SLOPE MOVEMENT ESTIMATION IN NAINITAL TOWN: DETERMINED BY PSINSAR TECHNIQUE USING SENTINEL-1 DATASET

Manoj Kuri, Govt. Engineering College Bikaner, Email: kuri.manoj@gmail.com
Manoj K. Arora, PEC University of Technology, Chandigarh, Email: manoj.arora@gmail.com
M. L. Sharma, Indian Institute of Technology, Roorkee, Email: sharmamukat@gmail.com

KEY WORDS: Slope movement, Persistent Scatterers, Velocity map, Kumaun Himalayas.

ABSTRACT: The purpose of this research was to investigate the potential of Persistent Scatterer Interferometric Synthetic Aperture Radar (PSInSAR) technique, using radar imaging satellite Sentinel-1 dataset to estimate slope movement at landslides prone Nainital town in Kumaun Himalayas.
Sentinel 1A and 1B SAR dataset of 37 single look complex (SLC) images acquired in Interferometric Wide (IW) Swath mode with HH polarization, is used for the PSInSAR processing. The initial sets of Persistent Scatterers were identified on the basis of normalized amplitude stability index. Mean Velocity map and time series plots have been produced for the study period from December 2015 to May 2017. Mean velocity maps of study area evidently revealed that there is noticeable movement along the slopes at few locations. Time series plots have been also generated for the selected persistent scatterers(PS) to determine the temporal behaviour of movement in satellite Line of Sight (LoS) direction.
At the NW and SW slopes, areas in proximity to Naini Lake have shown no movement and are stable during the study period of 18 months. On the N-NE slopes many locations at Sher- ka-Danda hill slopes has shown noticeable movement during the study period. Snow view peak are identified as unstable and maximum velocity is measured upto -23 mm/year in satellite Line of Sight (LoS) direction. Slow movement has been detected at the dense urbanized area of Lower Mall Road near Naini Lake and mean velocity around -10 mm/year has been measured. On the Southern slopes, displacement has been estimated at Baliya Nala Landslide area, which shows velocity around -25 mm/year for few identified points. The study clearly illustrates the usefulness of PSInSAR technique using Sentinel-1 dataset for estimation of slope movement in Kumaun Himalayas.

1. INTRODUCTION

Differential Synthetic Aperture Radar Interferometry (DInSAR) is a unique, remote sensing based technique. DInSAR makes use of phase information from two or more SAR images to measure surface displacement in satellite line of sight (LOS) direction, with millimetric precision (Gabriel *et al.*, 1989; Massonnet *et al.*, 1994; Zebker *et al.*, 1994). Traditionally, two or three pass DInSAR techniques have been applied to study single deformation episode, such as landslides, earthquakes and volcanic events; subsequently, advanced multi-temporal InSAR approaches SBAS(Small Baseline Subset Technique) and Persistent Scatterer Interferometric Synthetic Aperture Radar (PSInSAR) have been developed in order to analyze the temporal evolution of the surface displacements (slow moving landslides, ground subsidence etc.) via the generation of deformation time series analysis.

PSInSAR is a Multi-temporal InSAR technique, have been employed to produce time-series of slow deformation measurements over the long period of time. PS techniques apply statistical methods to identify pixels with a single dominant scatterer that are relatively less affected by decorrelation and use the associated interferometric phase to infer a deformation time-series. Methods to identify and isolate these PS pixels in interferograms have been developed by several research groups (e.g., Ferretti *et al*., 2001; Colesanti *et al*., 2003; Lyons and Sandwell, 2003; Werner *et al*., 2003; Hooper *et al*., 2004; Perissin and Wang, 2012). All of these methods use a functional model of how deformation varies with time to identify PS pixels, and have been very effective in identifying PS pixels that undergo periodic deformation. In these methods, an initial set of PS pixels with a high signal-to noise ratio (SNR) is identified by analyzing the amplitude variation, pixel by pixel, in a series of interferograms (Crosetto *et al.,* 2016).

PSInSAR technique has been utilized by many researchers to estimate slope movement and early detection of landslides at mountainous areas (Righini *et al.,* 2012; Tofani *et al.,* 2013; Lazecky *et al*., 2016). Recently few multi temporal InSAR based studies have been conducted to estimate slope movement in Indian Himalayas (Dwivedi, *et al.,* 2014; Vöge *et al.,* 2015, Bhattacharya *et al.,* 2015; Bhattacharya and Mukherjee, 2016; Kuri *et al.,* 2016).

2. STUDY AREA

The Nainital town is an important hill station in the lower Himalayas and attracts millions of tourists every year. Town is situated around natural lake at an altitude of 1,935 meter above mean sea level. The lake is approximately 1,400 meter long and 500 meter wide and, is surrounded by hills ranging in height from 2,085 meters to 2,612 meters. Highly urbanized Sher-ka-Danda hills are located to East - Northeast to Naini Lake. It merges with Naini hills in the north. The lake is surrounded by Ayarpatha-Deopatha hills in West and South-West. In South - Southeast direction Balia ravine (or Balia-Nala) is located, which is the only outlet of lake. Balia Nala passes through Kailakhan area.

Nainital is facing hill slope instability problems (Hukku *et al.,* 1974; Valdiya, 1985) since long and many landslides have occurred here in the past. Sher-ka-Danda and Balia Nala are active landslide areas (Valdiya, 1988; Thakur, 1996) in Nainital. Sher-ka-Danda slide presents a huge threat to the populated urban areas at and around the Naini Lake. This landslide has been active for more than a century (since 1880) and several medium-scale slides have already occurred in the past, some of them causing the loss of lives and severe damages to infrastructure.

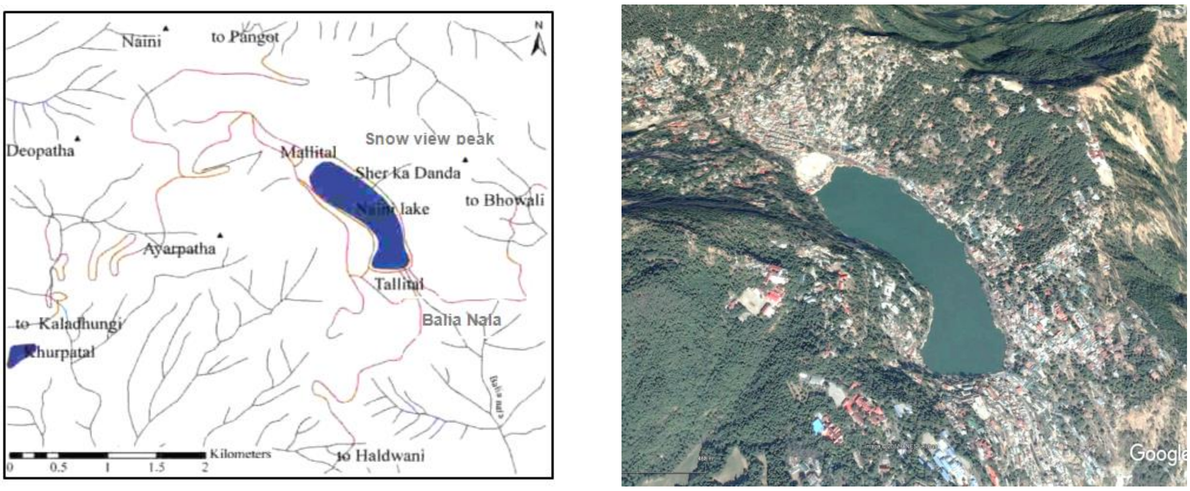


Figure 1: (a) Map showing study area and (b) today's urbanization around Nainital Lake.

In September 1880, a landslide occurred at the north end of the town on the slopes of Sher-Ka-Danda hill, burying 151 people. The first known landslide had occurred in 1866, and in 1879 there was a larger one at the same spot. The Assembly Rooms, the Naina Devi Temple were both destroyed in the disaster (Bhandari, 1986; Rautela, 2011) and it also filled a part of the lake. A recreation area known as 'The Flats' was later built on the site and a new temple was also erected. A historical views before and after landslide is shown in Figure 2. To prevent further disasters, storm water drains were constructed and building bylaws were made stricter.

Both sides of the Balia Nala are repeatedly affected by landslides and mass movement activities. The slides along both sides of the Nala are gradually increasing. A major landslide along the right bank of the Balia Nala occurred in 1972. Subsequently, the slopes at the lower elevation of the Balia Nala are continuously sliding due to toe erosion (Gupta *et al.,* 2016; Kumar *et al.,* 2017).


Figure 2: Historic photographs of the 1880 Nainital landslide area.
Left: prior to the landslide, 1875. Right: after the landslide, 1880.

3. REMOTE SENSING DATA

Sentinel-1 is a two satellite constellation (Sentinel 1A and Sentinel 1B) which provides C-Band SAR data continuity following the withdrawal of ERS-2 and the completion of the ENVISAT mission. Each satellite is having repeat cycle of 12 days. Both satellites share the same orbit plane with a 180° orbital phase difference. Using both satellites constellation, the repeat cycle is reduced to 6 days. Sentinel 1A and 1B SAR dataset of 37 (31 Sentinel 1A and 6 Sentinel 1B) single look complex (SLC) images acquired in Interferometric Wide (IW) Swath mode with HH polarization acquired for the study period from December 2015 to May 2017 have been used for PSInSAR processing. In IW swath mode SLC image is having 3 m by 20 m spatial resolution (in range and Azimuth direction respectively). Sentinel 1A and 1B dataset used for PSInSAR processing is shown in Figure 3.

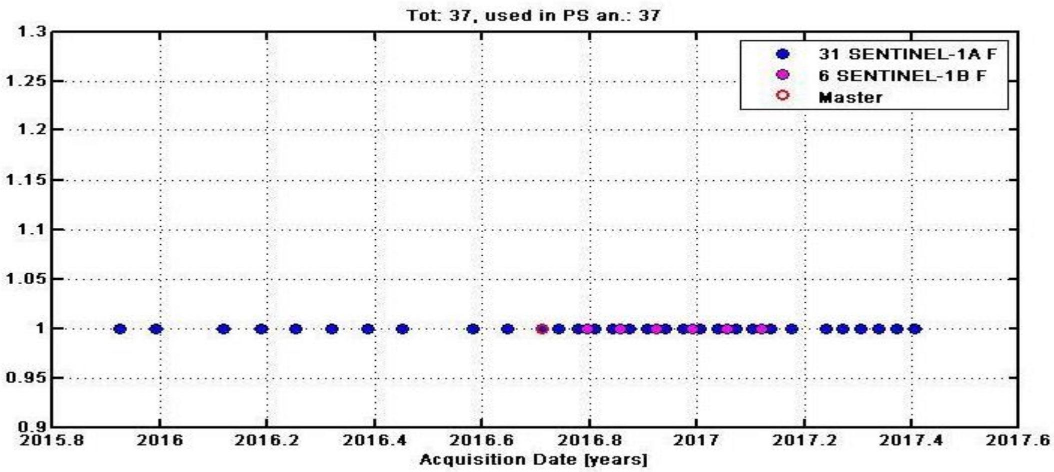


Figure 3: Sentinel 1A and 1B SLC dataset used for PSInSAR processing

4. PSINSAR PROCESSING

The PSInSAR technique implemented by SARPROZ® (Perissin *et al.*, 2011) was applied on the mentioned Sentinel-1 dataset. The SLC's were first co-registered and geocoded through the manual selection of a ground control point. ASTER Global DEM is used as external DEM and converted into the SAR geometry. For study area, ~1310 points have been selected and predictable as Persistent Scatterers candidates (PSC) on the basis of amplitude stability (PS with normalized amplitude stability index ≥ 0.65) in differential interferograms. Atmospheric phase screen (APS) was estimated for the selected PS candidates and phase models for corrections to the DEM and non-linear displacements were attributed to them.

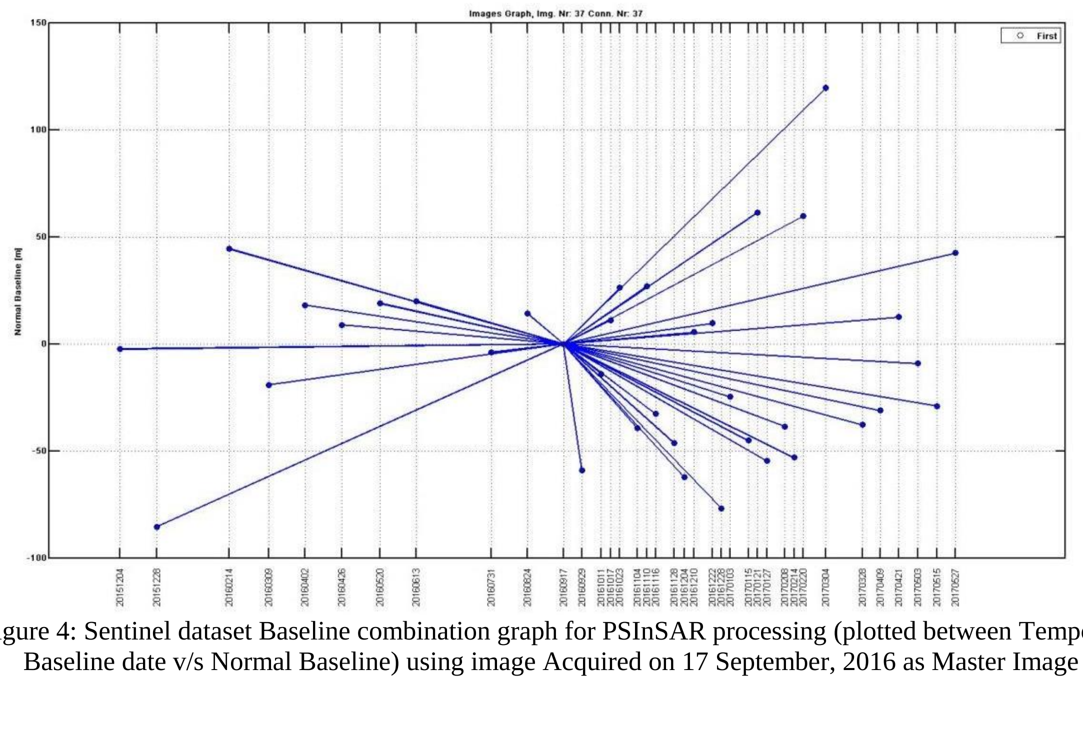


Figure 4: Sentinel dataset Baseline combination graph for PSInSAR processing (plotted between Temporal Baseline date v/s Normal Baseline) using image Acquired on 17 September, 2016 as Master Image

From the residual parameters from the comparison between the observed and the modelled phase, APS values for each image were computed for the probable PS candidates to PS and then incorporated for all the pixels in the image. For the PSInSAR processing, a larger set of points were further selected using normalized amplitude stability index ≥ 0.60. For each point, previously computed APS was detached and a value for DEM correction (residual height) was attained. Assessments of displacement value for all the PS was obtained and mean velocity map have been plotted for study area.

5. RESULTS AND DISCUSSION

Sentinel 1A and 1B data stack processed with PSInSAR que using SARPROZ tool. Mean velocity map and Cumulative displacement map for Nainital has been generated and is shown in Figure 5 and Figure 6 respectively. Time series plots have been also plotted for the four selected persistent scatterers to determine the temporal behaviour of movement in satellite Line of Sight (LoS) direction. Figure 7 (a to d) demonstrates PS time series in LoS direction for the selected point scatterers.

Mean velocity maps of study area evidently reveals that there is noticeable movement along the slopes at few sites at Nainital town. At the NW and SW slopes, areas in proximity to Naini Lake have shown no movement and are stable during the study period of one and half year.

On the N-NE Sher- ka-Danda hill slopes, noticeable movement of maximum -25 mm/year (negative sign means displacement away from satellite in LoS direction) has been measured for the study period. On the urbanized slopes at Snow view peak area and surroundings, identified as highly unstable and maximum velocity up to -23.4 mm/year has been measured in satellite LoS direction for selected PS P-1 and time series plot has also been generated, which shows cumulative displacement of -34.6 mm for study period.

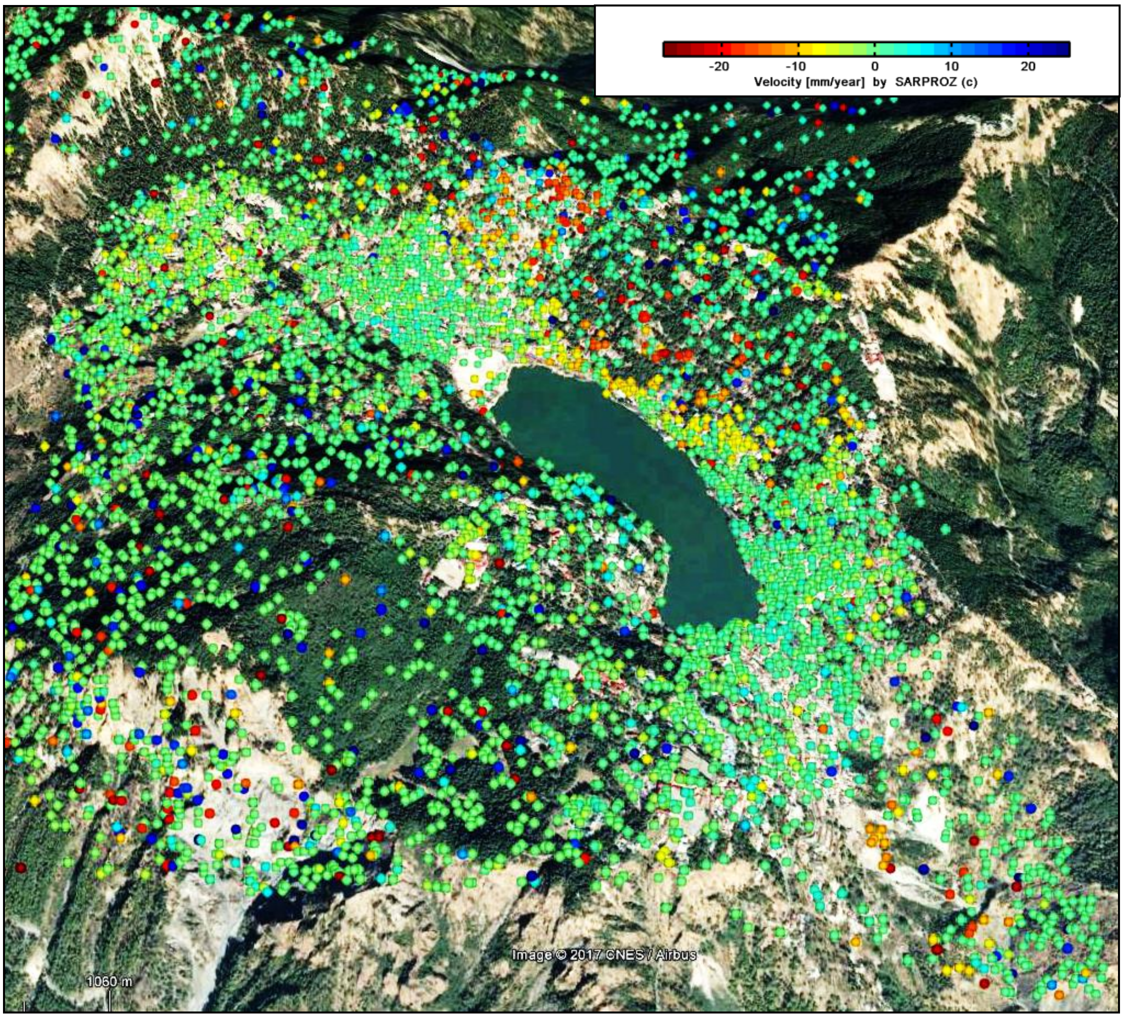


Figure 5: Mean Velocity Map (in mm/year) for Nainital processed using PSInSAR
(Background data: Google earth)

At the Northern slopes sparse PS point has been detected, which shows movement along the slope. For the Persistent scatterer point P-2 velocity of -20.7 mm/year and cumulative displacement of -30.6 mm has been detected. Slow movement has been detected at the dense urbanized area of Lower Mall Road near Naini Lake and mean velocity around -10.8 mm/year has been measured for selected PS P-3 and cumulative displacement of -16.0 mm.

On the Southern slopes, at Baliya Nala Landslide area velocities up to -25 mm/year has been detected in LoS direction. Slope movement on the both side of Balia Nala has been detected. For PS P-4 velocity -21.9 mm/year and cumulative displacement of -32.4 mm has been estimated for study period of one and half year.

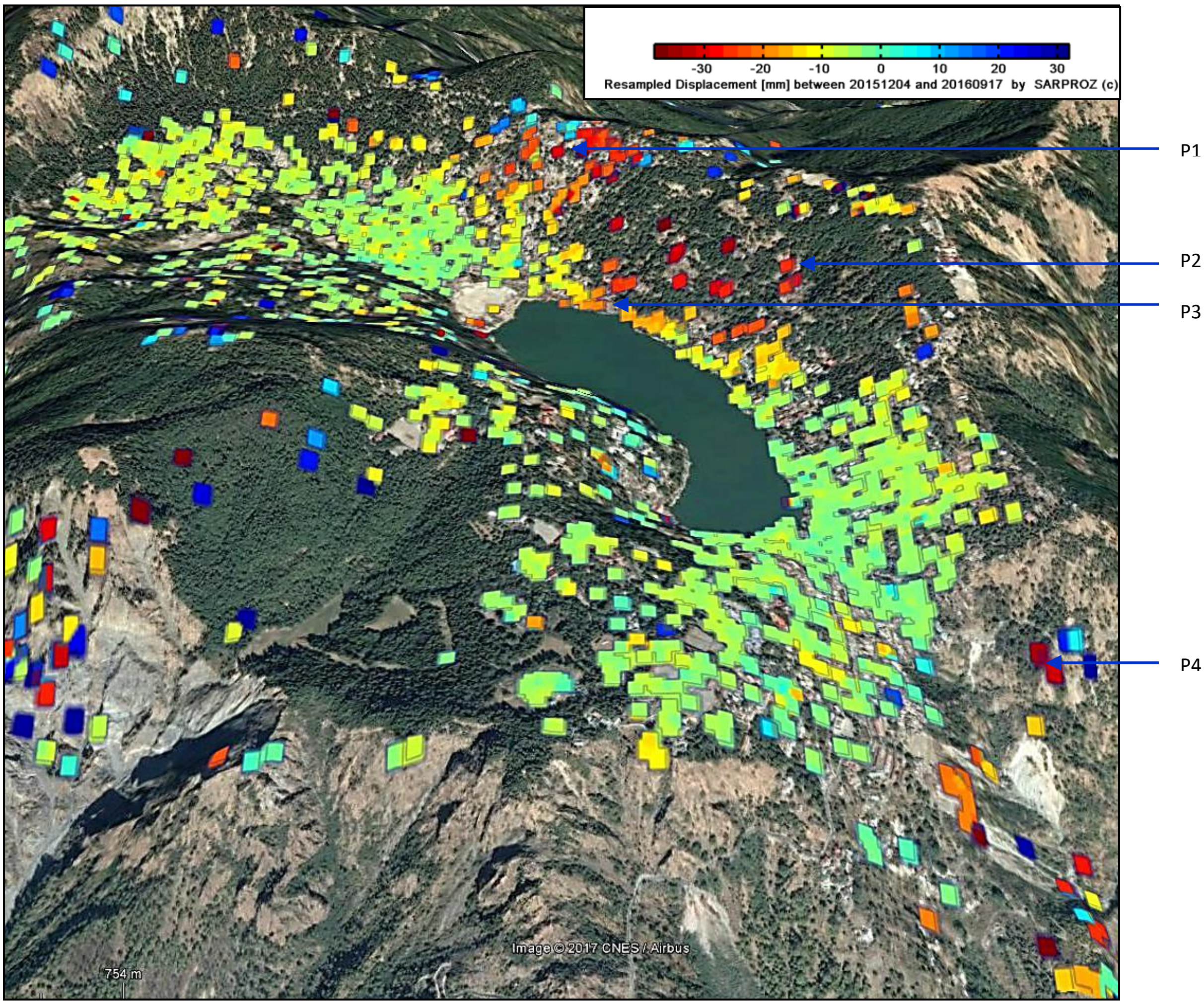
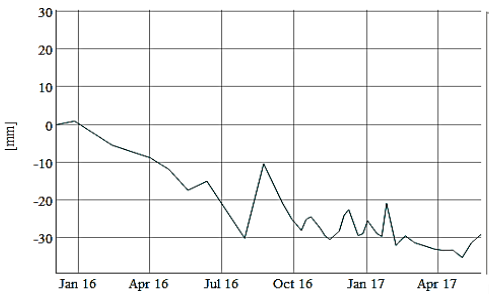
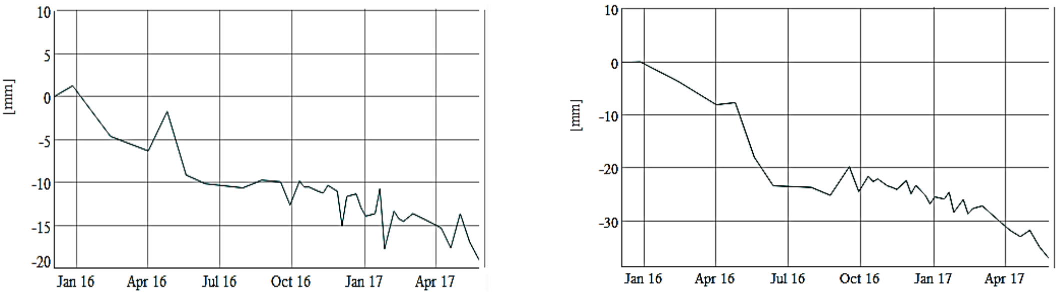


Figure 6: Cumulative displacement map along LOS for Nainital area (Background data: Google earth)



(a)Time series plot of PS point P-1

(b) Time series plot of PS point P-2



(c) Time series plot of PS P-3 (d) Time series plot of PS P-4

Figure 7: Displacement time series plot for selected Points (from Dec. 2015 to May 2017)

6. CONCLUSION

Multi Temporal PSInSAR processing with Sentinel-1A and 1B images brings significant results for detection of slope instability and estimation of slope movement at Nainital hill town. Especially, it is effective to detect slope movement at densely urbanized Sher-Ka-Danda hill slopes, where movement in this area and in its surrounding has been well known already. This fast and significant slope movement estimated on Sher-ka-Danda slope area may produces threat to the infrastructure and human life in near future.

Acknowledgments

The authors would like to thank ESA for providing the Sentinel 1A and 1B data, under free, full and open data policy adopted by the Copernicus programme. Data have been processed by SARPROZ© software and Google Maps™.

References

1. Gabriel, A. K., Goldstein, R. M. and Zebker, H. A., 1989. Mapping Small Elevation Changes over Large Areas: Differential Radar Interferometry. In: Journal of Geophysical Research, Vol. 94(B7), pp. 9183-9191.
2. Massonnet, D., Feigl, K., Rossi, M. and Adragna, F., 1994. Radar Interferometric Mapping of Deformation in the year after the Landers Earthquake. In: Nature, Vol. 369, pp. 227- 230.
3. Zebker, H.A., Rosen, P.A., Goldstein, R.M., Gabriel, A., and Werner, C.L., 1994. On the derivation of coseismic displacement fields using differential radar interferometry: The Landers Earthquake. In: Journal of Geophysical Research, Vol. 99, pp. 19617-19634.
4. Ferretti, A., Prati, C., Rocca, F., 2001. Permanent Scatterers in SAR Interferometry. In: IEEE Transactions on Geoscience and Remote Sensing, Vol. 39(1), pp. 8-20.
5. Colesanti, C., Ferretti, A., Novali, F., Prati, C. and Rocca F., 2003. SAR monitoring of progressive and seasonal ground deformation using the permanent scatterers technique. In: IEEE Transaction on Geosciences and Remote Sensing, Vol. 41, pp. 1685-1701.
6. Lyons, S. and Sandwell, D., 2003. Fault creep along the southern San Andreas from interferometric synthetic aperture radar, permanent scatterers, and stacking. In: Journal of Geophysical Research, Vol. 108, No. B1-2047, ETG 11.
7. Werner, C., Wegmüller, Urs., Strozzi, T. and Wiesmann, A., 2003. Interferometry Point Target Analysis for Deformation Mapping. In: Proceedings of IGARSS’03, 21-25 July 2003, Toulouse, France.
8. Hooper, A., Zebker, H., Segall, P. and Kampes M., 2004. A new method for measuring deformation on volcanoes and other natural terrains using InSAR persistent scatterers. In: Geophysical Research Letters, Vol. 31, L23611.
9. Perissin, D., Wang, T., 2012. Repeat-pass SAR interferometry with partially coherent targets. In: IEEE Transactions on Geoscience and Remote Sensing, Vol. 50 (1), pp. 271–280.
10. Crosetto, M., Monserrat, O., Cuevas-González, M., Devanthéry, N., Crippa, B., 2016. Persistent Scatterer Interferometry: A review. In: ISPRS Journal of Photogrammetry and Remote Sensing, Vol. 115, pp. 78–89.
11. Righini, G., Pancioli, V. and Casagli, N., 2012. Updating landslide inventory maps using Persistent Scatterer Interferometry (PSI). In: International Journal of Remote Sensing, Vol. 33(7), pp. 2068–2096.
12. Tofani, V., Raspini, F., Catani, F. and Casagli, N., 2013.Persistent Scatterer Interferometry (PSI) Technique for Landslide Characterization and Monitoring. In: Remote Sensing, Vol. 5(3), pp. 1045-1065.
13. Lazecky, M., Canaslan Comut, F., Nikolaeva, E., Bakon, M., Papco, J., Ruiz-Armenteros, A. M., Qin, Y., De Sousa, J. J. M. and Ondrejka, P., 2016. Potential of Sentinel-1A for Nation-Wide Routine Updates of Active Landslide Maps. In: The International Archives of the Photogrammetry, Remote Sensing and Spatial

Information Sciences, Volume XLI-B7, 2016, XXIII ISPRS Congress, 12–19 July 2016, Prague, Czech Republic, pp. 775-781.

14. Dwivedi, R., Varshney, P., Tiwari, A., Singh, A. K. and Dikshit, O., 2014. Assessment Of Slope Stability Using PS-InSAR Technique. In: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-8, 2014, ISPRS Technical Commission VIII Symposium, 9-12 December 2014, Hyderabad, India, pp. 35-38.
15. Vöge, M., Frauenfelder, R., Ekseth, K., Arora, M.K., Bhattacharya, A. and Bhasin, R.K., 2015. The use of SAR Interferometry For Landslide Mapping in the Indian Himalayas. In: The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XL-7/W3, 2015 36th International Symposium on Remote Sensing of Environment, 11–15 May 2015, Berlin, Germany, pp. 857-863.
16. Bhattacharya, A., Kuri, M., Arora, M. K. and Sharma, M. L., (2015). Application of SAR Interferometry for detection of landslide zone and deformation pattern, 6th Annual Conference of the International Society for Integrated Disaster Risk Management (IDRiM 2015), 28-30 Oct, 2015, New Delhi, India.
17. Bhattacharya, A. and Mukherjee, K., 2016. Review on InSAR Based Displacement Monitoring of Indian Himalayas: Issues, Challenges and Possible Advanced Alternatives. In: Geocarto International, January 2016, pp. 298-321.
18. Kuri, M., Bhattacharya, A., Arora, M. K., Sharma, M. L., 2016. Time Series InSAR Techniques to Estimate Deformation in a Landslide- prone area in Haridwar region, India. In: Proceedings of the IEEE,2016 IEEE International Geoscience and Remote Sensing Symposium (IGARSS'2016), 10-15 July 2016, Beijing, China, pp. 6839-6842
19. Hukku, B.M., Srivastava, A.K., Jaitle, G.N. , 1974. Evolution of lakes around Nainital and the problem of hillside instability. Himalayan Geology, Vol. 4, pp. 516-531.
20. Valdiya, K.S., 1985. Accelerated erosion and landslide-prone zones in the Central Himalayan region, Environmental Regeneration in Himalaya: Concepts and Strategies. Central Himalayan Environmental Association, Nainital, pp. 12-38.
21. Valdiya, K.S., 1988. Geology and Natural Environment of Nainital Hills, South Central Kumaun Himalaya. yanodaya Prakashan, Nainital, India.
22. Thakur, V.C., 1996. Landslide Hazard Management and Control in India, International Centre for Integrated Mountain Development. Kathmandu, Nepal.
23. Bhandari, R.K., 1986. Slope Instability in the Fragile Himalaya and Strategy for Development. In: Ninth Indian Geo Technical Society Annual Lecture, 28th Annual General Session, New Delhi, India, pp. 275-325.
24. Rautela, P., 2011. Slope instability and geo-environmental issues of the area around Nainital. Disaster mitigation and management centre, Dehradun, Uttarakhand, India.
25. Gupta, V., Bhasin, R.K., Kaynia, A.M., Tandon, R.S., Venkateshwarlu, B., 2014. Landslide Hazard in the Nainital township, Kumaun Himalaya, India: the case of September 2014 Balia Nala Landslide. In: Natural Hazards, Vol. 80, pp. 863–877.
26. Kumar, M., Rana, S., Pant, P.D., Patel, R.C., 2017. Slope stability analysis of Balia Nala landslide, Kumaun Lesser Himalaya,Nainital, Uttarakhand, India. In: Journal of Rock Mechanics and Geotechnical Engineering, Vol. 9, pp. 150-158.
27. Perissin, D., Wang, Z., Wang, T., 2011. The SARPROZ InSAR tool for urban subsidence/manmade structure stability monitoring in China. In: Proceedings of 34th International Symposium for Remote Sensing of the Environment (ISRSE), 10-15 April 2011, Sydney, Australia.