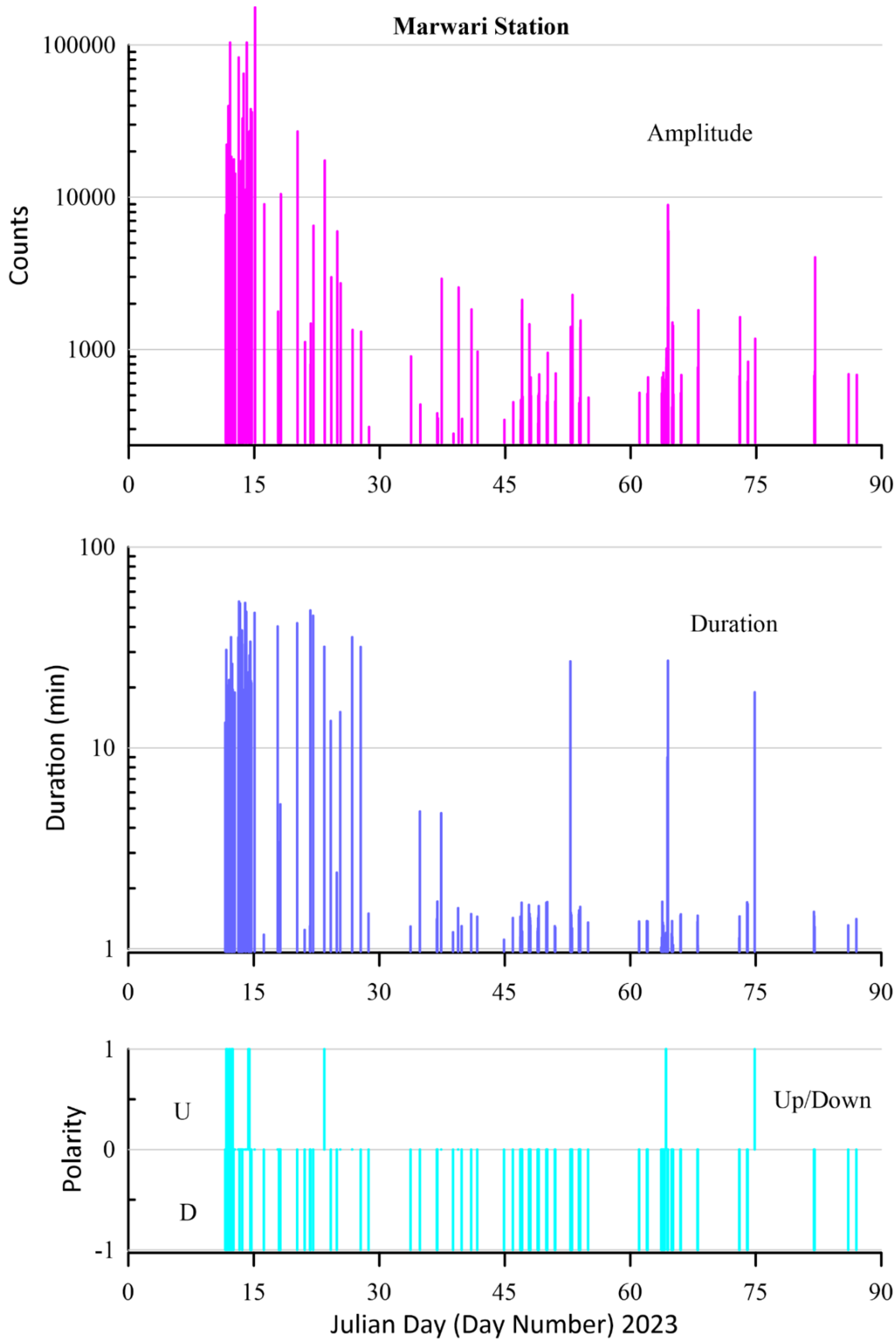


Figure 6: Records of anomalous signatures observed in the waveform during Jan-Mar 2023.

Conclusions:

1) Some micro-earthquake events of very small magnitudes (less than 1.8 M) are recorded at shallow focal depths of less 10 km.

2) Reported micro-earthquake activities are so far seen to be normal.

3) The concentration of micro-earthquake activity increases towards south and south west of the network region, which indicates that micro-earthquake activity is more prone to the 1999 Chamoli Earthquake epicenter zone.

4) In addition, some low magnitude earthquakes are also located from the adjoining parts towards Uttarkashi in the west, and towards Pithoragarh in the south.

5) Some low-frequency noise signatures are observed in the continuous data in the Marwari Station. Some noise is also observed in the Ravigram Station. The amplitude and frequency are on higher side recorded in the Marwari Station. This frequency and amplitude was higher in the month of January, especially before 20 January 2023. This noise is observed very less at present.

Requirement for further work:

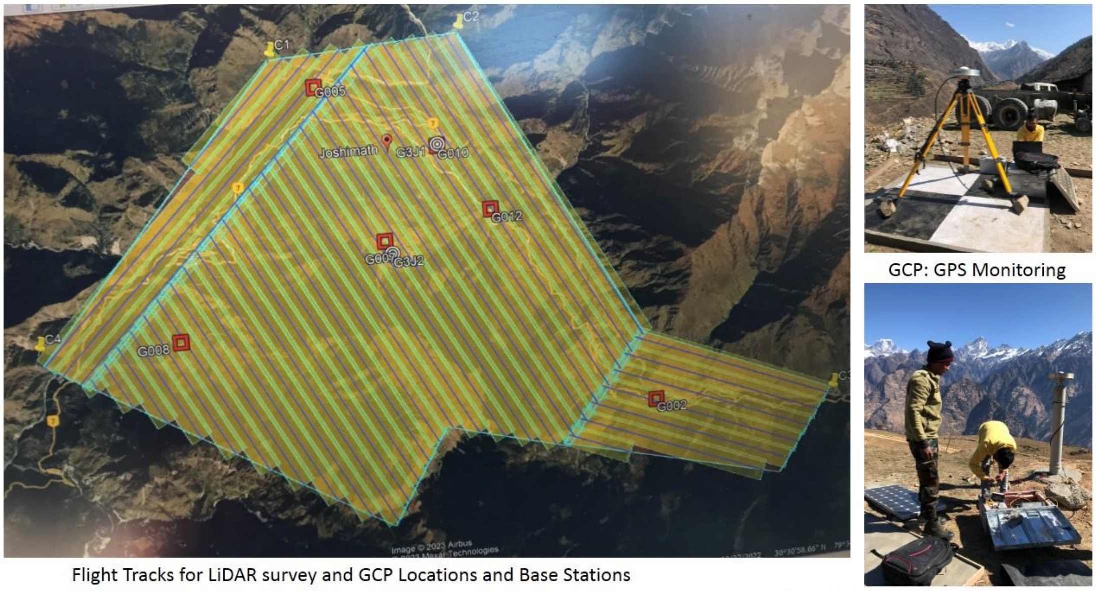
1) The 11 station observation is in progress, however, more data is required for sub-surface uppermost crustal structure investigation.

2) Further observations with the data from the network will provide information about seismic activities in this region.

DIGITAL HIGH-RESOLUTION MAPPING OF JOSHIMATH USING AIRBORNE LIDAR

In the light of the recent events of January 2023 where sudden appearance of cracks in houses and on ground surface were seen, especially seen in the western part of Joshimath in the wards of Sunil, Manohar Bagh, Singdhar and Marwari. This was accompanied by the gushing out of sediment-laden water in Jaypee Colony at an elevation of about 1665 m asl. The number of houses damaged and people displaced have been considerable. In this context, several Indian research institutes and organizations have come together to study the geological setup of the Joshimath town. The geophysical surveys show a saturated zone in the sub-strata around Manohar Bagh and Singhdhar wards. It was, therefore, necessary to have a high-resolution and large scale map of the region covering the entire town of Joshimath and surrounding regions, where rehabilitation is envisioned. Since Joshimath lies on a steep slope, with quite dense concrete built-up, along with some parts densely forested, Airborne-LiDAR technique of an elevation model seemed to be the most suitable and viable option for mapping the area.

Upon receiving a Work Order from Uttarakhand State Disaster Management Authority (USDMA), No. 1983/USDMA-1090(2023), dated 17 February 2023. Wadia Institute of Himalayan Geology, Govt. of India, Dehradun has been assigned with the task of providing high resolution map and digital elevation models of 100 sq km of Joshimath and the surrounding regions for landslide mitigation and management purpose.



Flight Tracks for LiDAR survey and GCP Locations and Base Stations

GCP: GPS Monitoring

Base Station: Permanently Running

Figure: LiDAR coverage and locations of GCPs for the Joshimath topographic mapping. The two Base Stations at NTPC Helipad, Ravigram and Auli

The deliverables from the LiDAR survey are:

1. LiDAR data:

(a) raw data

(b) Classified (ground, building, vegetation), geo-referenced point cloud

2. Images:

(a) raw data

(b) ortho-rectified images, 5 cm GSD, geo-referenced in tiff format

3. Digital Terrain Model (DTM) with 25 cm x 25 cm grid, tif format, georeferenced

4. Digital Surface Model (DSM) with 25 cm x 25 cm grid, tif format, georeferenced

5. Contours with contour interval 10 cm (or higher as requested), georeferenced, in ArcGIS Database

6. One set of deliverables in ITRF14 Ref. Frame, and WGS84 heights. Another set in ITRF14, orthometric (MSL) heights

Survey and Acquisition of Data:

The ground team started on-site establishment of Ground Control Points by constructing slabs of 6 X 6 feet concrete slabs at 6 locations, painted in black and white, and two pillar base stations, around the survey area (figure 1) starting from 23 February 2023. The airborne data collection started on 25 February 2023. However, due to bad weather, the helicopter has to abort operations. On 26th February 3 hours of flight survey could be completed before it started getting windy, with clouds, rain and snow at places. Flight survey was aborted before completion of acquisition. On 27th February acquisition of data started early morning and was finally completed by around 9 am.

Setting up of Auli GCP & Base Station

Figure 2: Setting up of Base Stations and GCPs

Thereafter, the ground team started GPS monitoring in 6 GCP locations, two base stations by taking measurements in each GCP points for 8 hours. The team also started the search for Survey of India benchmarks (BM) inside the survey area and close to the survey area, east, west, north and south. However, it was seen while trying to locate the BMs that:

1. The SoI BMs in Joshimath are displaced. And unless corrected in the leveling, they cannot be used. Some BMs are also missing.

2. The BMs towards east, Tapovan, Mirag and Raini are all destroyed during the 2021 Rishiganga Flood disaster.

3. Out of the BMs south of Joshimath, the BMs with descriptions near Helang, could not be located and looks like they are displaced. *Only one Type B BM in the compound of Police Station of Pipalkoti market could be found*.

4. Out of all BMs north of Joshimath, the team searched for all BMs upto Mana. Even after digging for a whole day the Mana Type B was not found. The Lambagarh Type B near the Jaypee Barrage was washed out during the 2013 Kedarnath disaster. *The Type M BM at Badrinath wad located in the compound of PWD IB was located. The Type B BM was located in the compound of PWD IB in Pandukeshwar*.

Figure 3: Bad weather, and acquisition using helicopter on good weather days

After locating the Badrinath, Pandukeshwar and the Pipalkoti, and after completion of the GCPs, GPS measurements were started for 24 hours in each SoI BMs.

After collection of all data, the team returned from field on 5th March 2023. Thereafter, Survey of India proceeded to correct their leveling data for their lines along the Alaknanda Valley. SoI height data was also measured for the GCPs created for the LiDAR survey. The final SoI AoI data was received on 10th April 2023.

Figure 4: Photos acquired from the helicopter over coverage area

Thereafter, the processing for the LiDAR data started. The present status of the processing is as follows:

1. Pre-processing of the raw tiff files for the photos completed and the trajectories generated.
2. Point-cloud data generated
3. Geoid Model for Joshimath developed using BM data. The Geoid model shows consistent
4. Vertical accuracy model assessment completed.
5. Classification completed for buildings, vegetation and ground.
6. Absolute height accuracy of LiDAR data in WGS 84 datum, derived using 5 GCPs shows Standard Deviation of 8 cm, and RMSE 11 cm, which has been found to be good. This has been obtained by comparing LiDAR derived heights with GPS derived heights measured using the 6X6 feet GCP points.
7. Manual removal of buildings and built-up area has been done.
8. Apply geoid model to point cloud

The next work in line is as follows:

1. Convert point cloud data to DEM. This will be provided, along with contours (10 cm/100 cm according to requirement) in 7 days. *The DEM (BARE GROUND) and the DSM (with all features including buildings and vegetation) will be provided with top priority.*

2. Orthophotos generation from photographs collected from survey.

Conclusions:

Some suggestions for constraining time-line of work includes:

1. SoI BM should be monitored and data upgraded regularly, even in other places of Uttarakhand, Himalaya.
2. Since Uttarakhand is a mountain state, and often faces mountain disasters, it is of utmost importance that LiDAR topographic mapping is done for the state. Planning of management and mitigation is convenient if bare-ground topography and the surface models are available to planners and decision makers.
3. Optimum utilization of the DEM derived from LiDAR is very important. As this is a powerful base of information, WIHG will be able to guide Govt. of Uttarakhand for utilization of the DEM in planning.