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Application of PSInSAR method for determining of land subsidence in Hanoi city by Cosmo-Skymed imagery

Tran Van Anh*[1], Tran Quoc Cuong[2], Nguyen Duc Anh[2], Ho Tong Minh Dinh[3], Tran Trung Anh[1], Nguyen Nhu Hung[4], Luong Thi Thuy Linh[5]

[1]*Hanoi University of Mining and Geology, Duc Thang, Bac Tu Liem,Hanoi, Vietnam*
[2] *Institute of Geological Sciences, VAST, Hanoi, Vietnam*
[3] *National Research Institute of Science and Technology for Environment and Agriculture, France*
[4]*Le Quy Don Technical University*
[5] *Institute of Strategy and Policy on Natural Resources and Environment*

Abstract

Differential Interferometry SAR (DInSAR) method is one of techniques for subsidence detection in many years ago. However, this method exposed disadvantages, these are errors from atmospheric effects, the baseline of image pairs and the influences of the digital terrain model (DTM) that is used for eliminating the topographic phase in DInSAR if using Two-pass method. Because of these reasons, recently Persistent Scatterer Interferometric Synthetic Aperture Radar (PSInSAR) method is replaced for land deformation detection.

The paper focuses on determining the subsidence using PSInSAR method with 27 scenes of Cosmo-Skymed. The assessing of atmospheric effects to the results was computed by Cramer-Rao formula which proved the capability of using series of Cosmo-skymed image for subsidence detection with less influencing from atmosphere.

The subsidence computed from Cosmo-Skymed is dominated in the southern part of Hanoi such as Phap Van - Linh Dam, part of Dai Kim, Yen So; Thanh Xuan Nam, Ha Dinh, Ha Dong district such as Van Quan, Phuc La, Mo Lao, Ha Cau, Ta Thanh Oai, Vinh Quynh. The average of subsidence in this area is about 25mm/year in the period of 2011-2014.

Key word: land subsidence, interferometry, PSInSAR, Cosmo-Skymed

1. Introduction

Land subsidence is the geological disaster and cause a serious impact in urban areas. It may be a result of many influencing factors such as tectonic shifts, the stretching of the lithosphere, the impact of underground mining, extraction of groundwater, weak land, increasing external loading etc ... Land subsidence takes place slowly but cause very serious harm, especially for large urban areas developing . To monitor this phenomenon regularly both broad and strong subsidence areas are essential and more important for predicting, preventing and reducing the harmful effects of land subsidence in economic projects , living conditions.

The subsidence can be detected by some techniques. The traditional technique is leveling survey that is the most accurate method but it is costly and time consuming. Recently radar image utilization for subsidence detection is become popularization

* Corresponding author. Tel.: 0986811971
E-mail address: tranvananh@humg.edu.vn

With the surface deformation research, the differential SAR Interferometry (DInSAR) is commonly used. This method using two images is termed as “Two pass” or three, four images, termed as “Three pass” or “Four pass”. DInSAR was first applied on Seasat images at Jet Propulsion Laboratory JPL to measure small elevation changes over larger swaths 50km in Imperial Valley, California (Gabriel and Goldstein, 1989). Since then many scientists have applied this technique for measurement of geographical process including land subsidence in mining areas (Ferreti et al., 2000), landslides in mountainous areas (Rott et al., 2000) and detection of volcanic deposit, etc.

However, the DInSAR method for subsidence detection exposed its disadvantages, these are errors from atmospheric influences, the baseline of image pairs and the influence of the digital terrain model (DTM) that is used for eliminating the topographic phase in DInSAR if using Two-pass method. Because of these reasons there were some new approaches that have been tried to remove the errors, such as Persistent Scatterer Interferometric Synthetic Aperture Radar PSInSAR which was the first applied in 2000 by Ferreti et al. PSInSAR uses a series of images and chose the permanent scatter (PS) points which is the fixed scattering points are selected as the high buildings, roads, bridges. Some other researches investigated the error by using PSInSAR method (Colesanti et al., 2003). The study of Colesanti et al. monitored the fault creep along the Hayward Fault in California. In this case, the authors estimated the line of sight (LOS) directional displacement rate due to fault creep using PSIn-SAR technique. The projection of LOS displacement along the fault direction was compared with creep meter records with less than 10 percent error. Dehls and Nordgulen (2003) monitored land subsidence in Oslo in Norway caused by tunnel construction and related groundwater drainage. The subsidence of this study area was surveyed using leveling and the field records were compared to PSInSAR results.

There have been a few investigations using DInSAR and MT-InSAR methods for subsidence detection in Hanoi. Raucoules and Carnec (1999) used ERS-1/2 SAR C band data for detecting the subsidence over the urban area with several pairs of interferometric images. They detected signatures of ground movement about 1.5cm in noisy differential interferograms. Our research (e.g. Tran et al 2007) employed JERS-1 L band with “Three pass” method in the period of 1995 - 1998. The distributions of subsidence were detected in the southern part of city with 2cm to 3cm per year, and the around of West Lake (Ho Tay). This research proved the capabilities of “Three pass” method for detecting subsidence. Nevertheless, this study did not assess some influential factors to the results acquired by DInSAR. Recently the research of Dang et al. (2014) with utilizing MT-InSAR for land subsidence detection in the Hanoi area by ALOS data. In this research, there were 21 SAR image scenes acquired in L-band used. The subsidence was distributed by PS points, especially the subsidence caused by buildings or roads.

In the period of 2010 to 2014, number of construction sites were increased, the ground water was also extracted more, which was the major cause of subsidence. In this study we detect land subsidence in Hanoi using PSInSAR method with a data set of Cosmo Skymed in the period of 2010 to 2014. The paper aims to use the PSInSAR method for land subsidence detection of the southern city of Hanoi. The results showed that the determination of subsidence by PSInSAR is possible to determine subsidence with adequate precision.

2. Methodology

As you know, the PSI method is a method developed from traditional method of determining ground deformation named DInSAR (Differential SAR Interferometry). This method determines the land deformation by the phase shift between two or three images acquired in different times over the same area on the surface which is called differential interferometry. The equation (1) illustrates the phase of land deformation.

Assuming that if a DEM of the imaged scene is available, φTopo can be simulated and subtracted from ΔφInt (this is the inverse operation performed in InSAR DEM generation), obtaining the so-called DInSAR phase ΔφD-Int:

$$\Delta\varphi_{D-Int} = \Delta\varphi_{Int} - \varphi_{Topo\_simu} = \varphi_{Displ} \qquad (1)$$

where φTopo simu is the simulated topographic component, which implicitly contains flat-earth phase component. Note that the orbital errors affect this simulated topographic component, even if the flattening process is not explicitly done. Eq. (1) summarizes the DInSAR working principle, which allows the displacements of the imaged scene to be derived from two complex SAR images.

Eq. (1) represents a simplified DInSAR observation equation. A comprehensive equation includes Eq.(2):

$$\Delta\varphi_{D-Int} = \Delta\varphi_{Int} - \varphi_{Topo\_stimu} = \varphi_{Displ} + \varphi_{Topo\_res} + \varphi_{Atm\_s} - \varphi_{Atm\_M} + \varphi_{Orb\_s} - \varphi_{Orb\ M} + \varphi_{Noise} + 2.k.\pi \qquad (2)$$

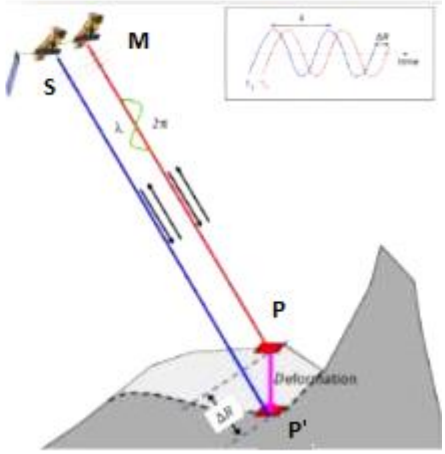

Fig.1. Scheme of the DInSAR deformation measurement

where φTopo_res is the residual topographic error (RTE) component, φAtm is the atmospheric phase component at the time of acquisition of each image, φOrb is the phase component due to the orbital errors of each image (errors that affect the position of M and S in (Fig. 1)
and φNoise is the phase noise. The last term, 2 . k .π, where k is an integer value called phase ambiguity, is a result of the wrapped nature of $\Delta\varphi_{D\text{-}Int}$, i.e. the fact that the DInSAR phases are bounded in the range (-π, π].
The goal of any DInSAR technique is to derive φ_{Displ} from $\Delta\varphi_{D\_Int}$. This implies separating φDispl from the other phase components of Eq. (2). An essential condition to accomplish this separation is to analyses pixels characterized by small φNoise, which are typically related to two types of reflectors: those where the response to the radar is dominated by a strong reflecting object and is constant over time (Permanent Scatterer, PS) and those where the response is constant over time, but is due to different small scattering objects (Distributed Scatterers, DS). The major DInSAR limitations include: (i) the temporal and geometric decorrelation that influence the φNoise component (Hanssen, 2001); (ii) the phase unwrapping that concerns the estimation of k (Ghiglia and Pritt, 1998); and (iii) the atmospheric component (Zebker et al., 1997). The DInSAR stacking techniques (Zebker et al.,1997; Sandwell and Price, 1998; Wright et al., 2001) include different approaches to reduce the atmospheric effects by averaging various interferograms. PSI represents a specific class of DInSAR techniques, which exploits multiple SAR images acquired over the same area, and appropriate data processing and analysis procedures to separate φDispl from the other phase components represented in Eq. (2).

The term PSI is used in this work to indicate a number of different techniques including the Permanent Scatter approach (the first PSI technique proposed by Ferretti et al. (2000, 2001)), other techniques based on PSs, those based on DSs and other hybrid methods. Other authors refer to PSI with the terms time series radar interferometry (Van Leijen, 2014), advanced DInSAR (Herrera et al., 2007), etc. The main outcomes of a PSI analysis include the deformation time series and the deformation velocity estimated over the analysed PSs or DSs.

3. Study Area and data used

Hanoi, the capital of Vietnam, is located at latitudes 20°53' - 21°23' N and longitudes 105°44' - 106°02' E in the plain of North Vietnam. Hanoi is surrounded by six provinces; Thai Nguyen in the north, Bac Ninh and Bac Giang in the east, Hung Yen in the southeast, Ha Tay in the south and southwest, and Vinh Phuc in the west. There are many rivers flowing eastwards to the sea that is a convenient transport cluster for all the Northern provinces. Because Hanoi is in a river delta, most of the Hanoi area is flat with elevations below 20 m except the northern mountainous part up to 400 m height. The general topography is sloped gently from North-West to South-East in accordance with trend of Red river's flow. In the center of city, the elevation is about 8 m – 12 m, while the southern part of the city the elevation is about 3 m - 5 m. Figure 2 shows the location of Hanoi in the Red River Delta.

Currently, Hanoi is facing subsidence situation. The results of subsidence research showed that subsidence period 1988-1995 were almost the entire inner city area (except the Red River) and the surrounding areas were subsided. Strong subsidence zone (average speed> 10 mm / year) is the center and south of the city. Some places as Giang Vo – Thanh Cong and Phap Van sunk with an average speed of 20-44 mm / year. According to the Institute of Science - Technology and Constructed Economy (Hanoi Department of Construction), the results of monitoring surface subsidence of land subsidence at 10 measuring stations over the years show that all 10 positions are subsidence. Thanh Cong is the fastest subsidence areas with speed 41.42 mm / year, Ngo Si Lien is 31.52 mm / year, Phap Van 22.16 mm / year (Capital Security newspaper, 2008), more serious, land subsidence tends to increase 1-2 mm per year. May 2013 did occur subsidence, tilting house at the Hoang Cau. Many old apartment building subsidence continues.

After Hanoi was expanded the administrative border in August 2008, the capital, with an area of 3324.92 square kilometer, including 11 counties and 18 districts. Due to population increasing pressure, an augmenting of housing construction, construction of civil works and mining thus the providing of drinking water will also increase. Therefore, the intensity and scale of the subsidence phenomenon occurred in urban areas can cause effects or risks to constructions, as well as economic activities, and increasingly large impact to more people.

The data set is Cosmo-Skymed images, X band (3,1 cm) (see the table 1), beside that we used Shuttle Radar Topography Mission SRTM DEM 90m for DEM phase simulating. Cosmo-SkyMed images are purchased on the times with good weather: no rain, clear skies, little fog. Cosmo- Skymed used in our research in the period from 2011 to 2014 with the mode of Stripmap, the size of scene is 40x40 km and 3m spatial resolution (Figure 2).

Table 1: The information of Cosmo-Sky-med images

TT	**Date of acquisition (Local time)** (Date-Month-Year)	**Polarization**	**Mode**	**Hướng quỹ đạo**	**Baseline B [m]**
1	28-05-2011	HH	SCS_B	Ascending	-601
2	06-07-2011	HH	SCS_B	Ascending	-213
3	16-08-2011	HH	SCS_B	Ascending	644
4	23-08-2011	HH	SCS_B	Ascending	1036
5	24-09-2011	HH	SCS_B	Ascending	1083
6	11-11-2011	HH	SCS_B	Ascending	1283
7	22-12-2011	HH	SCS_B	Ascending	-295
8	23-01-2012	HH	SCS_B	Ascending	-95
9	11-03-2012	HH	SCS_B	Ascending	-19
10	06-06-2012	HH	SCS_B	Ascending	-66
11	17-07-2012	HH	SCS_B	Ascending	810
12	25-08-2012	HH	SCS_B	Ascending	294
13	22-11-2012	HH	SCS_B	Ascending	758
14	31-12-2012	HH	SCS_B	Ascending	-247
15	21-03-2013	HH	SCS_B	Ascending	941
16	**09-06-2013**	**HH**	**SCS_B**	**Ascending**	**0**
17	28-08-2013	HH	SCS_B	Ascending	108
18	15-10-2013	HH	SCS_B	Ascending	-298
19	16-11-2013	HH	SCS_B	Ascending	1118
20	18-12-2013	HH	SCS_B	Ascending	767
21	20-02-2014	HH	SCS_B	Ascending	149
22	28-06-2014	HH	SCS_B	Ascending	-301
23	30-07-2014	HH	SCS_B	Ascending	-180
24	31-08-2014	HH	SCS_B	Ascending	846
25	02-10-2014	HH	SCS_B	Ascending	351
26	03-11-2014	HH	SCS_B	Ascending	655
27	04-12-2014	HH	SCS_B	Ascending	242

In the table 1, the bold line is the image that is chosen for the Master image and the other one are the slave images. The column 6^{th} is the baseline of each pair of image (between slave and master image).

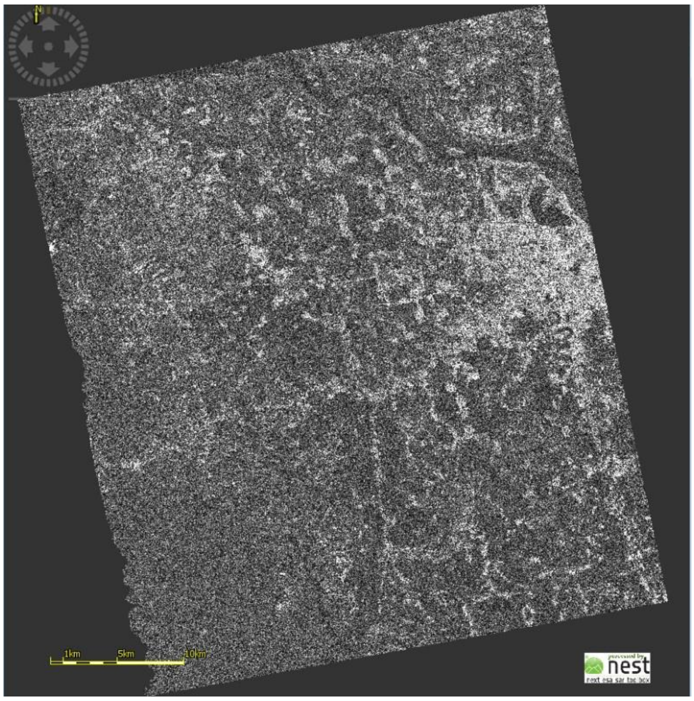

Figure 2 . Cosmo-SkyMed image acquired on 28/5/2011 (Local time)

According to this technique, firstly the permanent scatter of the points PS were selected by using coherent criteria and then a series of interfometric images were processed by using small baseline to determine the distributed scatter points DS. PSInSAR processing is basically the same as doing of DInSAR but in this case we have to deal with the interference simulation and a series of interference images . In PSInSAR technique, a master SAR image is selected and then register all remaining images as the slave images (Figure 3).
In PSInSAR method, instead of process on the whole image, the processing is done on the PS points. To select the PS points, the stable objects and correlated preserving over time that are adequate requirement. The criteria for PS selection: Firstly we need to choose a reliable PS points (i.e., only a very small part of the selected point are affected by noise). On the other hand, the number of PS points is the most number of points. Two parameters need to be optimized is the standard classification threshold and the size of the calculation window. The large size of window the higher precision of calculation but the PS point will be less. Classification threshold is calculated through the analysis phase of the pixel value in time series. Normally, we need to consider about the reliability of the PS points and the number of points. However, this problem can be overcome in the analysis step of PS, while the PS point is not satisfactory will be removed. The image processing chain is illustrated in the figure 3.

4. Accuracy assessement

To assess the accuracy of the subsidence from radar image processing, the Cramer-Rao formula (HCRB) is used. HCRB can be applied in the case of a set of PS points objects and the other part is random objects DS points . The minimum term of HCRB is the accuracy determined from the parameters. According Tebaldini, 2009, the standard deviation HCRB speed of subsidence value calculated from number of SAR images (N) can be determined by the formula:

$$\sigma_v^2 = \left(\frac{\lambda}{4\pi\delta t}\right)^2 \left(2\sigma_\alpha^2 + \frac{1-\gamma_t^2}{2\gamma_t^2 L}\right)\frac{6}{N^3-N} \quad (3)$$

Where: λ is the wavelength, δt is the time between two pass of satellite, L is the number of independent samples, γ_t is relative reducing caused by different time, σ_α is caused by phase changes of atmosphere - APS (atmospheric phase screens). In the above factors, the biggest impact is the APS. APS delay is independent frequency but the APS phase will be affected inversely proportional to the wavelength.

In the case of Cosmo-Skymed parameters: λ = 3.1 cm, γt = 0.5, $\delta t = 11$ days, L = 50, N = 27. Results in Figure 3-10, shows that, in ideal conditions with $\sigma_\alpha = 0$ then the accuracy of subsidence computed from Cosmo-Skymed is approximately 0.0000002 rad. If $\sigma_\alpha = 20\ rad$ the subsidence error from 27 Cosmo-skymed will be less than 2mm per year. Thus we can say that with the big number of images the atmospheric influence is little.

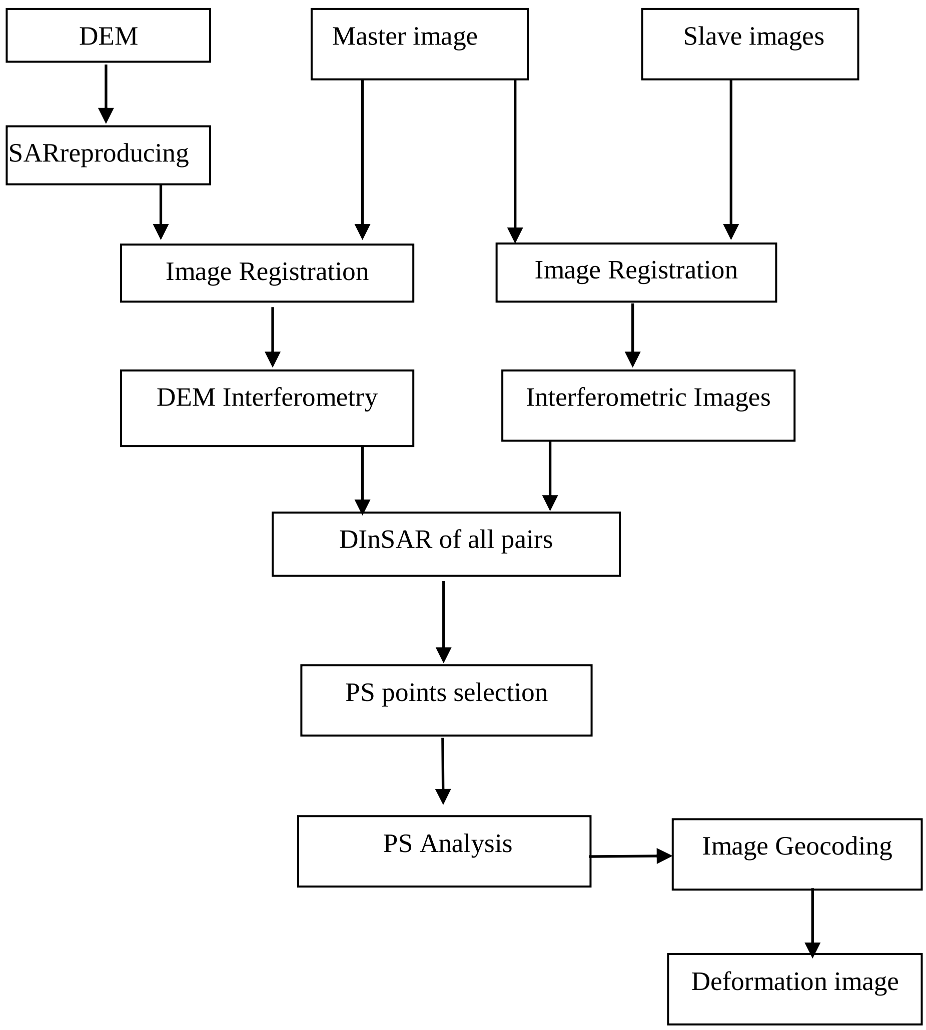

Figure 3: Image processing flow chart

5. Result and Discussion

The image processing results of Cosmo-Skymed in the period of 2011-2014 is 410000 PS and DS points (Figure 4). The Results indicated subsidence with large areas include northern Thanh Cong, Hoang Cau; Hoang Mai District, Southern Tan Mai Ward, Thinh Liet, Phuong Liet, Dinh Cong, Giap Bat, Phap Van - Linh Dam (Hoang Liet), part of Dai Kim, Yen So; Thanh Xuan Nam, Ha Dinh, Ha Dong district as Van Quan, Phuc La, Mo Lao, Ha Cau, Ta Thanh Oai, Vinh Quynh.

The maximum value of the average rate of subsidence of this period appear in Ha Dong and Hoang Mai are -25 mm / year. In this areas the subsidence are much more than the other areas because two reasons: first is weak land is existed in the southern area, this is the main reason caused subsidence, the second is the development of the city much in the southern part of Hanoi, so the water extraction much and concurrently with construction or build up appear fast. There were some areas appear less subsidence, even there were uplift concentrated in the northern areas such as Tay Ho or Cau Giay district, where the weak land is not being there.

For validating with the real subsidence, we referred the subsidence map used levelling survey that made by Geological Institute (VAST) (1995). Although the subsidence map from levelling survey and subsidence from Cosmo-Skymed are different time, the subsidence distribution(Figure 5) showed the same place with our processing from Cosmo-Skymed, especially in the southern part of Hanoi city. The highest rate of subsidence was also distributed in the Linh Dam where the weak land is existed.

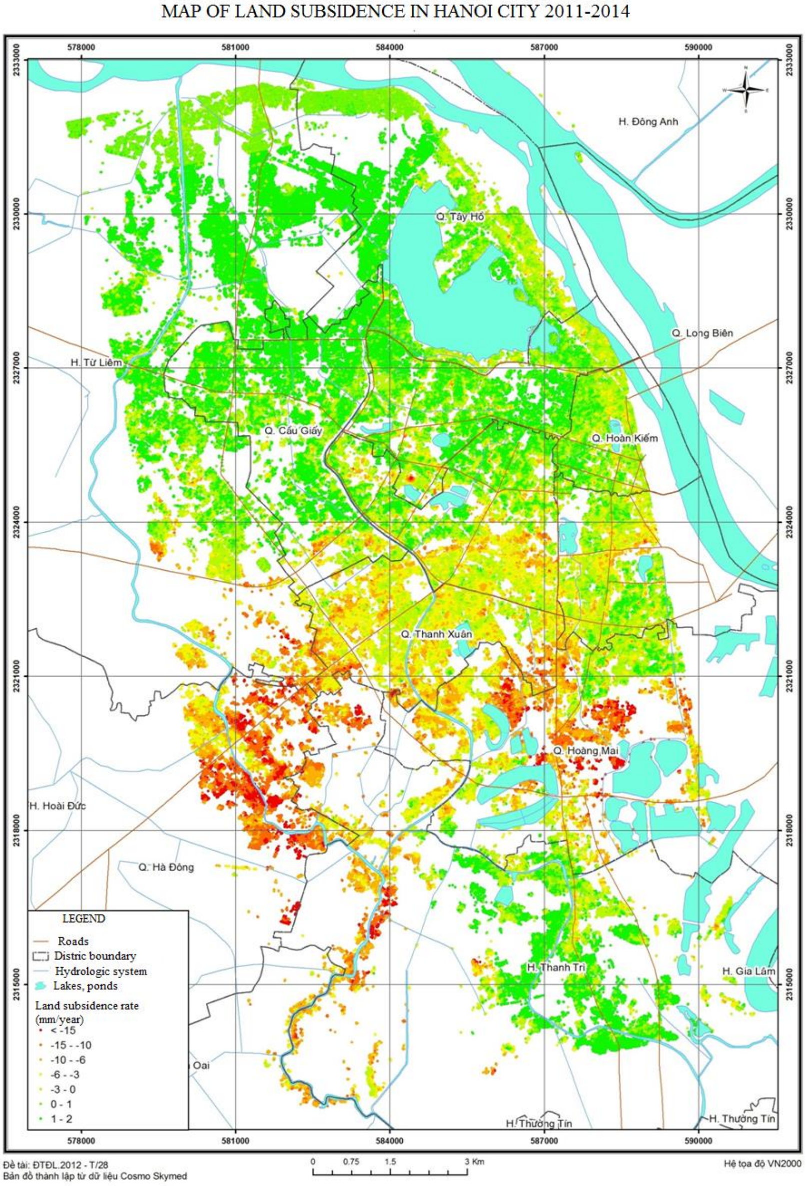

Figure 4:Subsidence distribution of Hanoi city from Cosmo-Skymed

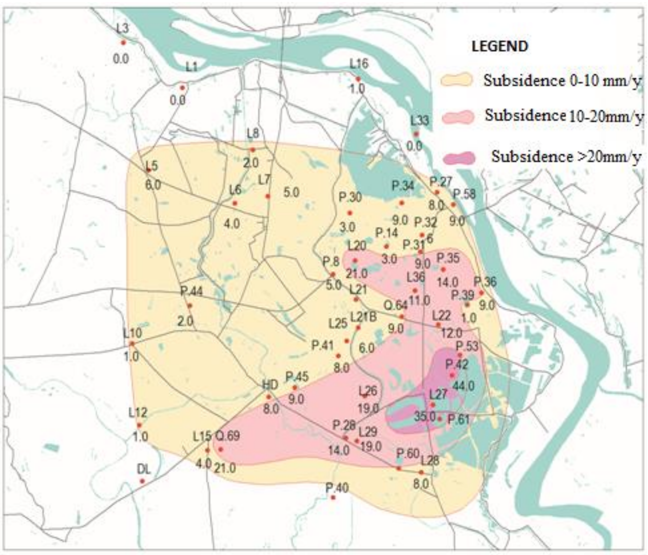

Figure 5: Subsidence distribution of Hanoi city from levelling survey

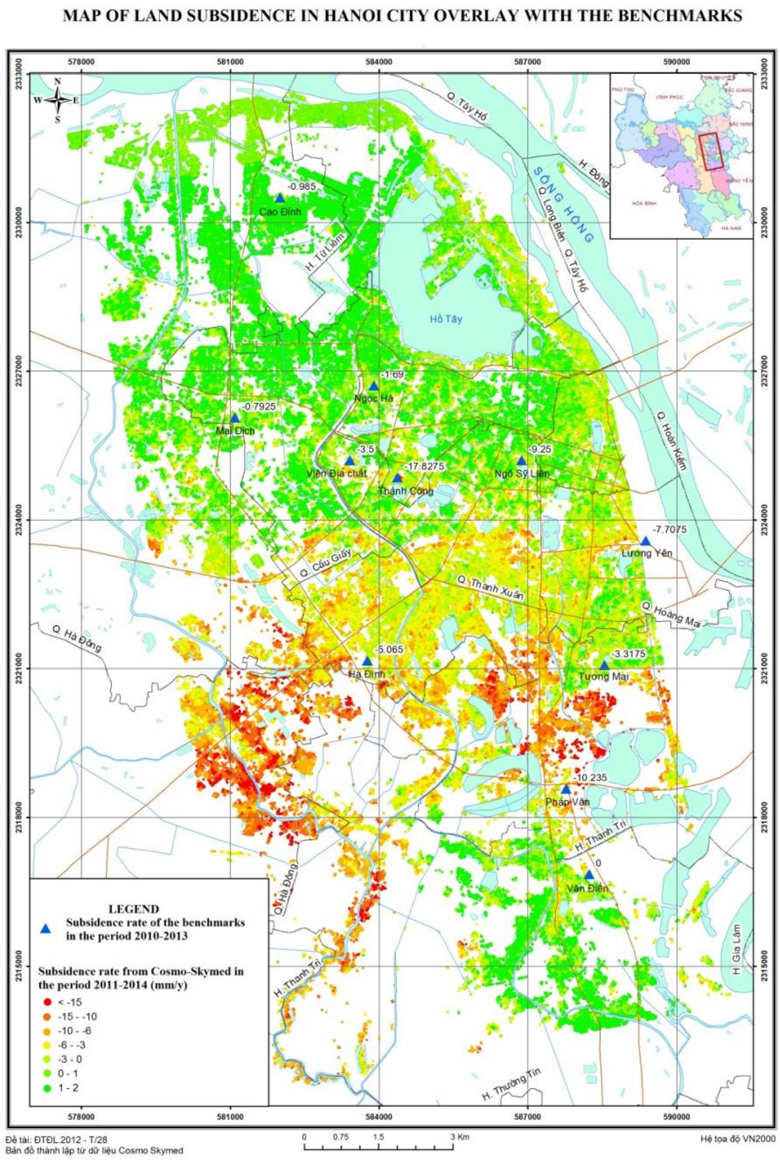

Figure 6: Map of land subsidence in Hanoi city from Cosmo-SkyMed overlaid with the benchmarks

For more evidence of subsidence in the south of Hanoi, we have collected data from several benchmarks that measured by field survey. These points are measured in the period from 2010 to 2013. The distribution position of subsidence identified by Cosmo-Sky Med are matching with the benchmarks (Fig. 6). The table 2 illustrates the information of two methods at 5 subsidence positions. The relationship of two data types is computed and showed on the fig. 7, the correlation value is 0.98. It demonstrates that the determination of subsidence using radar interferometry were in the same places with the real distribution of subsidence in Hanoi city.

Table 2: Subsidence values of two methods

Name of benchmarks	Sub_Cosmo Skymed (mm/y)	Sub_surveying (mm/y)
Ha Dinh	-5.33	-6.75
Tuong Mai	-2.98	-4.42
Thanh Cong	-13.78	-23.77
Ngoc Ha	-0.98	-2.25
Mai Dich	-0.34	-1.06

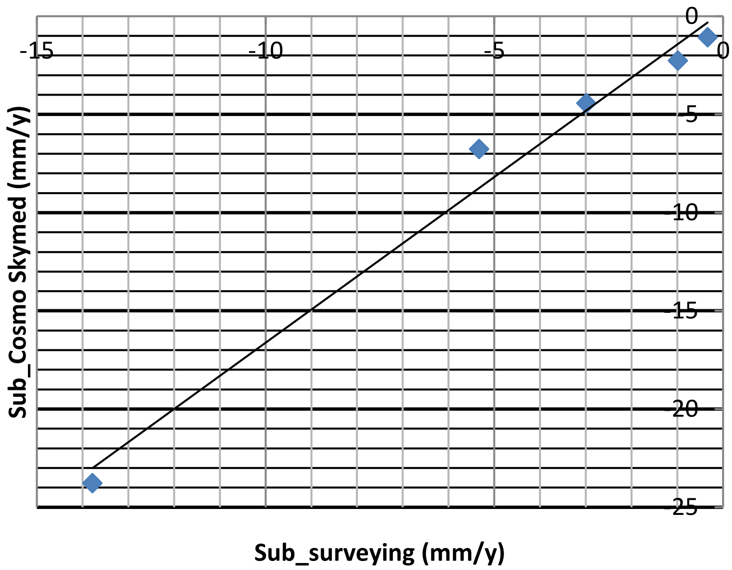

Figure 7. The subsidence values of two methods from 5 stations

6. Conclusions

By using the radar interferometry technique: PSInSAR integrating small baseline we could detect the subsidence in the southern and south-west Hanoi, matched with the levelling survey. The correlation of subsidence points detected by PSI method and levelling survey are 0.98. It is absolutely proved the PSI ability for subsidence determination.

The subsidence computed from Cosmo-Skymed is dominated in the southern part of Hanoi as Phap Van - Linh Dam, part of Dai Kim, Yen So; Thanh Xuan Nam, Ha Dinh, Ha Dong district as Van Quan, Phuc La, Mo Lao, Ha Cau, Ta Thanh Oai, Vinh Quynh. The average of subsidence in this area is about 25mm/year in the period of 2011-2014.

The Cosmo-skymed images with X band (3.1 cm) could be used to monitoring the subsidence in Hanoi urban area with adequate accuracy.

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References

Ferretti, A., Prati, C., Rocca, F., 2000. Nonlinear subsidence rate estimation using permanent scatterers in differential SAR interferometry. IEEE TGRS 38 (5), p2202–2212.

Ghiglia, D.C., Pritt, M.D., 1998. Two-dimensional Phase Unwrapping: Theory, Algorithms, and Software. Wiley, New York.

Hanssen, R., 2001. Radar Interferometry. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Herrera, G., Tomás, R., López-Sánchez, J.M., Delgado, J., Mallorqui, J.J., Duque, S., Mulas, J., 2007. Advanced DInSAR analysis on mining areas: La Union case study (Murcia, SE Spain). Eng. Geol. 90 (3), p148–159.

Sandwell, D.T., Price, E.J., 1998. Phase gradient approach to stacking interferograms. J. Geophys. Res.: Solid Earth (1978–2012) 103 (B12), p30183–30204.

Van Leijen, F., 2014. Persistent Scatterer Interferometry based on geodetic estimation theory (Doctoral dissertation). TU Delft, Delft University of Technology

Wright, T., Parsons, B., Fielding, E., 2001. Measurement of interseismic strain accumulation across the North Anatolian Fault by satellite radar interferometry. Geophys. Res. Lett. 28 (10), p2117–2120.

Zebker, H.A., Rosen, P.A., Hensley, S., 1997. Atmospheric effects in interferometric synthetic aperture radar surface deformation and topographic maps. J. Geophys. Res.: Solid Earth (1978–2012) 102 (B4), p7547–7563.