REPORT ON

SATELLITE BASED DEFORMATION ANALYSIS OF JOSHIMATH TOWN

INDIAN INSTITUTE OF REMOTE SENSING
INDIAN SPACE RESEARCH ORGANISATION
DEPARTMENT OF SPCE, GOVERNMNE OF INDIA
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REPORT/ DOUCUMENT CONTROL SHEET

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15.	**Abstract (with keywords)**	This document contains the deformation results of Joshimath Town derived from satellite datasets. Three types of results are shown in the report – i) time series measurement using multi-temporal SAR interferometry techniques, ii) differential SAR interferometry using a pair of images at a time, and iii) continuously operating reference station (CORS) datasets. **Keywords:** Time-series, deformation measurements, SAR data processing, CORS		

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REPORT ON JOSHIMATH LAND DEFORMATION

1. BACKGROUND

Joshimath town of Chamoli district in Uttarakhand state (figure 1) was recently in news due to the significant increase observed in the land deformation and associated development of cracks in several buildings. The recent events in Joshimath town has put the focus of the fragility of the Himalayan region to various natural hazards. Figure 1a shows the location of the study area and Figure 1b shows the topographical visualization along with the slope and elevation profile. Indian Institute of Remote Sensing (IIRS)/ISRO taking cognizance of the media news report about consistence slipping of the slope in Joshimath and the resultant development of cracks in buildings, roads and other infrastructure has carried out space based analysis of various datasets to understand the phenomenon. The area has been analyzed using time series Satellite based Radar Interferometry and complemented by Continuously Operating Reference Stations (CORS) to understand the direction and rate of movement.

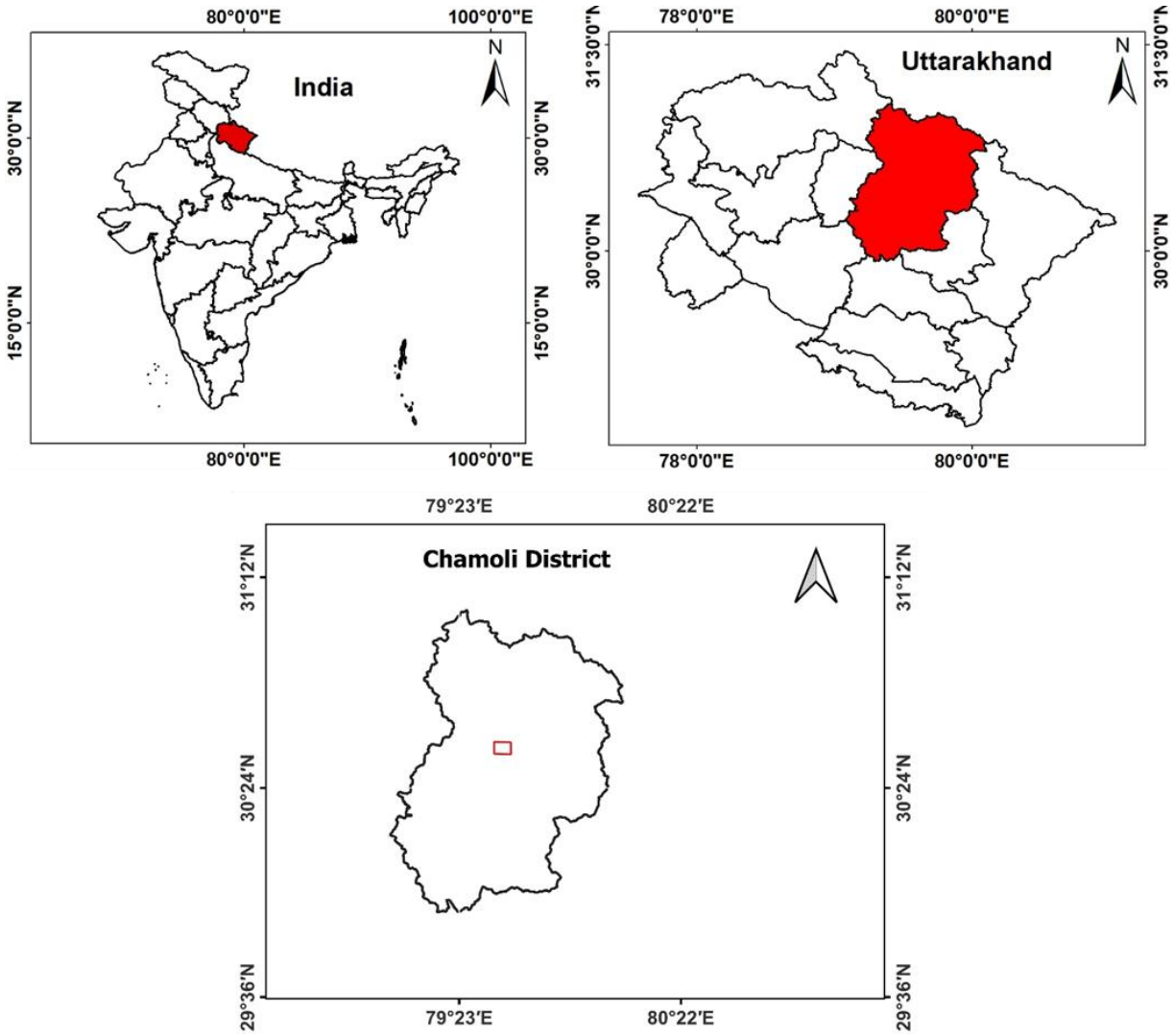


Figure 1: Location map showing location (red square) of the Joshimath town and surroundings

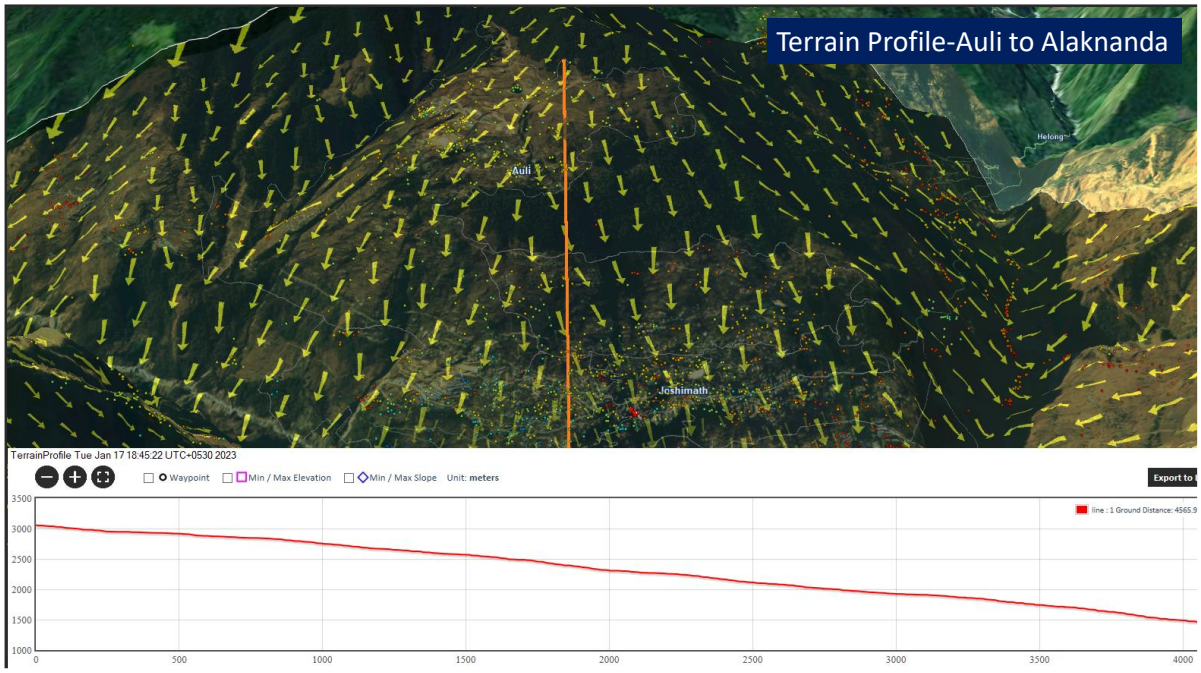


Figure 2: Terrain profile of the Joshimath between Auli and Alaknanda river (The arrows indicate the direction of slope in the region).

2. SPACE BASED OBSERVATIONS

2.1 Small BAseline Subset (SBAS) Interferometry SAR Technique

Total 102 Sentinel-1A space borne Synthetic Aperture Radar (SAR) images acquired from June 10, 2019 to February 25, 2023 with a revisit period of 12-day, were used to derive long time series deformation using Small BAseline Subset Interferometry SAR (SBAS-InSAR). SBAS-InSAR is an advanced version of Differential Interferometric SAR technique, that analyzes targets (pixels) with stable phase, and moderate to high coherence throughout the investigation period and derive the displacement time-series along the radar line of sight (LOS). Total 290 interferograms (Figure 3) were processed using 102 Sentinel-1 images to derive a time-series measurement of land deformation (displacement) along the radar line of sight (LOS).

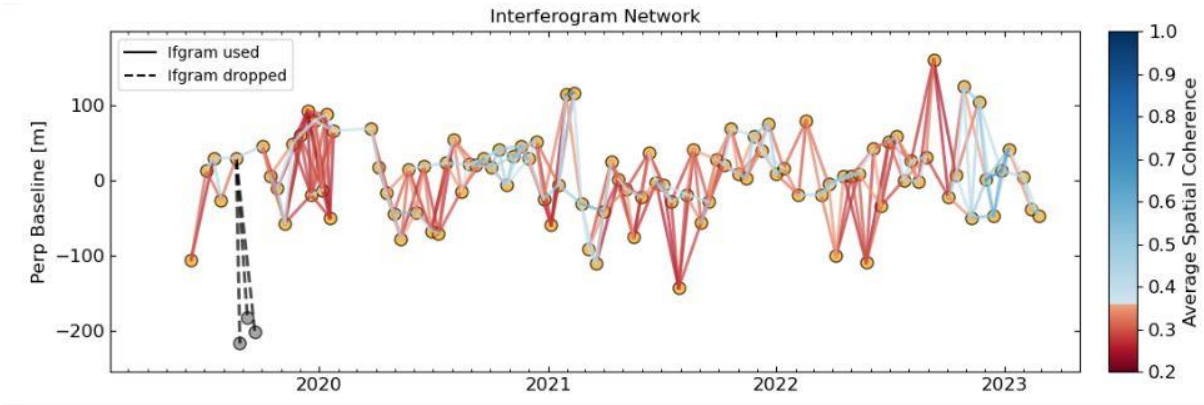


Figure 3: Multi-connected network of Interferograms generated using 102 images of Sentinel-1 SAR sensor

Figure 4 shows the radar line of sight (LOS) deformation and its rate of movement from June 2019 to February 2023. The yellow to red points (pixels) show the subsidence in increasing order of magnitude (away from satellite) and has been overlayed on the high resolution satellite DEM. The regions in the central part and few paches in the eastern part of the Joshimath town shows higher rate of subsidence (around 12 cm / year) compared to other areas of Joshimath town. Further the time-series LOS displacement was plotted over central and southern (at high altitude) numbered by 1, 2 and 3 to understand the LOS movement over entire investigation period (June 2019 – February 2023). Figure 5 show the time-series graphs of radar LOS displacement (deformation) versus time. From SBAS-InSAR based analysis it was observed that there was an increase in the land deformation activity (around 12 cm/yr). The enhanced deformation activity was observed in the central, eastern, and southern (high altitude) parts of the Joshimath town in patched manner. The deformation over Joshimath town is not uniform and not over whole region. The major changes in the deformation started from February 2021 when Rainy flash flood occurred, and a sudden movement is observed during June 2022, Oct-Nov 2022, and Jan-2023, and continued till date. These satellite based observations are related to land surface motion only and needs to be correlated with the geophysical, geotechnical observations.

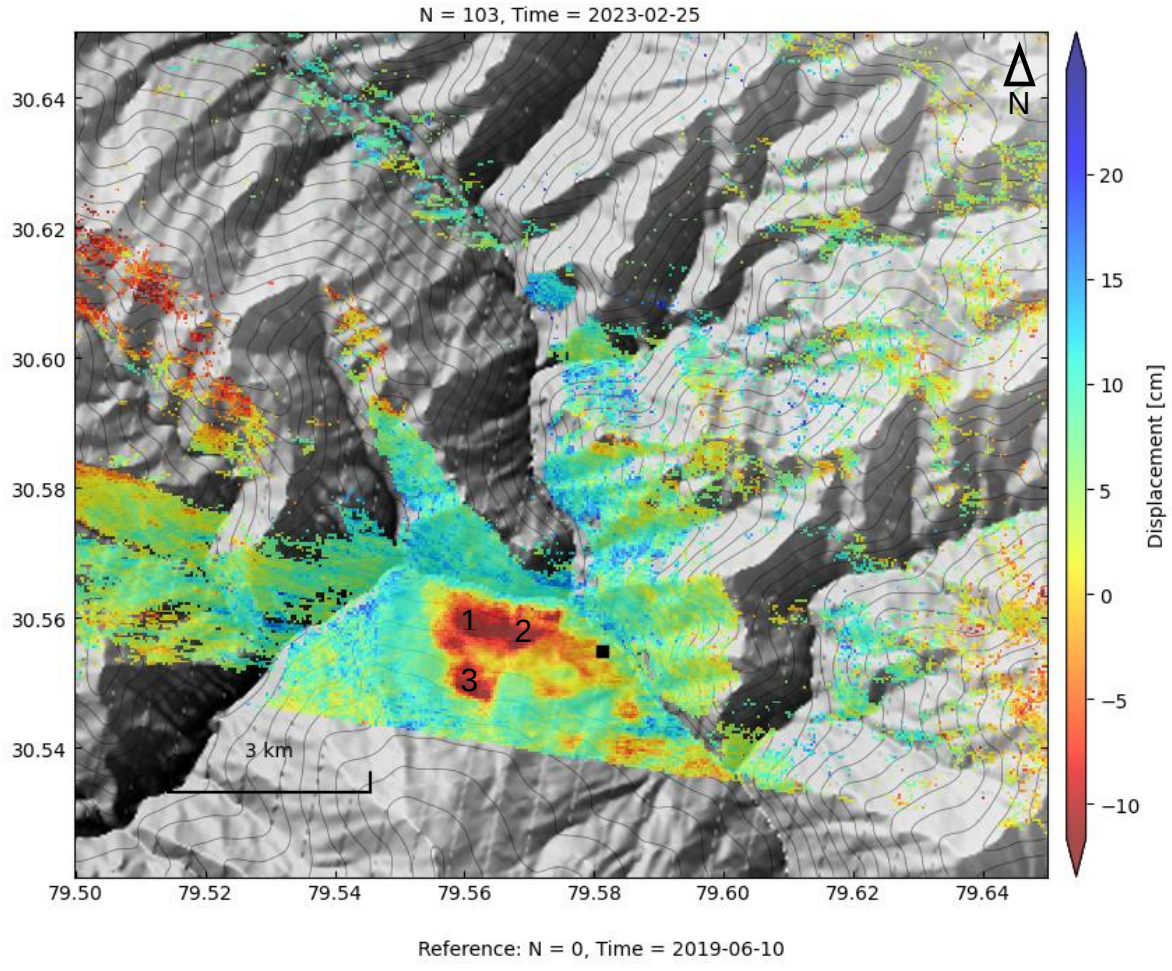


Figure 4: Radar line of sight (LOS) deformation movement between June 2019 and February 2023. The colored points (reddish) show the movement away from the satellite and represents land subsidence of different magnitude.

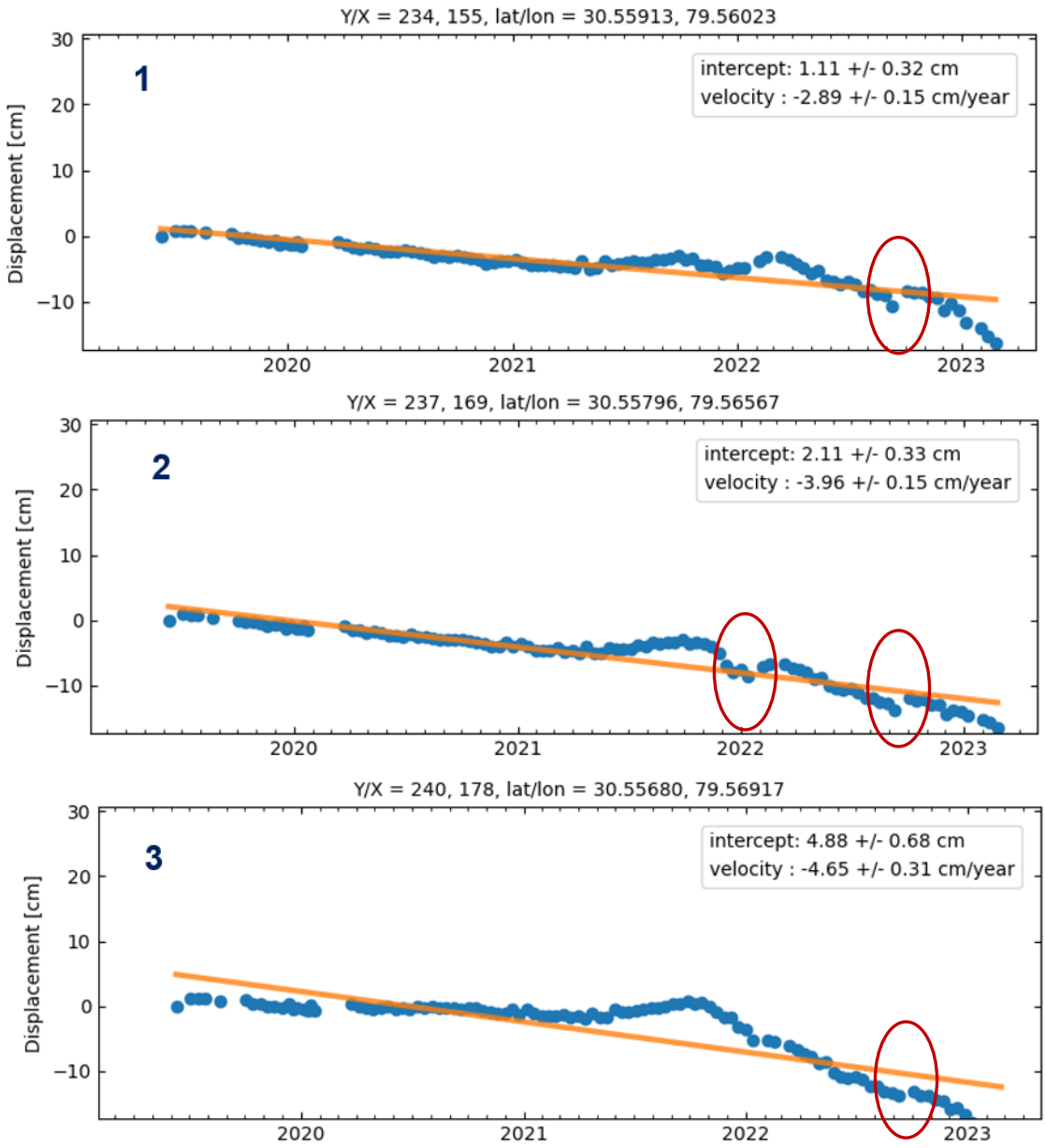


Figure 5: Radar LOS time-series deformation (displacement) between June 2019 and February 2023. The red circle shows the sudden change in movement of land surface. Locations 1, 2 and 3 are corresponding to locations shown in Figure 4

However, the satellite based observation needs to be supported by ground based observation and instrumentation. The subsidence in this region may be due to toe-cutting phenomenon, slope instability as a result of seepage of local drainage water in the soil, terrain and edaphic characteristics, loose and unconsolidated moraine materials of the slope (due to old landslide) and Flash flood events in and around the area in Recent Past. This has resulted in development of cracks in the ground as well as houses in Joshimath Town (Figure 6).

Figure 6: Field information of the damage to infrastructure and houses due to land slippage in Joshimath Town collected during field visit in April 2022 and collected from social media in January 2023

2.2 Differential SAR Interferometry (DInSAR):

The Land deformation analysis of the Joshimath, Uttarakhand area was carried out using Differential SAR Interferometry (DInSAR) technique from Sentinel-1A imagery during the period from September 2022 to January 2023. The pairwise interferometric datasets with temporal baseline of 12 days of Sentinel-1A has been taken for the study and is shown in Table-1. The Single Look Complex (SLC) data of Interferometric Wide (IW) swath mode of Sentinel-1A has been used for the study. The subsidence map for the Joshimath area is

generated using DInSAR technique from the pairwise Sentinel-1A datasets. The various steps involved in the DInSAR process is shown in Figure 7.

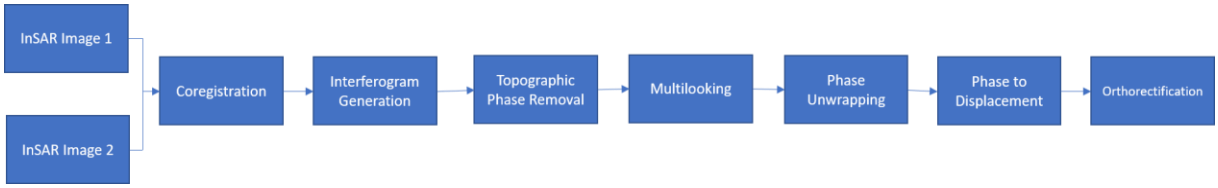


Figure 7: DInSAR Flow Diagram

Table 1: Sentinel-1A Interferometric Datasets used in the study

SN	Date of Pass	Pass	Look	Polarization
1	10/09/2022	Descending	Right	VV
	22/09/2022	Descending	Right	VV
2	22/09/2022	Descending	Right	VV
	04/10/2022	Descending	Right	VV
3	16/10/2022	Descending	Right	VV
	28/10/2022	Descending	Right	VV
4	09/11/2022	Descending	Right	VV
	21/11/2022	Descending	Right	VV
5	15/12/2022	Descending	Right	VV
	27/12/2022	Descending	Right	VV
6	27/12/2022	Descending	Right	VV
	08/01/2023	Descending	Right	VV
7	31/12/2022	Ascending	Right	VV
	12/01/2023	Ascending	Right	VV
8	07/01/2023	Ascending	Right	VV
	19/01/2023	Ascending	Right	VV
9	12/01/2023	Ascending	Right	VV
	24/01/2023	Ascending	Right	VV

The study finds that there is a slight deformation starting from October 2022 and observed in the Interferometric datasets of 16 October 2022 & 28 October 2022. It was further observed that there is a sudden increase of deformation the Interferometric datasets of 9 November 2022 & 21 November 2022 and continues up to 19 January 2023. However, from the Interferometric datasets of 12/01/2023 & 24/01/2023, it is observed that there is reduction in land deformation activity in the studied area to a considerable extent. The study also finds that there is no substantial subsidence observed from the interferometric datasets of September 2022.

The Figure 8a shows the deformation map (Gray scale) overlays on Pansharpened Cartsat-2E image (False Colour Composite) of Joshimath area. The Figure 8b shows the subsidence map (Gray Scale) generated from different Interferometric Sentinel-1A datasets. The darker tones in the subsidence map represents area with higher deformation and brighter tones represents areas with the low deformation activity.

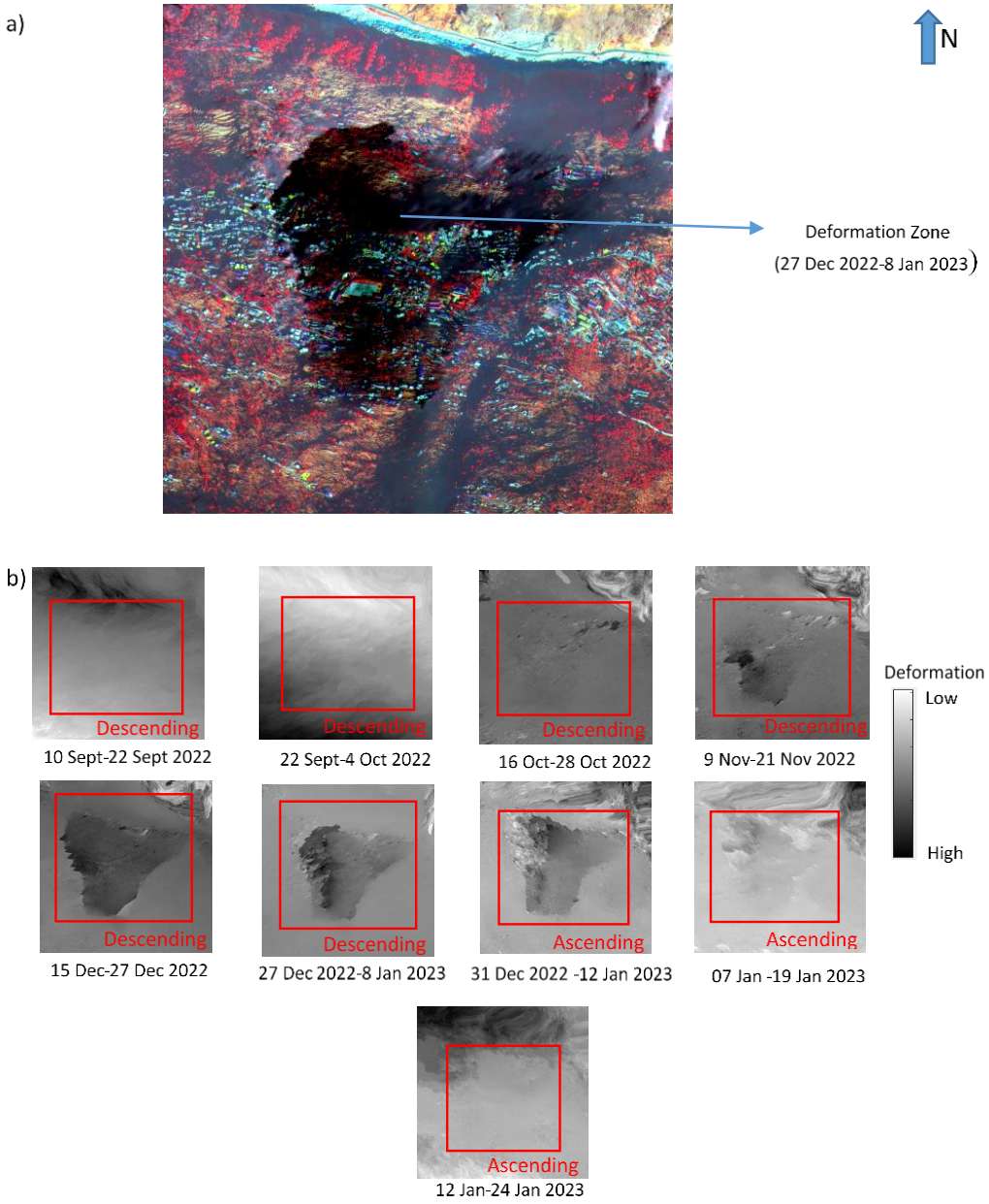


Figure 8: deformation map generated from Sentinel-1A Interferometric datasets 9September 2022 to January 2023)

2.3 Application of CORS data in the study of land deformation at Joshimath

Data from the CORS station JOSH (located in Joshimath, installed by Survey of India, Dehradun) have been analyzed. Along with JOSH, four other CORS stations PURO, CHAM, BHEL, MAND (installed by IIRS, ISRO, Dehradun) and 20 IGS stations data (located on Indian and other neighboring plates) have been analyzed in GAMIT/GLOBK software in three components (North, East & Vertical) with respect to ITRF2014. The data analyzed have been recorded at 1 sec sampling interval and 24 hrs observation from 1st January 2022 to 30th March 2023. The total displacement (mm) and average displacement (mm/day) have been estimated for this period at four time intervals in North, East and Vertical components (Table 2). The time series (1st October 2022 to 07th February 2023, 1st January 2022 to 30th March 2023 and 20th

January 2023 to 30th March 2023) showing changes in displacement at these three components explains the reason for this alarming natural disaster (Figure 9-11). From this perspective, it can be stated that GNSS data measurements can be executed in the study of subsidence at the Joshimath region.

Table 2: The estimated displacement value and the average displacement for four time intervals in North, East and Vertical component at Joshimath GNSS station

TIME INTERVAL	**NORTH**		**EAST**		**VERTICAL**	
	Total displacement (mm)	Avg. displacement (mm/day)	Total displacement (mm)	Avg. displacement (mm/day)	Total displacement (mm)	Avg. displacement (mm/day)
1 Jan-10 Nov 2022	453	1.5	93	0.3	-246	-0.78
13 Nov-30 Dec 2022	322	6.8	41	0.9	-181	-3.8
31 Dec-8 Jan 2023	86	9.5	4.6	0.5	-50	-5.5
9 Jan-7 Feb 2023	33	1.1	2	0.06	-23	-0.8
20th January 2023-30th March 2023	41.65	0.6	9.21	0.1	-21.43	-0.3

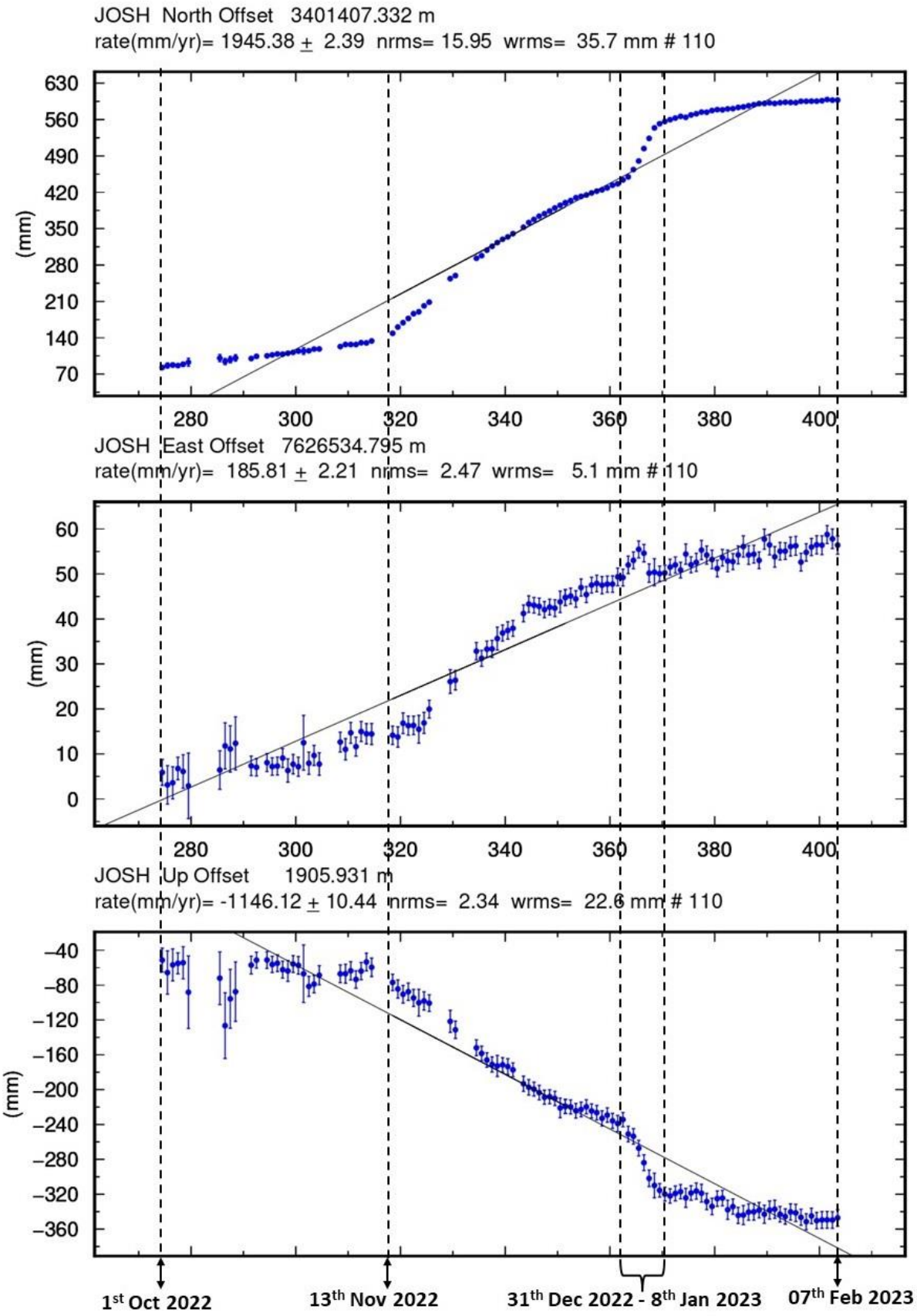


Figure 9: The time series at JOSH GNSS station illustrates the displacement estimated in the three components, North, East & Vertical, to study the subsidence crisis at Joshimath region from 1st October 2022 to 7th February 2023

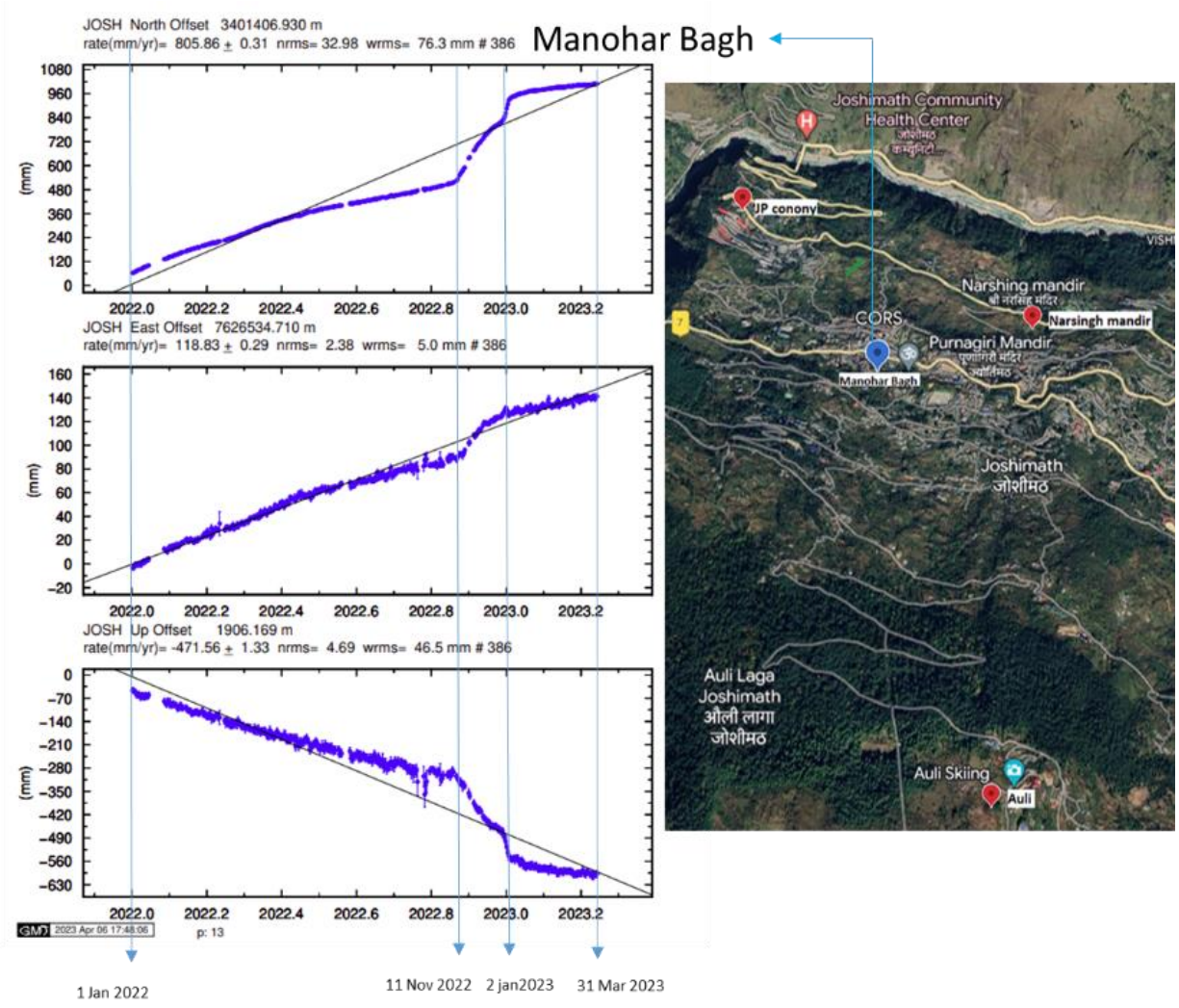


Figure 10: The time series at JOSH GNSS station illustrates the displacement estimated in the three components, North, East & Vertical, to study the subsidence crisis at Joshimath region from 1st January 2022 to 30th March 2023

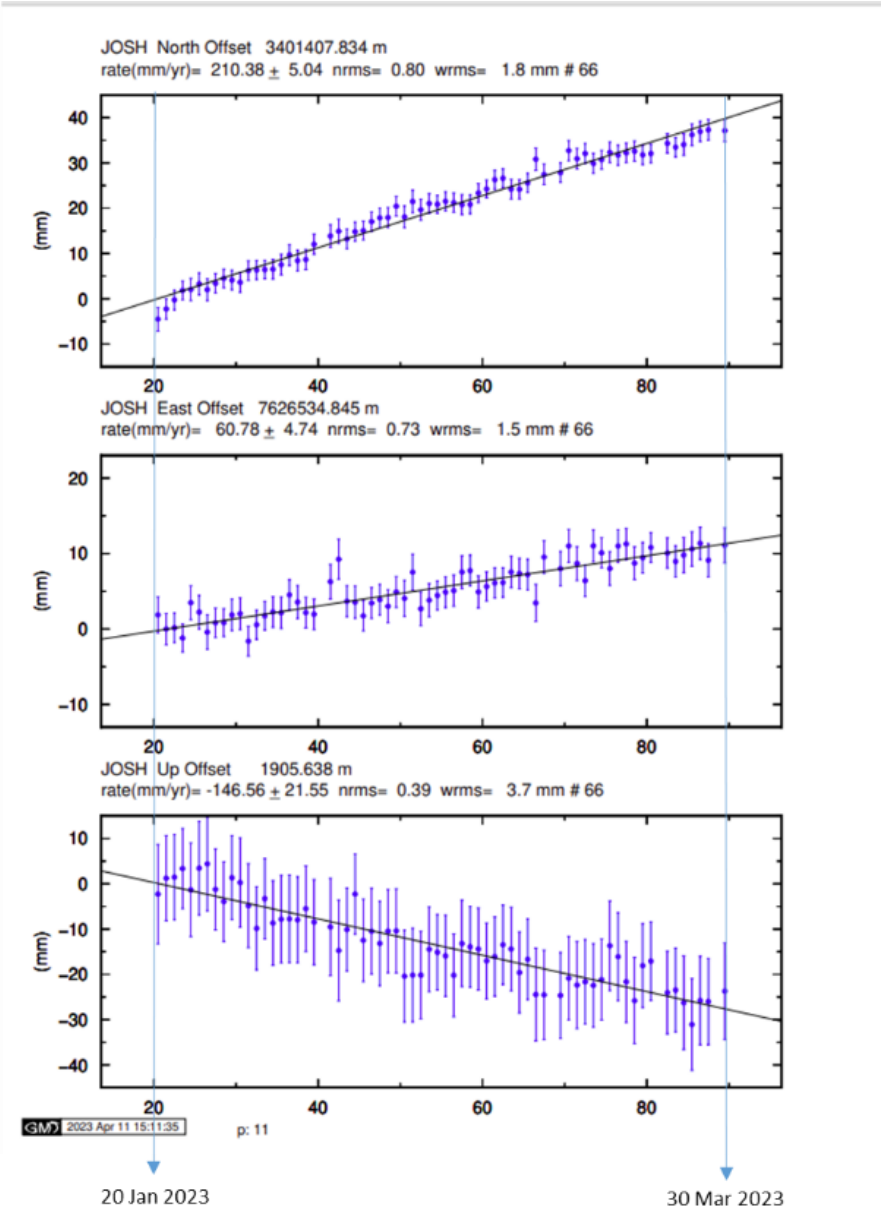
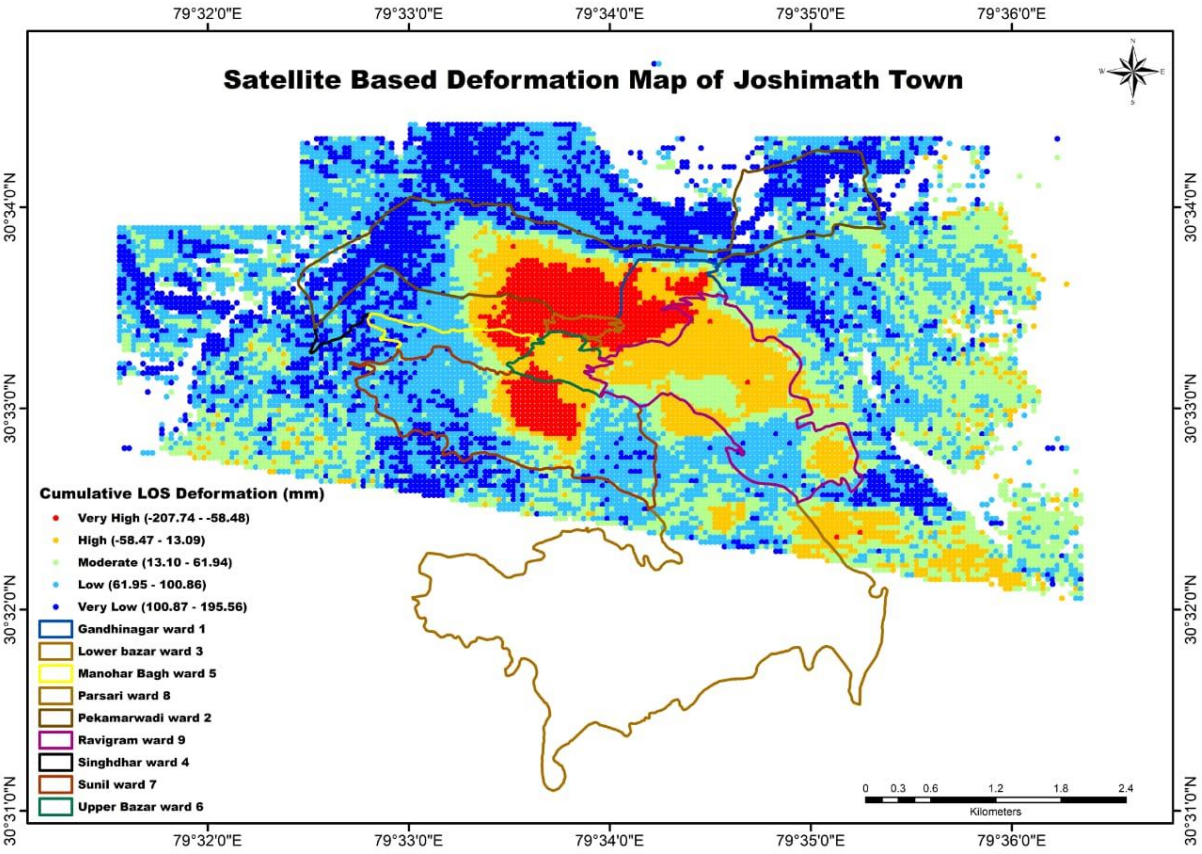


Figure 11: The time series at JOSH GNSS station illustrates the displacement estimated in the three components, North, East & Vertical, to study the subsidence crisis at Joshimath region from 20th January 2023 to 30th March 2023

Survey of India has installed Continuously Operating Reference Stations (CORS) at Joshimath. One of such station is installed in Joshimath, which is working continuously from December 2021. On analysing Joshimath CORS station data at various epochs, it has been observed that during 2022 Joshimath CORS station position has shown significant movement between 25-Nov-22 to 06-Jan-23.


Satellite Based Deformation Map of Joshimath Town
79°32'0"E
79°33'0"E
79°34'0"E
79°35'0"E
79°36'0"E
30°34'0"N
30°33'0"N
30°32'0"N
30°31'0"N
Cumulative LOS Deformation (mm)
Very High (-207.74 - -58.48)
High (-58.47 - 13.09)
Moderate (13.10 - 61.94)
Low (61.95 - 100.86)
Very Low (100.87 - 195.56)
Gandhinagar ward 1
Lower bazar ward 3
Manohar Bagh ward 5
Parsari ward 8
Pekamarwadi ward 2
Ravigram ward 9
Singhdhar ward 4
Sunil ward 7
Upper Bazar ward 6
0 0.3 0.6 1.2 1.8 2.4
Kilometers