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ASSESSMENT OF SLOPE STABILITY USING PS-INSAR TECHNIQUE

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ABSTRACT:

In this research work, PS-InSAR approach is envisaged to monitor slope stability of landslides prone areas in Nainital and Tehri region of Uttarakhand, India. For the proposed work, Stanford Method for Persistent Scatterers (StaMPS) based PS-InSAR is used for processing ENVISAT ASAR C-Band data stacks of study area which resulted in a time series 1D-Line of Sight (LOS) map of surface displacement. StaMPS efficiently extracted the PS pixels on the unstable slopes in both areas and the time series 1D-LOS displacement map of PS pixels indicates that those areas in Nainital and Tehri region have measurement pixels with maximum displacement away from the satellite of the order of 22 mm/year and 17.6 mm/year respectively.

1. INTRODUCTION

Synthetic aperture radar (SAR) is an advanced technology of radar community. It is an active microwave remote sensing mechanism which is capable of monitoring geophysical parameters (e.g. displacement vector) of earth features. It provides data in various formats which can be easily absorbed by the researchers as well as by the industry. Interferometric SAR (InSAR) uses two or more SAR images at different acquisition time to generate interferograms and digital elevation model (DEM), and thereby determine the change in the position of resolution cells in the satellite line of sight (LOS). It is widely used for deformation monitoring purposes but severely affected from the errors such as temporal and spatial decorrelation.

In order to overcome the aforementioned limitations of InSAR, permanent scatterer InSAR (PS-InSAR) was abstracted and devolved by Ferretti *et al.* (2000). PS-InSAR identifies measurement pixels known as permanent scatterer (PS) with stable amplitude and phase history over a long interval of time. Examples of such PS candidates are manmade objects such as buildings, roofs etc. Although PS-InSAR is more accurate and consistent it too suffers from some limitations *i.e.* less PS density in non-urban areas, one dimensional representation of 1D-LOS (Greif and Vlcko, 2013).

In order to remove the aforesaid limitations, Stanford Method of Persistent Scatterer (StaMPS) approach is conceptualized and developed by Hooper *et al*. (2007). StaMPS based PS-InSAR method uses spatial correlation of interferogram phase to identify phase stable pixels even with low amplitude stability which makes the approach capable of detecting PS pixels in non-urban areas.

In this research work, we have applied StaMPS based PS-InSAR processing for assessing the slope stability in Nainital and Tehri regions of Uttarakhand, India.

2. STUDY AREA AND SATELLITE DATASET

Landslide is the one of the most threatening geo-hazards of the Himalaya causing colossal damages to the infrastructure and livelihood of common people. Therefore, two Himalyan town of Uttarakhand, India-Nainital and Tehri are under our scanner in this research work.

2.1 Geological settings of study areas

Nainital, is a popular hill station in the state of Uttarakhand at the Kumaon foothills of the lesser Himalayas. Nainital township is situated in a valley containing a kidney-shaped lake at an altitude of 2,084 metres above sea level and surrounded by mountains. The town has experienced disastrous landslide events in 1867, 1880, 1893, 1898, 1924 and 1998 according to (Sharma, 2006).

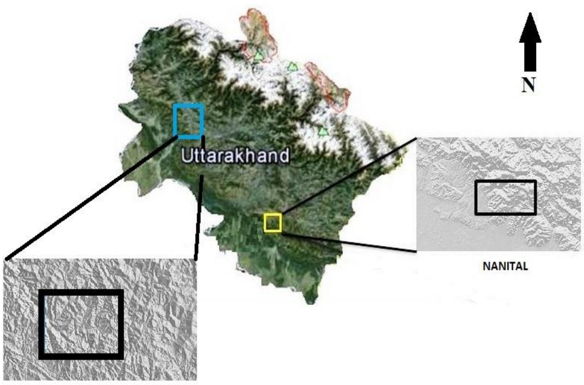

Figure 1. Study area location

Tehri town is inhabited near Tehri reservoir at the union of Bhagirathi and Bhilangana rivers at an altitude of 1,750 m (5,740 ft). In the past, much causality has been reported because

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of the multi events of landslide induced by Tehri reservior. Also in December 2010, debris from the landslip has blocked a division tunnel forcing a stop to generation of electricity. This has caused a loss of more than Rs 100 crore. Due to aforesaid facts, it has become an area of interest for this slope stability study.

2.2 Satellite Dataset of Nainital and Tehri

In order to monitor the critical slopes around Nainital lake, we have processed 13 descending ENVISAT C-Band ASAR images of track 248 (frame: 3015) acquired between October 2008 to August 2010.. Similarly, to monitor critical slopes around Tehri reservoir, 16 Envisat ASAR C-Band SLC images of track 291 (frame: 83) acquired between January 2009 to July 2010 are used. ASAR image of 25th December 2009 and 9th October 2009 is chosen as the master image for Nainital and Tehri region respectively based on minimizing the temporal, Doppler and perpendicular baseline (B⊥) (Hooper *et al.,* 2007)

The aforementioned dataset is presented in Table 1 and 2 along with the critical perpendicular baseline length with respect to master image, acquisition date, orbit number and Doppler centroid frequency. Apart from the SLC images, a 90 m resolution SRTM Digital Elevation Model (DEM) (Figure 1) is used to remove the topographic phase from the differentially corrected interferogram. The orbital corrections are done with the help of precise orbits obtained from ESA. The DORIS precise orbits for the year 2008, 2009 and 2010 are used to remove orbital bias.

S. No.	Acquisition date	Orbit No.	B⊥ (m)	Doppler Centroid(Hz)
1.	31Oct2008	34871	155.6	166.231
2.	05Dec2008	35372	43.7	168.060
3.	07Aug2009	38879	44.9	170.098
4.	11Sep2009	39380	476.3	165.710
5.	16Oct2009	39881	-161.1	163.154
6.	20Nov2009	40382	377.8	171.735
7.	**25Dec2009**	**40883**	**0**	**162.437**
8.	29Jan2010	41384	339.2	171.353
9.	05Mar2010	41885	28.0	168.613
10.	09Apr2010	42386	324.5	172.944
11.	18Jun2010	43388	252.8	182.534
12.	23Jul2010	43889	-65.2	177.749
13.	27Aug2010	44390	-37.9	177.370

Table 1. Satellite data stacks for Nainital Area

S. No	Acquisition date	Orbit No.	B⊥ (m)	Doppler Centroid(Hz)
1.	12Jan 2009	36417	301.6	172.014
2.	16Feb 2009	36417	305.1	348.914
3.	23Mar2009	36918	651.1	169.777
4.	27Apr 2009	37419	251.1	165.833
5.	01Jun 2009	37920	390.4	171.174
6.	06Jul 2009	38421	207.8	173.297
7.	10Aug2009	38922	173.2	173.608
8.	14Sep2009	39423	598.7	176.089
9.	**19Oct2009**	**39924**	**0**	169.287
10	23Nov2009	40924	50.33	172.812
11	01Feb2010	41425	567.8	174.730
12	08Mar2010	41427	112.3	177.697
13	12Apr2010	42429	390	184.121
14	17May2010	42930	426.9	166.537
15	21Jun 2010	43431	273.4	190.413
16	26Jul 2010	43932	-27.9	186.428

Table 2. Satellite data stacks of Tehri region

3. STAMPS APPROACH

The PS-InSAR method developed by Ferretti *et al.* (2000), and modified by Hanssen, (2003), Lyons and Sandwell (2005) and Crossetto *et al.* (2005) succeeded in finding PSs in urban areas and required a minimum of 15-20 interferograms to obtain a time series of deformation of each detected PS pixel. The StaMPS method, introduced by Hooper *et al.* (2007) came as an improvement to the above mentioned methods in the sense that the method is capable of finding PS pixels in urban as well as nonurban areas and also less number of interferograms is sufficient to map the surface displacement. The method involves four major steps, namely Interferogram generation, Phase stability estimation, PS detection and Displacement estimation.

3.1 Interferogram Generation

The interferogram generation in StaMPS is done using a single master image and is based on the maximization of the correlation amongst the set of images used for processing. The correlation consists of a number of parameters as stated in the following equation by Hooper *et al.* (2007):

$$\begin{aligned}\rho_{total} &= \rho_{temporal} \cdot \rho_{spatial} \cdot \rho_{dopler} \cdot \rho_{thermal} \\ &\approx \left(1 - f\left(\tfrac{T}{T_c}\right)\right) \cdot \left(1 - f\left(\tfrac{B_{perp}}{B^c_{perp}}\right)\right) \cdot \left(1 - f\left(\tfrac{F_{DC}}{F^c_{DC}}\right)\right) \cdot \rho_{thermal}\end{aligned} \tag{1}$$

Here ρ_{total}, $\rho_{temporal}$, $\rho_{spatial}$, ρ_{dopler} and $\rho_{thermal}$ represent total correlation, temporal correlation, spatial correlation, correlation in Doppler centroid frequency and correlation in thermal noise respectively. The values of T and T_c state the temporal baseline and the critical temporal baseline, B_{perp} and B^c_{perp} are the perpendicular baseline and the critical perpendicular baselines respectively, F_{DC} and F^c_{DC} are the values of Doppler centroid frequency and its critical value respectively. Based on this, a master image is chosen and each of the slave images is then co-registered with the selected master image and resampled to the grid of the master image. The slave images go under complex multiplication with the master image to produce a set of interferograms. The topographical correction is done using an external DEM to convert the interferograms into differential interferograms, which are suitable for PS processing. The differential interferograms are input to the next step.

3.2 Phase stability estimation

The pixels are initially selected on the basis of amplitude stability, in which those pixels which have a value of the amplitude dispersion index D_A (ratio of the standard deviation (σ_A) and the mean of amplitude values (μ_A) within the threshold are selected as initial PS candidates.

$$D_A = \frac{\sigma_A}{\mu_A} \qquad (2)$$

The candidates are tested for phase stability using a measure γ_X stated in the following equation Hooper *et al.* (2007):

$$\gamma_x = \frac{1}{N}\left|\sum_{i=1}^{N} \exp\left\{\sqrt{-1}\left(\varphi_{x,i} - \tilde{\varphi}_{x,i} - \Delta\hat{\phi}^{u}_{\theta_{\theta,x,i}}\right)\right\}\right| \qquad (3)$$

N represents the number of interferograms, $\varphi_{x,i}$ represents the wrapped phase value of the x^{th} pixel in the i^{th} interferogram, $\tilde{\varphi}_{x,i}$ is the mean value of $\varphi_{x,i}$ and $\Delta\hat{\phi}^{u}_{\theta_{\theta,x,i}}$ represents the change in the spatially uncorrelated part of the look angle error for the x^{th} pixel in the i^{th} interferogram.

3.3 PS Detection

The pixels which satisfy the convergence of γ_X to the threshold value are picked as PS pixels. The selected PS pixels contain a wrapped phase value, which is to be unwrapped, *i.e.* they must be added by an estimated number of phase cycles of 2π to retrieve the original phase value, a process known as phase unwrapping. Other nuisance terms, such as the master and atmospheric error terms, spatially uncorrelated look angle error, satellite orbit errors are also estimated and removed from the unwrapped phase $\phi_{x,i}$ of the detected PS pixels.

3.4 Displacement Estimation

The displacement can then be estimated using the phase values of the individual PS pixels. A 1D Line of Sight (LOS) displacement map is generated as an output of the StaMPS method.

4. RESULTS AND DISCUSSION

4.1 Time series displacement analysis of Nainital

In this section, results of StaMPS based PS-InSAR processing of the 13 Envisat ASAR SLC images of Nainital and its surrounding area is presented. With 13 SLC images, 12 geocoded interferograms are generated as shown in Figure 2.

The parameters used for StaMPS based PS-InSAR processing are shown in Table 3. Initially, more than 100000 PS candidates were selected using a D_A value of 0.35 with the area being divided into 6 patches and finally 5606 pixels were detected as PS pixels. The processing resulted in generation of time series displacement of PS pixels in satellite LOS as shown in Figure 3 (X and Y axis represent longitude and latitude respectively) with cold and warm colours representing movements towards and away from the satellite respectively.

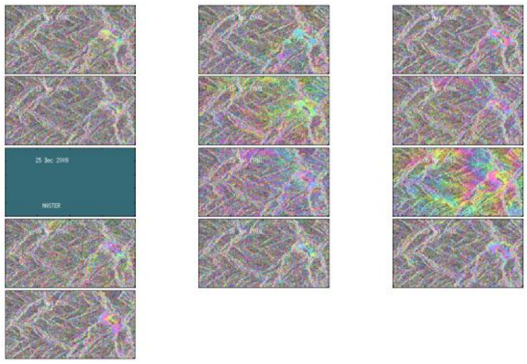

Figure 2. Interferograms for the Nainital region. The image acquired on 25th December 2009 is chosen as the master image.

Parameters	Value of parameter
Number of SLC images (N)	13
Pixel grid size	50
Amplitude dispersion threshold (D_A)	0.35
Rate of convergence (γ_X)	0.005
Number of patches in azimuth	3
Number of patches in range	2
Overlapping pixel between patches in azimuth	200

Table 3. Parameters for StaMPS processing of Nainital region

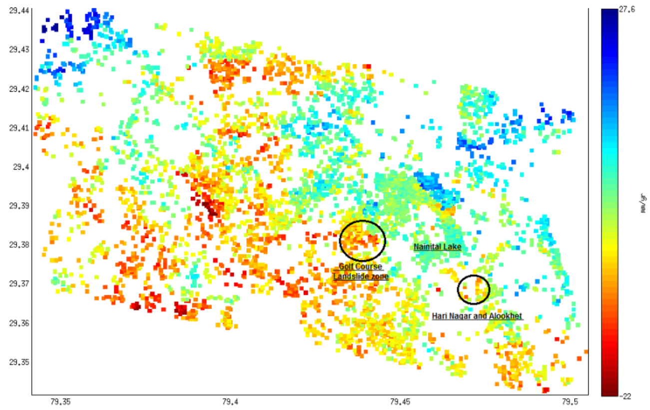

Figure 3. 1D-LOS displacement plot of Nainital region

Although in recent times no major landslip activity has been reported but there are a few number of unstable slope zones (Golf course landslide, Hari nagar-Aloo Khet) identified after PS-InSAR processing as circled in Figure 3.

4.2 Time series displacement analysis of Tehri

In this section, results of StaMPS based PS-InSAR processing of the 16 Envisat ASAR SLC images of Tehri region are presented. With 16 SLC images, 15 geocoded interferograms are generated as shown in Figure 4. The parameters used for StaMPS based PS-InSAR processing are shown in Table 4. Initially, more than 12,50,000 PS candidates were selected based on the D_A value of 0.45 and 19,549 PS pixels were detected. The processing resulted in generation of time series displacement plot as shown in Figure 5.

Figure 4. Interferograms for the Tehri region. The image acquired on 19th October 2009 is chosen as the master image.

Parameters	Value of parameter
Number of SLC images (N)	16
Pixel grid size	50
Amplitude dispersion threshold (D_A)	0.45
Rate of convergence (γ_X)	0.005
Number of patches in azimuth	3
Number of patches in range	2
Overlapping pixel between patches in azimuth	200

Table 4. Parameters for StaMPS processing of Tehri region

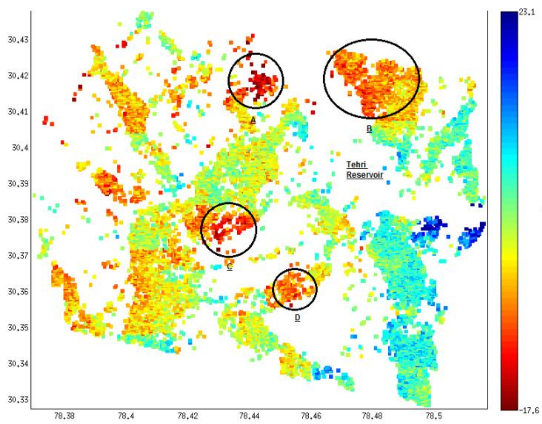

Figure 5. 1D-LOS displacement plot of Tehri region

In the time series displacement plot (Figure 5), few unstable slope zones with warm colours are marked as A, B, C and D. A and B regions are near to Tehri reservoir and have PS pixel with maximum displacement of 17.6 mm/year. Another unstable slope zone (C, D) near to New Tehri township is identified with warm colours.

5. CONCLUSION

We have successfully applied StaMPS based PS-InSAR processing in Nainital and Tehri regions of Uttarakhand, India. Time series displacement plots clearly show that there are various patches of area having significant displacement away from the satellite LOS and are probable unstable zones. We also draw conclusion that the results achieved after PS-InSAR approach can be a valuable input in comprehensive assessment the slope stability, if supplemented with other sub-surface investigation. In future, a thorough field survey is essentially required to comment on the present status of these unstable zones. Further, if the ASAR images in satellite data stacks are increased, a more precise estimation of the deformation pattern can be observed. StaMPS based Small Baseline Subset (SBAS) can also be investigated for this study.

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