URBAN SUBSIDENCE DETECTION USING THE SENTINEL-1 MULTI-TEMPORAL INSAR DATA

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ABSTRACT

This paper outlines the results of subsidence estimation over an urban area using Sentinel-1 data and Permanent Scatterer Candidate (PSC) Interferometric Synthetic Aperture Radar (PS-InSAR) technique. The study area selected is Chandigarh City (UT, India) and its near vicinities, which is located at the junction of three Indian states namely Punjab, Haryana and Himachal Pradesh. PS-InSAR is a well-established technique to identify and monitor the ground deformation using the satellite imagery. This technique has been extensively used for monitoring the earth surface deformations. Time series Sentinel-1 data comprising of 43 ascending images acquired during 2014 to 2017 over the study area have been used in this study. The high spatial and temporal resolution of this data allowed to carry out the time series analysis in an effective manner. Sarproz software package has been used for all PS-InSAR processing. The atmospheric phase screen (APS) of the SAR data has also been estimated and removed to minimise the noise in the estimated values. The results indicate the significant rate of the subsidence over the study area. The maximum rate of subsidence estimated is around -20 mm/year in specific locations. However, a large part of the study area showed a comparably low rate of subsidence. The possible cause for the high rate of subsidence in this area may be the depleting ground water levels in the region which also corroborates with the available literature. This study provides preliminary information on the probable danger to the urban infrastructure in the area.

1. Introduction

This paper outlines the preliminary results of the estimation of subsidence in the Chandigarh city. Chandigarh city is situated in the foothills of Himalayas, mainly comprising of the alluvium soil. The presence of alluvium soil makes this region more fictile to subsidence due to the fluctuation in the ground water levels. This city and the surrounding area has seen an exponential growth in the industries and the urban population which may adversely affect the ground water levels. Rodell et al., 2009 estimated the mean ground water depletion rate to be 4 ± 1 cm per year in the north-western states of India i.e. Rajasthan, Punjab and Haryana. Land subsidence induced by the depleting ground water levels has been the case of many cities in the different parts of the world, including Las Vegas (Amelung et al., 1999), California (Galloway et al., 1998), Iran (Motagh et al., 2007), Kolkata (Chatterjee et al., 2006) and many others.

Urban subsidence estimation is a major challenge for the town planners and the administration due to the large area and the rapidly changing situations. Therefore, remote sensing especially SAR data has played an important role in this area. The availability of SAR data has increased over the last decade. This has led to the development of new and advanced techniques for surface deformation studies. Differential SAR Interferometry (D-InSAR) technique has shown promising results in the field of ground subsidence studies ((Galloway et al., 1998; Amelung et al., 1999; Strozzi & Wegmuller, 1999). Different D-InSAR techniques have been developed over the years, e.g. PS-InSAR (Ferretti et al., 2000, 2001), SBAS (Berardino et al., 2002; Perissin and Wang, 2012), SqueeSAR (Ferretti et al., 2011) etc.

PS-InSAR technique an extension of DInSAR technique which has been extensively used for large-scale and long-term monitoring small surface deformations in urban areas (Colesanti et. al., 2003; Bürgmann et al., 2006; Perissin et. al, 2012). In PS-InSAR technique point-wise stable PSC are selected based on the stability of phase over a long period and then atmospheric phase, DEM error and system/thermal noise etc., are estimated and removed, and finally, precise displacement of PSC is measured. The displacement is derived in the radar line-of-sight (LOS) direction of a satellite by computing the phase difference between two temporally separated SAR images (Gabriel et al., 1989; Massonnet et al., 1993).

2. Study Area

The area selected for this study is Chandigarh City (UT, India) and its near vicinities (located between 30.51 to 30.97 N latitude and 76.56 to 77.00 E longitude), which is located at the junction of three Indian states namely Punjab, Haryana and Himachal Pradesh. The Chandigarh city is situated in the foothills of Himalaya. The area is covered by the alluvium soil consisting of a layered sequence of clay, silty clay, and sand. The study area is shown in Figure 1.

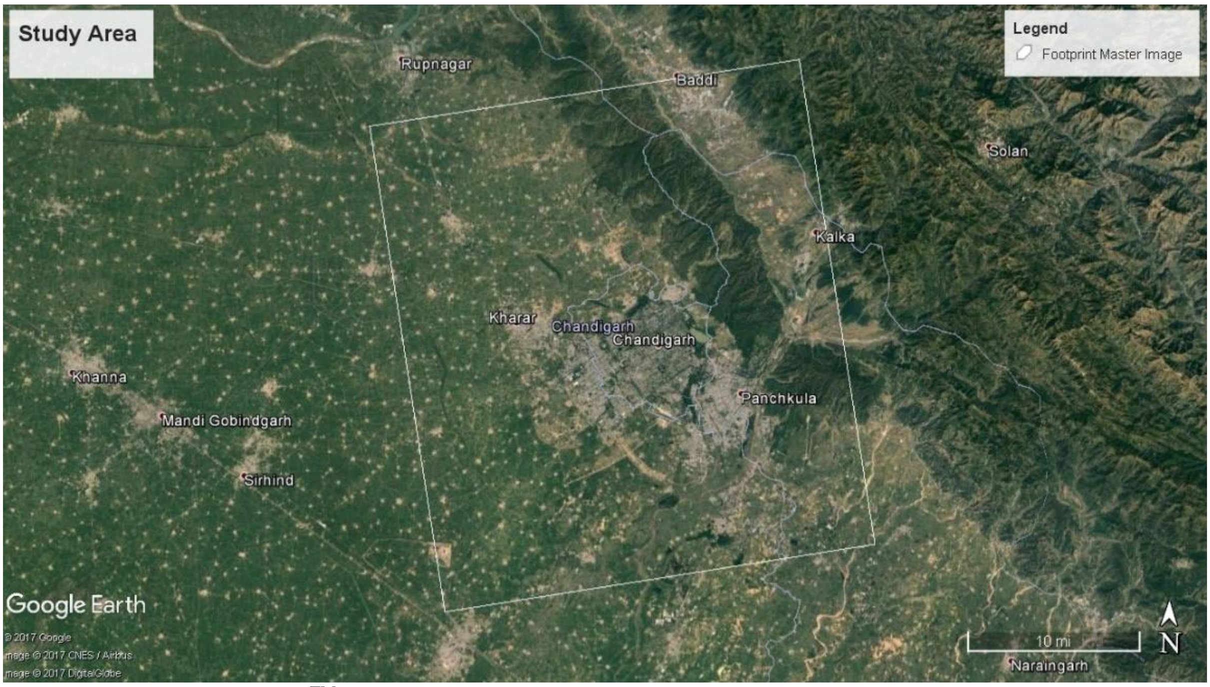

Figure 1: Google Earth™ image showing study area and the footprint of master Image.

3. Data used

Ascending images (43 nos.) from Sentinel-1 acquired during 2014 to 2017 have been used in this study. Sentinel-1 provides continuous global images in the C band with an interval of 12 days. The master acquisition has been selected by optimising the distribution of perpendicular and temporal baselines, maintaining the coherence. No precipitation has been recorded during master image acquisition time. The image acquired on 29th May, 2016 has been selected as a master image which rendered maximum 150 m perpendicular baseline. ASTER Global DEM v2 has been used for the reference during processing.

Figure 2 shows an overview of perpendicular and temporal baseline distribution of slave images with respect to the master image.

4. Methodology

For a detailed description of the PS-InSAR approach, refer to Ferretti et al., (2000) and Colesanti et al., (2003). In brief, the applied processing steps are as follows: master image selection, SAR data co-registration, generating reflectivity map and amplitude stability index map, PSC selection, multi-image sparse grid phase unwrapping, APS estimation and removal, PSC phase reading, and displacement estimation. However, Sentinel images are acquired in Terrain Observation with Progressive Scans (TOPS) acquisition mode (Torres et. al., 2012). Therefore some additional steps are involved to avoid aliasing the data during the co-registration (for details refer Qin & Perissin (2016)).

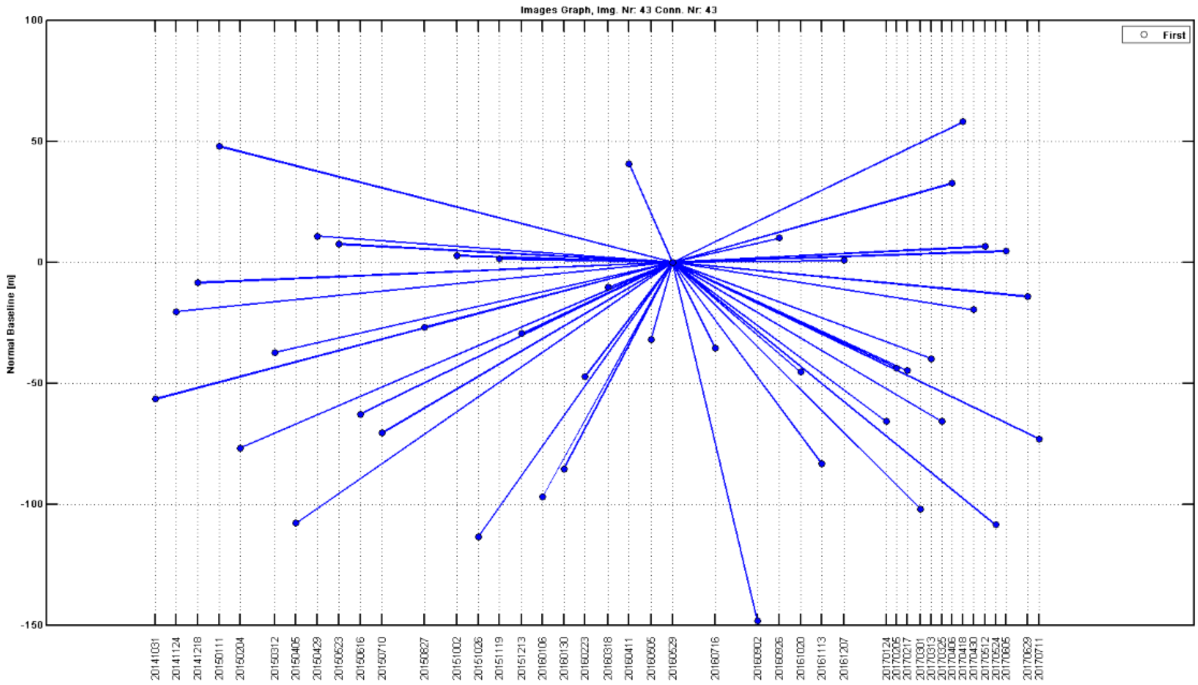

Figure 2. Interferometric combinations as used in this study.

In TOPS processing first step is called 'Deramping'. The steering of the antenna during TOPS acquisition introduces an additional quadratic phase term in azimuth direction for which Doppler frequency exceeds the azimuth pulse repetition frequency. This may introduce aliasing in the data during co-registration. To avoid this quadratic ramp of each image is estimated and removed after reading the single look complex (SLC) value of TOPS data and before co-registration of interferometric pairs. This is followed by initial coarse co-registration and then sub-pixel co-registration with an accuracy of 1/1000 (Prats-Iraola et al., 2012). Then, interferogram is generated following the processing steps for generating interferograms using stripmap data.

Suitable PSC have been selected based on the amplitude stability index calculated as per the equation 1.

$$\mathrm{DA} = 1 - \frac{\mathrm{mA}}{\sigma A} \qquad \text{eq. 1}$$

Where mA and $\boldsymbol{\sigma_A}$ are the mean and the standard deviation of the amplitude values.

The threshold used to select the suitable PSC is 0.7 and using this threshold around 26 thousand PSC have been selected. Then APS has been estimated and applied to further refine the overall coherence of the PSC. After refining the PSC, the displacement of the PSC has been retrieved for the complete timeline. Sarproz software package (Perissin et. al, 2011) has been used for all PS-InSAR processing. It is a powerful software developed in MATLAB environment which allows complete processing of TOPS data, from importing TOPS image to multi-temporal analysis in an efficient manner.

5. Result and Discussion

Due to the small temporal gap, all the images were co-registered with high accuracy which was evident by a large number of tie points generated during the co-registration process. High-quality interferograms have been generated due to high coherence between the master and slaves. Around 26 thousand PSC's displacement were generated which had a decent distribution over the whole study area.

The estimated rate of subsidence is shown in Figure 3. The rate of subsidence varied from 0-20 mm/year. The high rate of subsidence estimated was localized in specific locations. Some sectors of Chandigarh city and the nearby town of Khara showed a high rate of subsidence. However, a large part of the study area showed a comparably low rate of subsidence, i.e. less than 10 mm/yr. The results also agree with the available literature (Kala, 2015). The possible cause of the subsidence has not been investigated in the field, however, the depletion in the ground levels in this region may be one of the causative factors. Rodell et al. (2009) studied the condition of ground water in this region using GRACE data and concluded that the ground water is depleting at an alarming rate in this area.

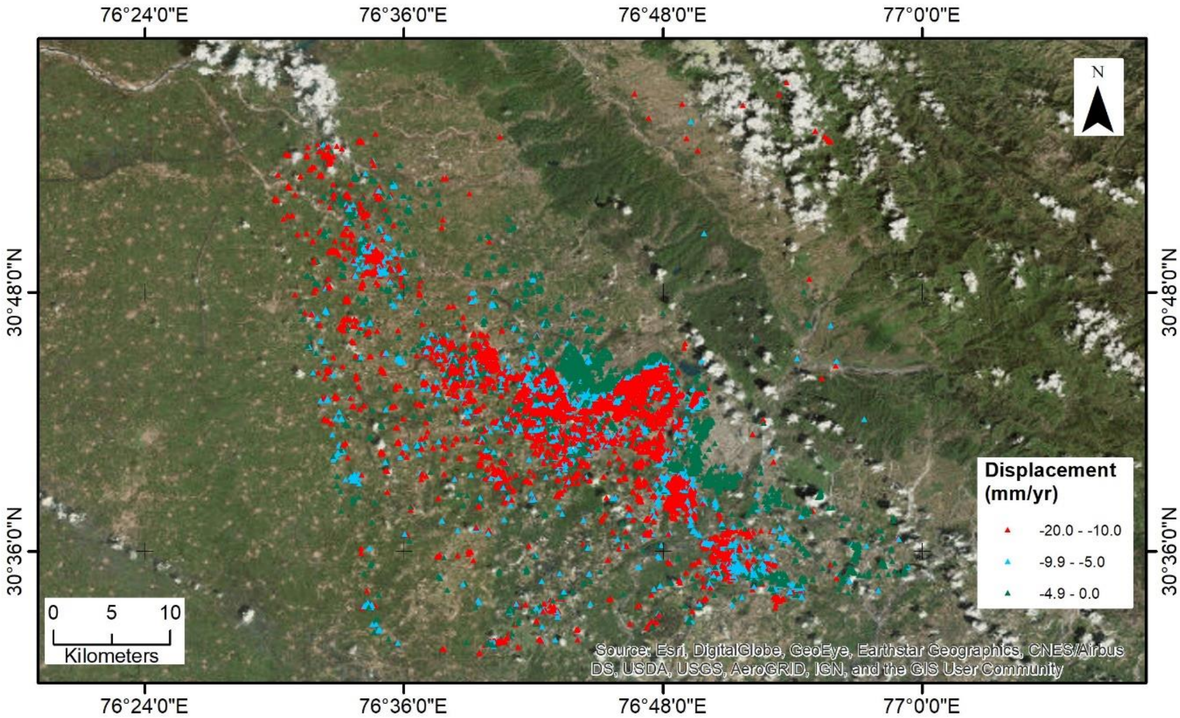

Figure 3. Estimated displacement (mm/yr) in Chandigarh and surrounding (background image is from ESRI provided in ArcGIS software).

6. Conclusion

The paper outlines the estimation of subsidence in the Chandigarh city and the surrounding area. The maximum rate of subsidence is around 20 mm/yr which is localized in some patches. However, most of the area showed a comparably low rate of subsidence. Sentinel-1 data have been used in this study for detection of urban subsidence using PS-InSAR technique. The future extension of this work may include field verification for the cause and the rate of subsidence. Multiple sensors and long-time series data may provide more insights into the ground water conditions of the area.

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