Mapping Land Subsidence of Krishna – Godavari Basin using Persistent Scatterer Interferometry Technique

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ABSTRACT

SAR Interferometry (InSAR) is a technique by which a wide area can be mapped for surface deformation. The conventional InSAR technique has limitations due to baseline restriction, atmospheric phase delay and temporal decorrelation. Persistent Scatterer Interferometry (PSI) technique is an advanced InSAR technique, and it mitigates the atmospheric phase delay effect and geometric decorrelation to a large extent by utilizing a stack of interferograms and gives time series deformation with high accuracy. Extraction of oil and natural gas from underground deposits leads to land subsidence. The East coast of Andhra Pradesh (AP) state in Krishna-Godavari basin is most likely to be affected by this phenomena because of extraction of oil and natural gas from its underground reservoirs for the last two decades. In this paper, an attempt is made to know how the urban cities in this region are affected due to land subsidence using PSI technique. For this, two coastal test areas are selected and ALOS-1 PALSAR datasets from 2007 to 2011 comprising of 11 and 13 scenes are processed using PSI technique. Although the area predominantly agriculture, small villages, towns and cities provide adequate Persistent Scatterers (PS). From the results, land deformation rates of different cities in test area are observed. The subsidence rate of Palakollu town is -20 mm/year and Kakinada city is around -14 mm/year. Narsapur town is showing 4mm/year upliftment because it has more prospect of groundwater recharge from river Godavari.

1. INTRODUCTION

Spaceborne InSAR is proven to be a very effective technique for measuring land deformation. SAR sensors have capabilities like day/night operation in any weather conditions, temporal coverage and historical data (backdating), spatial coverage and the possibility to monitor more structures at the same time (Rosen et al., 2000). Persistent Scatterer Interferometric SAR (PSI) is an advanced technique of SAR interferometry, which overcomes the limitations of conventional SAR interferometry such as temporal decorrelation, baseline decorrelation and atmospheric effects (Crosetto et al., 2010). The Persistent Scatterer Interferometry (PSI) technique is developed in the late 1990s (Ferretti et al., 2000, 2001). The main characteristics of this multi-temporal or time series InSAR processing methods are that they utilize a stack of differential interferograms produced with a single master image utilizing high coherent pixels over the time known as “Permanent Scatterers/ Persistent Scatterers”. PSI is an advanced technique in the family of extensions to the conventional InSAR technique that allows us to estimate a deformation time series for regions that are traditionally considered decorrelated.

Land subsidence is the lowering of the land surface elevation with respect to a datum such as the sea level, due to the changes that take place underground because of manmade or natural causes. Prediction of displacement rate is very problematic and thus the assessment of future behaviour is almost impossible. On the other hand, monitoring the land deformation measurements are critical for the study and detailed understanding of tectonics, earthquakes, volcanism, landslides and ground subsidence as well as uplift. Several studies are focused on studying land subsidence due to coal extraction (Bhattacharya et al., 2012), groundwater exploitation (Schmidt and Bürgmann, 2003), oil and gas extraction (Chaussard et al., 2013; Fielding et al., 1998) and seismic activities (Tomonori et al., 2017). In India, subsidence over Jharia coal field is studied and mapped by several researchers (Bhattacharya et al., 2012; Gupta et al., 2014; Prakash et al., 2001). Urban subsidence of Kolkata city using DInSAR was studied by Chatterjee et al., (2006) using ERS C-band SAR images. This paper is comprised of the work that studied the slow land subsidence phenomenon in the coastal region of Krishna-Godavari (KG) river basin. Present study area is exposed to the extraction of oil and gas from last two decades. Therefore, an attempt is made to map the deformation rates over urban areas of the KG Basin, which are prone to the subsidence due to the extraction of oil and natural gas.

2. STUDY AREA AND DATASETS

For the study of land subsidence, coastal region of the Krishna-Godavari (KG) basin area is selected. The KG basin is located on the east coast of India. It is a proven petroliferous pericratonic basin and it contains about 5 km thick sediments with several cycles of deposition, ranging from Late Carboniferous to Pleistocene age. KG Basin is spread across more than 50,000 square kilometres in the Krishna river and Godavari river basins in Andhra Pradesh. Government and private sector oil companies are extracting huge amounts of oil and natural gas from KG basin. In KG basin, a private sector oil company discovered the biggest natural gas reserves in India in 2002 named D-6 block. The consequences of increased use of energy resources led to potential environmental hazards caused by these operations including the danger of a blowout. Mainly in the East Godavari sub-basin, particularly in the wells at Amalapuram, Razole and Narsapur, the presence of overpressure zones, have led to major disasters in the past years. It is estimated that there are currently 300 oil and gas wells are present in this region (see Figure 2) and extracting oil and natural gas from deposits deep underground will lead to land subsidence. Therefore, an attempt is made to study the land subsidence phenomena in this area.

The study is carried over two different areas in the KG basin, which is shown in the Figure 1. Over the two different areas, ALOS-1 PALSAR datasets (Dataset-1&2) are obtained. Figure 2 shows the locations of oil and gas fields/wells in the Krishna-Godavari Basin, along the coast of Andhra Pradesh.

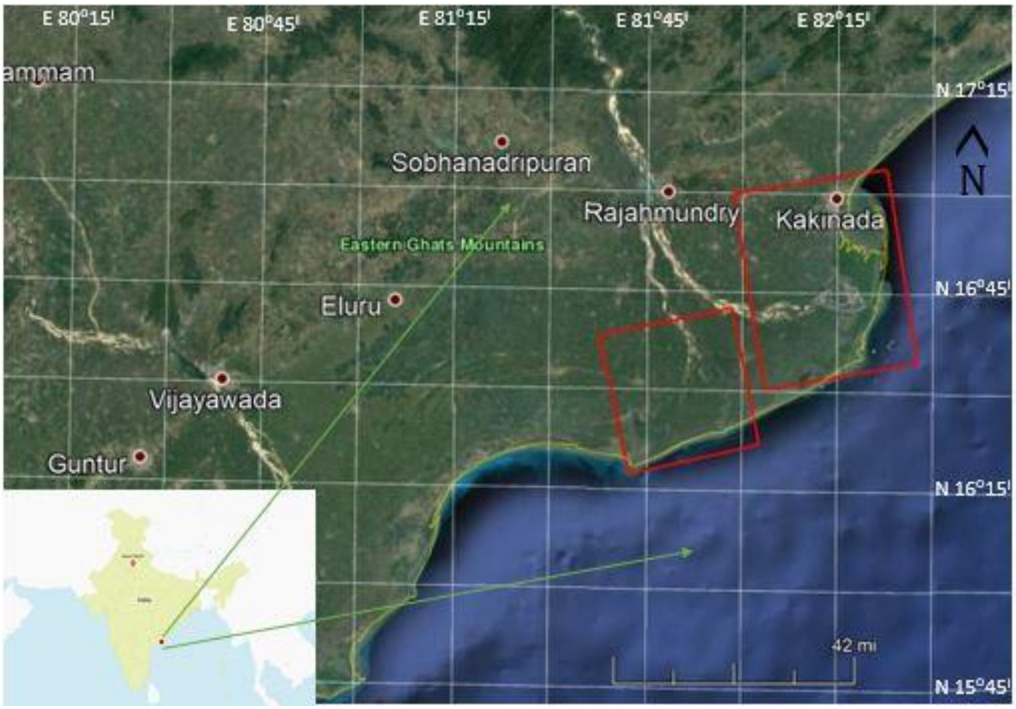

Figure 1: Footprints of ALOS PALSAR images over the study area. Dataset-1 (left red box) is acquired over Palakollu-Narsapur, AP and the Dataset-2 (right red box) is acquired over Kakinada, AP in Krishna-Godavari Basin.

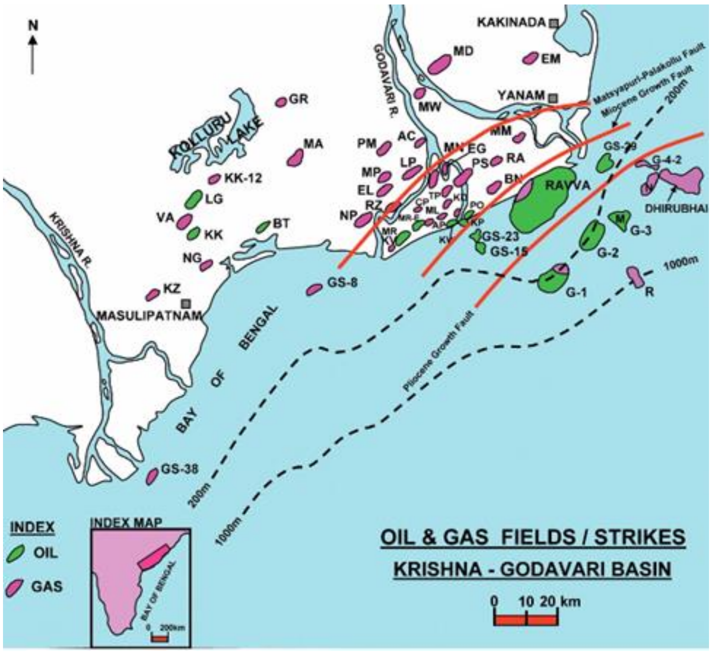

Figure 2: Oil and Gas fields/wells in the Krishna-Godavari Basin, on the coast of Andhra Pradesh.
Source: The Leading-Edge Book, v.25, S.K. Gupta, p830-837.

Table 1 and Table 2 show ALOS PALSAR images used in this study. 11 ALOS L-band images are acquired over Palakollu-Narsapur area (Dataset-1), whereas 13 images are acquired over Kakinada city area between 2007 and 2011. For Palakollu-Narsapur area ALOS PALSAR image acquired on 10-02-2010 is chosen as master image, whereas 05-03-2008 image is selected for Kakinada city study area. For both study areas, Table 1 and 2 present acquisition dates, temporal and normal baselines with respect to master image. Figure 3 and 4 show the images graph and dataset plots of Palakollu-Narsapur and Kakinada study areas respectively.

Table 1: 11 ALOS scenes over the Palakollu-Narsapur study area (Dataset-1).

S. No.	Date of Acquisition	Temporal Baseline (days)	Normal Baseline (m)
1.	2007/08/05	920	25
2.	2007/09/20	874	380
3.	2008/02/05	736	-280
4.	2008/03/22	690	-110
5.	2008/06/22	598	30
6.	2009/09/25	138	625
7.	2010/02/10	0	0
8.	2010/06/28	-138	-60
9.	2010/11/13	-277	330
10.	2010/12/29	-323	-190
11.	2011/02/13	-369	-840

Table 2: 13 ALOS Scenes over Kakinada city study area (Dataset-2).

S. No.	Date of Acquisition	Temporal Baseline (days)	Normal Baseline (m)
1.	2007/03/03	369	1140
2.	2007/09/03	185	600
3.	2007/10/19	139	600
4.	2008/01/19	47	320
5.	2008/03/05	0	0
6.	2008/04/20	-47	-250
7.	2008/07/21	-139	1360
8.	2009/01/21	-323	1700
9.	2009/03/08	-369	1580
10.	2010/01/24	-691	760
11.	2010/03/11	-737	400
12.	2010/07/27	-875	300
13.	2011/01/27	-1059	-200

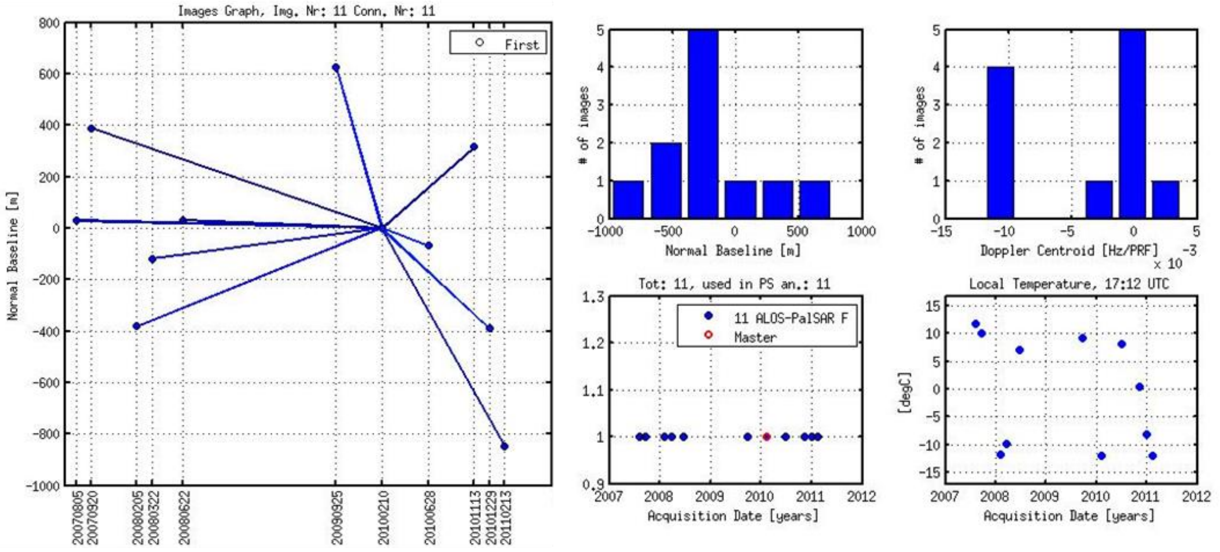

Figure 3: ALOS-1 SAR images over Palakollu-Narsapur study area showing normal baselines with respect to master, Doppler centroid and temperature.

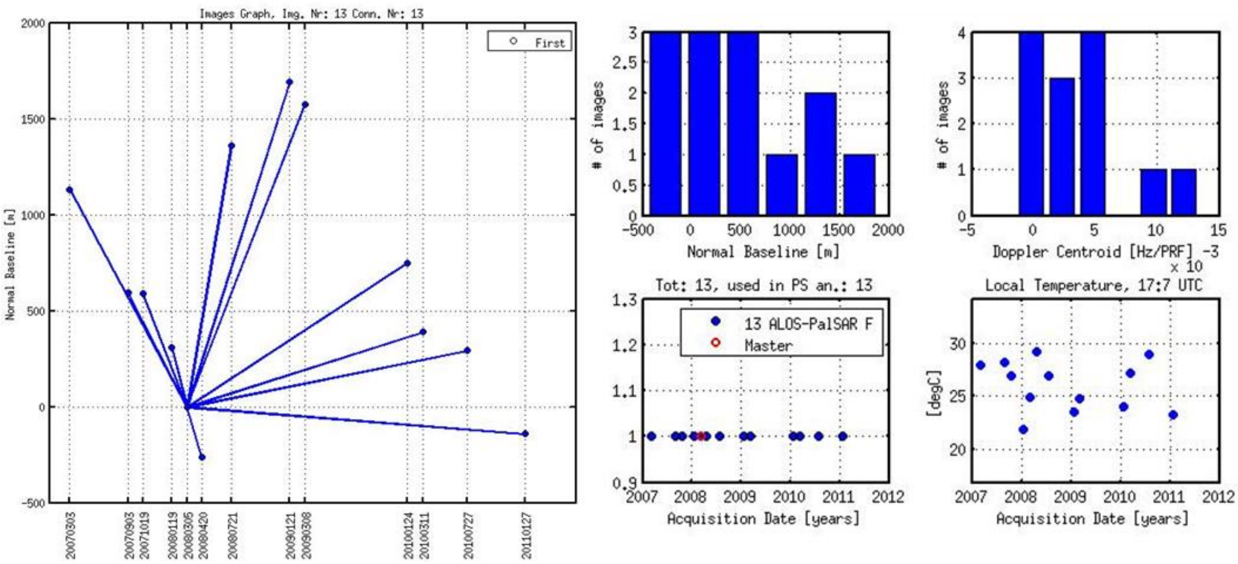

Figure 4: ALOS-1 SAR images over Kakinada study area showing normal baselines with respect to master, Doppler centroid and temperature.

3. METHODOLOGY

For this present work, SARPROZ software is used, which is a very powerful and versatile software that implements a wide range of Synthetic Aperture Radar (SAR), Interferometric SAR (InSAR) and Multi-Temporal InSAR processing techniques. It is developed in MATLAB by Daniele Perissin (www.sarproz.com). It has a good graphical interface and completely parallelized for high performance**.** Most of the PS selection algorithms are amplitude-based and operate on coregistered SAR images. Therefore, precise coregistration of SAR images is performed for reliable estimation of pixel amplitude statistics and the identification of persistent scatterers in the area of interest. Differential interferograms are formed by removing topographic phase using 30m SRTM DEM. Amplitude-based method is used to detect the PS according to the analysis of the amplitudes of pixels in time series. We have used Amplitude Stability Index for PS point selection. Scatterers with ASI > 0.7 are chosen as PS points. An equation for ASI and relation between ASI and Amplitude Dispersion (D_A) is given below.

$$ASI = 1 - D_A = 1 - \frac{\sigma_A}{\mu_A} \qquad (1)$$

where, D_A is amplitude dispersion, σ_A is standard deviation of backscattering intensity and μ_A is mean of backscattering intensity. Later, PS points with temporal coherence > 0.65 are overlaid on reflectivity map. A reflectivity is temporal average of amplitudes of all SAR images. Atmospheric phase delays are estimated and removed using filtering approach. Finally, displacement is calculated and displacement maps are geocoded.

4. RESULTS AND DISCUSSION

The subsidence rate in KG basin is mapped in the range of +30 mm/year to -30 mm/year. Over the built-up area (urban area) the number of persistent scatterer points are higher than that of vegetated area. The rate at which the urban cities are subsiding in the KG Basin is not the same for every built-up area, which is seen from the degree of the scatterer's brightness i.e. different shades in the red and blue colour. Due to good prospect of groundwater recharge from nearby water bodies, some areas that are on the banks of river subsidiaries may show minor subsidence rate or uplift because of ground water recharge in underground aquifers. This phenomenon is seen in the result of the first dataset. Narsapur town, which is on the bank of river Godavari show uplift, whereas the Palakollu town shows the signs of subsidence. Deformation results are overlaid on Reflectivity map. The same results are geocoded and overlaid on Google Earth imagery. Figure 5 shows deformation map of Palakollu-Narsapur area. For the urban built-up area of Narsapur, the subsidence rate is in between -20mm/year to -25mm/year whereas for Palakollu 4mm/year uplift is observed. The subsidence rate over Kakinada is observed as -14mm/year. Figure 6 shows deformation map of Kakinada city area. It may be noted that there may be an error in the estimation of subsidence due to several reasons such as DEM error, atmospheric phase delay, less number of images used, time intervals of the images used.

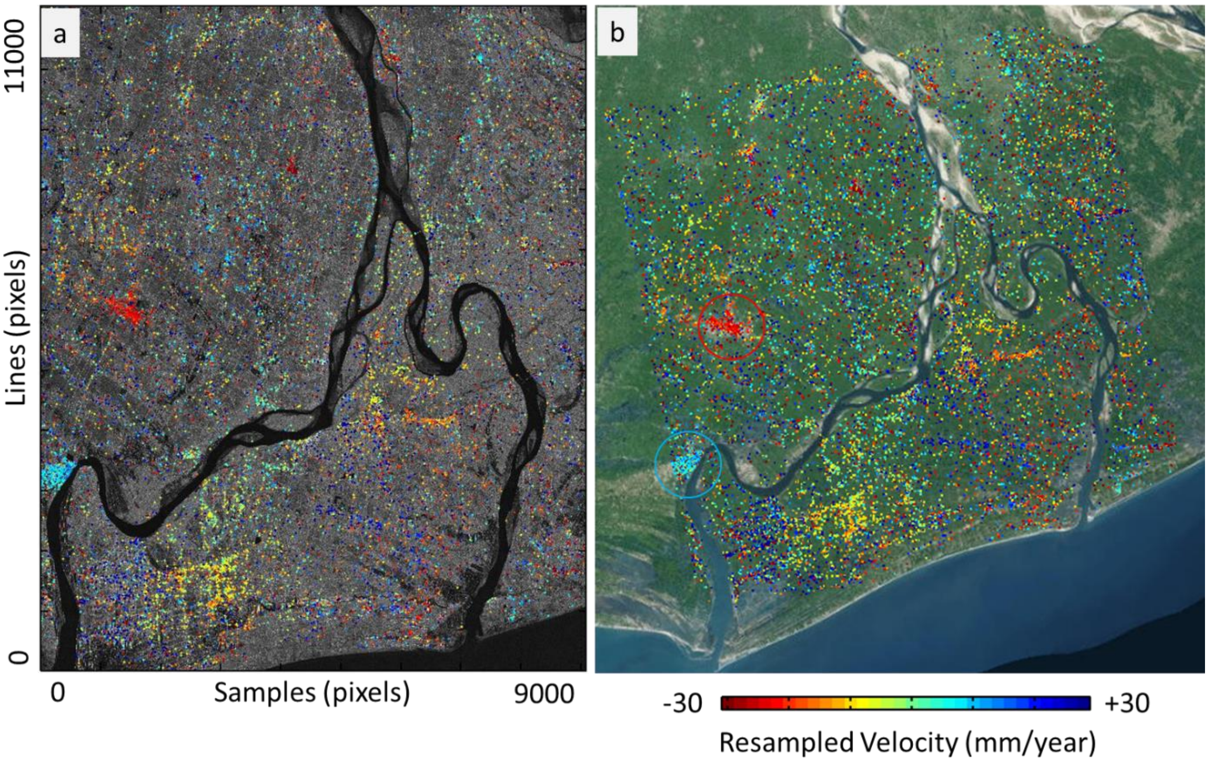

Figure 5: Subsidence evolution rate mapped over (a) Reflectivity map and (b) Google Earth (Geocoded) The blue circle is over Narsapur and the red circle drawn over Palakollu.

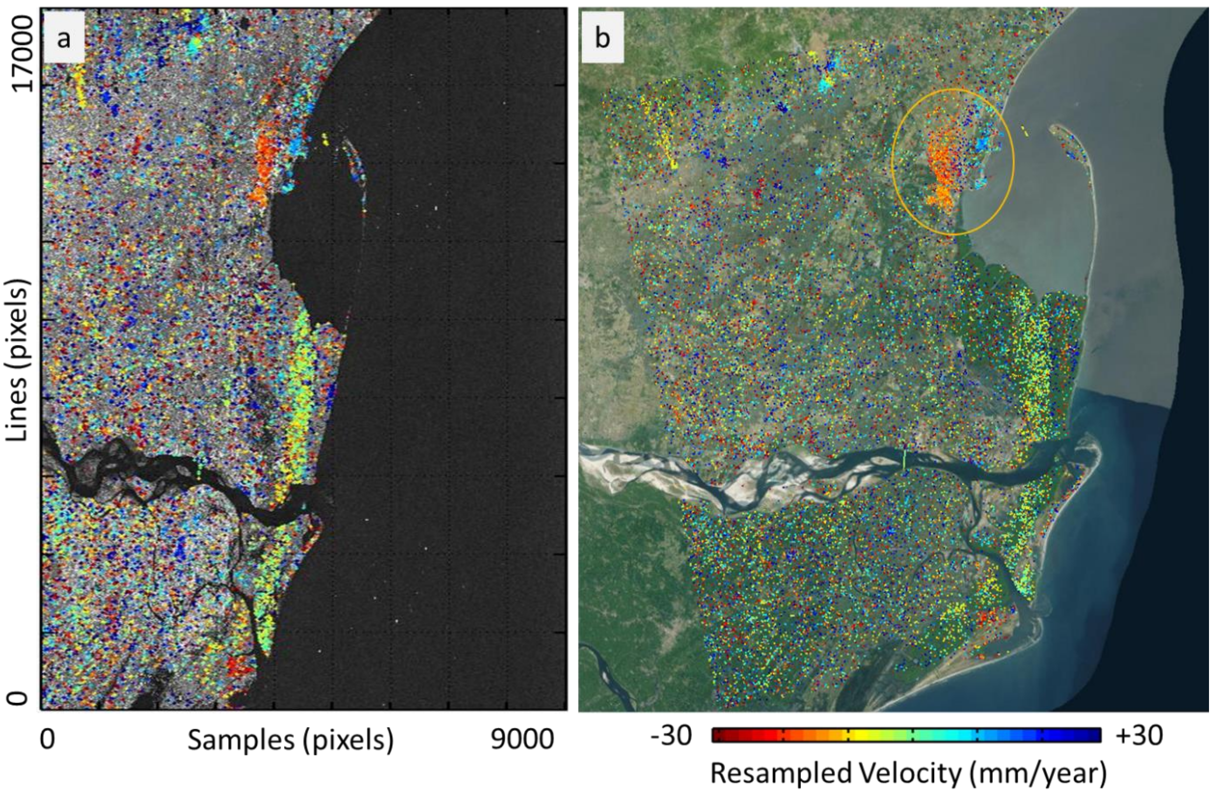

Figure 6: Subsidence rate mapped over (a) Reflectivity map and (b) Google Earth (Geocoded). The area enclosed by orange circle shows Kakinada city.

5. CONCLUSION

Land subsidence over Palakollu – Narsapur and Kakinada city is studied due to oil and natural gas extraction and also inherent land subsidence. Deformation rates over these areas using ALOS PALSAR images are reported. Even though deformation rates are same at all places, subsidence is observed over Narsapur and Kakinada areas, whereas uplift is observed in Palakollu area. The cause for this deformation is to be geologically validated in future research work. The results obtained in this work can be inter compared with other PSI approaches. As the areas are urban, C-band Sentinel-1 data would also be useful in determining present-day deformation over these areas.

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