Vietnam Journal of Earth Sciences, 41(4), 339–357, Doi: 10.15625/0866-7187/41/4/14236

(VAST)

Vietnam Academy of Science and Technology

Vietnam Journal of Earth Sciences

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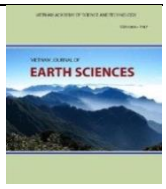

Application Terrasar-X data for studying land subsidence in Hanoi City

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Received 11 February 2019; Received in revised form 17 August 2019; Accepted 1 September 2019

ABSTRACT

SAR Interferometry (InSAR) is a technique to measure land subsidence and can build a subsidence map on a large spatial scale with high accuracy. The study presented the application of PSInSAR for determining the subsidence of the central area of Hanoi through Terrasar-X data set from 2010 to 2015, with 23 images. The result shows that some area has the high subsidence in the districts of Hanoi such as Hoang Mai, Ha Dong and the slow subsidence such as Dong Da, Hai Ba Trung with subsidence velocity is less than -10mm/year. Besides, the correlation between ground subsidence measured by PSInSAR and subsidence monitoring of building CC02 Van Quan in Ha Dong district for the same period was computed with a correlation coefficient (R2) of 0.94. The PSInSAR technique can detect and estimate subsidence phenomena effectively with X-band.1.

Keywords: Land subsidence;, interferometry; PSInSAR; Terrasar-X.

1. Introduction

Interferometric Synthetic-Aperture Radar is one of the different methods which are applied commonly to research land deformation in the world. Specifically, this method is applied widely to measure land subsidence and mapping in the wide-area with approximate millimeters of accuracy.

The simplest of InSAR is through processing two images of the same or different satellites over the same area acquired at different times with the same frequency based on the phase difference of the radar image pair. The interferometric phase can be formed by a pair of images with a very short period of time, at this time, the terrain does not change and the interferometric phase contains only the topographic phase. But if the time interval is large the terrain changes, then the interferometric phase includes the topographic phase and the changing phase of the terrain. This is the principle that allows land subsidence research in this study.

Differential InSAR technique was firstly applied by using Seasat images to study the

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small change of the elevation in a large area (about 50 km) in Imperial Valley, California, the United States (Graham, L.C, 1974). Chatterjee et al. researched the land subsidence situation due to groundwater exploitation by InSAR technique applied to Kolkata, India with data from 1992-1998 (Chatterjee R.S et al., 2006). The monitoring times were before the rainy season and after the rainy season. The monitoring results by satellite InSARtechnology showed that during the period 1992-1998 the California subsidence rate was about 5-6.5 mm/year. Fruneau et al. studied subsidence due to groundwater exploitation in Paris (France) (Fruneau Bénédicte et al., 2005) by 40 radar images, 87 measuring points of the atmospheric characteristics and 670 surveying points of subsidence on the field. The study has restricted the disadvantages of InSAR method which is affected by atmospheric differences between 2 times. Studied subsidence in Mexico City from 2002 to 2007 using InSAR technique (López-Quiroz et al., 2009). The study has solved the loss of coherence in pairs of interferometric images and increased the accuracy of the results of subsidence monitoring. With 14 images of RadarSat-1 resolution of 8.9 m from October 2005-October 2009, terrain model from InSAR(SRTM) resolution of 90 m, surveying points of land subsidence and using persistent scatterer interferometry (PSI) method, 40 interferometric images were established for Bangkok city to study ground subsidence (Aobpaet Anuphao et al., 2010). By using the PSI method, Aobpaet and colleagues has limited the effects of the atmosphere and the correlation loss compared to the traditional InSAR method. According to Hirose's study, 17 scenes of JERS-1/SAR during the period of February 1993 - September 1998 were used to create 41 pairs of interferograms with baseline less than 1000 m for Jakarta (Indonesia) (Hirose Kazuyo et al., 2001) which pointed out that during the period of 1993–1995, Jakarta was subsided 10 cm and from 1995–1998 was 6 cm. The result from InSAR was compared with the surveying points of subsidence.

However, these studies, InSAR technique has not been applied with X-band and under severe atmospheric conditions typical of tropical regions.

Application of InSAR technique to determine land subsidence in Vietnam, up to now, focus in two big cities, Ho Chi Minh City and Ha Noi City. For instance, the study of Le V.T and Ho T.M.D (2008) combined DEM-SRTM data, computed interferogram by InSAR technique then experimented the PSInSAR processing technique with ERS-1 images and ERS-2 images in Ho Chi Minh City. Van Anh Tran (2007) used JERS-1 radar imagery in L-band in the period of (1995-1998) to study land subsidence in urban and suburban areas of Hanoi City, the research used subsidence measurement data in ground-stations for validating with interferogram from images. Another study of the same authors researched land subsidence in the period of 2000 to 2005 which used Envisat ASAR images in Hanoi city through processing by DInSAR technique (Van Anh Tran et al., 2015). Dang Vu Khac (2013) utilized 22 ALOS PALSAR images in L-band in the period of 02/2007 to 02/2011 with StaMPS/MTI technique, this method combines two approaches which are Persistent Scatterers and Small Baseline in order to separate subsidence signals from pixels and increase the ratio between signals and noise. Tran Quoc Cuong (2014) applied InSAR technique in order to determine land subsidence in Hanoi City from 2000 to 2014; the research approaches the newest and the best SAR database which are TerraSAR-X images and Cosmo-Skymed images with the wavelength of both are 3.1 cm (X-Band) by PSInSAR technique and SqueeSAR

technique. Minh Hai Nguyen (2014) Using Differential InSAR Three-pass method to research the Hanoi Ground deformation with Three images taken on April 10, 2012, June 26, 2012 and April 30, 2013 of TeraSAR-X satellite. The results show that Hanoi ground has relatively small changes, for example, subsidence (-41mm / year) of the North Thang Long Industrial Zone from 2012-2013. Tran V.A et al. (2014) Application of InSAR technique in creating Digital Elevation Model. The author used JERS1 images L-band and Terrasar-X images by InSAR technique. The results show that Using Terrasar-X is impacted easier by atmospheric so the results often have loss coherence where Digital Elevation Model often fail when created. Besides, JERS1 images in L-band, the resolution is lower but have rarely loss coherence so Digital Elevation Model is easier created and the impact of scattering is less than Images with shorte wavelength. the distribution and evolution of recent subsidence patterns detected in the Historical Centre of Hanoi, Vietnam in the period from April 2012-November 2013 (Le S.T. et al., 2016) by processing 23 TerraSAR-X images using StaMPS (Stanford Method for Persistent Scatterer) SB (small baseline) InSAR (Interferometric Synthetic Aperture Radar) approach to reveal the subsidence patterns. A total of 6.29 million radar targets were obtained, maintaining the average density of 217,012 points/km^2. The author suggests that image oversampling not only increased the number of measurement points 4.4 times more than the standard processing chain but also removed some of the noisiest points. The observed subsidence patterns are mostly related to adjacent groundwater extraction and construction activities, with the maximum subsiding rate reaching -18.1 mm/year for the study period April 2012 to November 2013.

In this paper, the author used Terrasar-X images with the wavelength of 3.1 cm (X-Band) to determine land subsidence in the central area of Hanoi City with the wider extent, time to research subsidence with radar image data by the end of 2015 is farther than previous studies. In addition, the research also combined with a comparison of the correlation between subsidence value by SAR data and its value by leveling method.

The structure of the article consists of an introduction, study area, research methodology, results and discussion of research results.

2. Study area

The study of land subsidence includes the entire inner city and part of suburban districts with an area of 16 × 25 km. The study area (Fig. 1). According to the geological map of the scale of 1/50000 Hanoi area established by the Hanoi Geological Division, the Quaternary geological structure of the area has 5 sedimentary formations, from the bottom up are the layers: Le Chi, Hanoi, Vinh Phuc, Hai Hung, and Thai Binh. Le Chi Formation (Q_1^1 *lc*): In the Hanoi sheet area, the Le Chi Formation is covered by younger Quaternary formations, and has been met only within boreholes from Nhon toward the south-southeast of Hanoi City Hanoi Formation ($Q_1^{2\text{-}3a}$ *hn*): The Hanoi Formation is composed of sediments of two following origins:

Fluvio-proluvial sediments ($apQ_1^{2\text{-}3a}$ *hn*): distributed in the form of terrace II in Xuan Mai, Thach That, Hoa Lac, Viet Tri, Da Phuc, Kim Anh and Hiep Hoa areas. In the plain, they have been met within deep boreholes Fluvial sediments ($aQ_1^{2\text{-}3a}$ *hn*): met within almost all boreholes with pebble, granule, grit, sand, silt and clay, 4–47 m thick.

Vinh Phuc Formation (Q_1^{3b} *vp*): The Vinh Phuc Formation is composed of the following origins:

Fluvial sediments (aQ_1^{3b} *vp*): distributed in the edge of the plain in Vinh Yen, Hiep Hoa, Me Linh, Soc Son, north Dong Anh, Thach That, Viet Tri, etc.

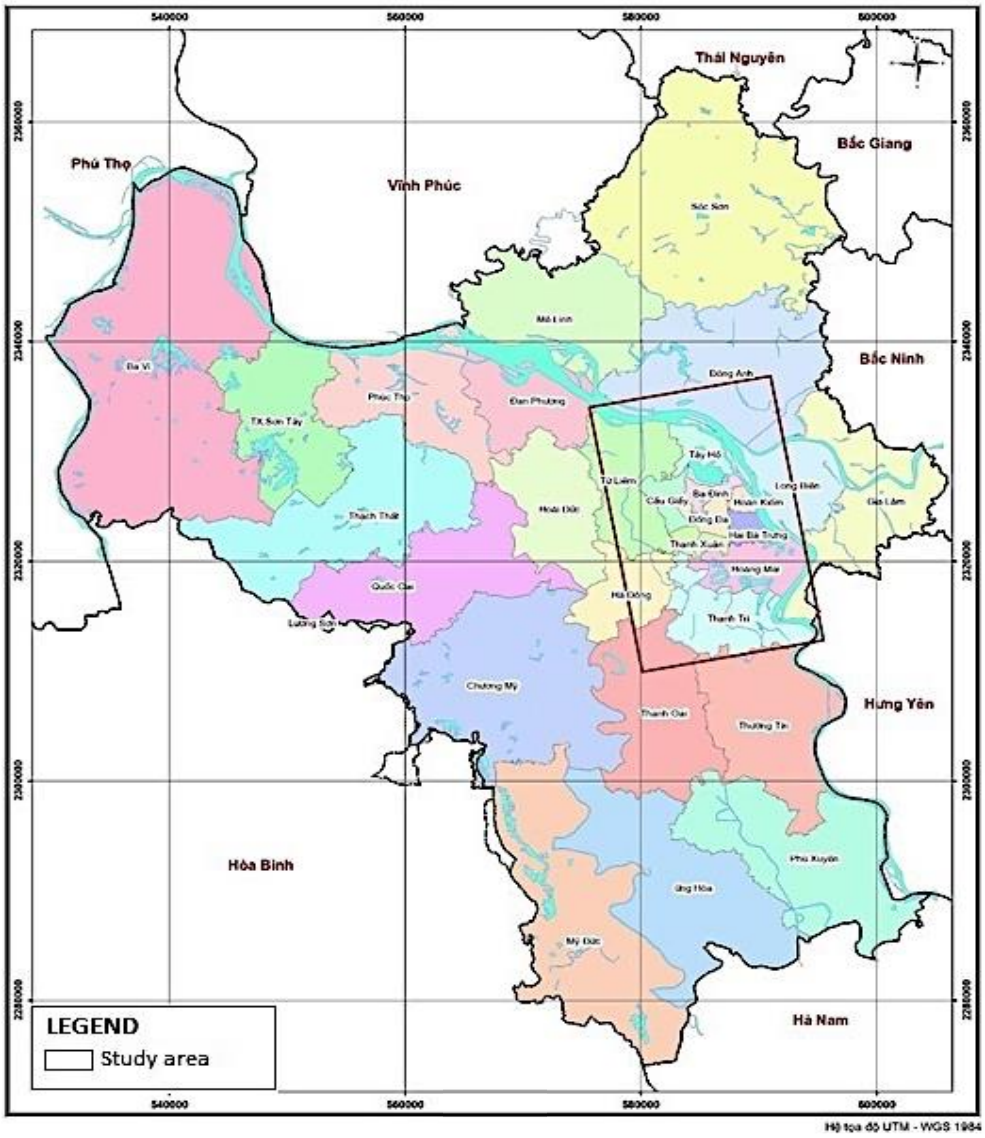


Figure 1. The study area

Fluvio - lacustrine - marshy sediments ($albQ_1^{3b}$ *vp*): distributed limitedly in Soc Son and Vinh Yen areas

Fluvio-marine sediments (amQ_1^{3b} *vp*): distributed limitedly on the surface in Mai Lam, Tu Son and more largely within boreholes. They are composed of gray clay and silt mixed with a little sand, 2.5–19.6 m thick.

Hai Hung Formation (Q_2^{1-2} *hh*): In the Hanoi Map sheet area, the Hai Hung Formation includes following origins: Lacustrine-marshy sediments (lbQ_2^{1-2} *hh*), Fluvio-marine-marshy sediments ($ambQ_2^{1-2}$ *hh*) and Marine sediments (mQ_2^{1-2} *hh*).

Thai Binh Formation (Q_2^3 *tb*): This formation consists of youngest sediments in the survey area, formed since about 3000 years to recent days. It has the following origins: Fluvial sediments (aQ_2^3 *tb*) and Fluvio-lacustrine-marshy sediments ($albQ_2^3$ *tb*).

The central area of Hanoi and the surrounding districts have rapid urbanization, in addition to the pressure of infrastructure on the land surface, the population increase also

makes the underground water extraction for domestic service is one of the main causes of land subsidence seriously in recent years.

3. Data and methodology

3.1. Data

SAR Data

In this study, the Terrasar-X images are used with the support of "Hanoi subsidence project", ĐTĐL.2012-T/28, including 23 images acquired from 2012 to2015 for Hanoi city. Data collection is shown in Table 1.

Table 1. Terrasar-X images collection

No.	Date (day/month/year)	No.	Date (day/month/year)
1	10/04/2012	13	25/07/2014
2	21/04/2012	14	07/09/2014
3	22/06/2012	15	29/09/2014
4	11/09/2012	16	10/10/2014
5	30/04/2013	17	21/10/2014
6	05/07/2013	18	01/11/2014
7	20/09/2013	19	23/11/2014
8	12/10/2013	20	29/05/2015
9	23/10/2013	21	12/07/2015
10	**25/11/2013**	22	16/09/2015
11	11/06/2014	23	19/10/2015
12	22/06/2014		

Source: From Vietnam National science project DTDL.2012-T/28

Subsidence measurement data (Table 1)

Subsidence value by leveling method is taken from the construction has over a period consistent with the calculation time from radar data and this value measured used from the completion of roof construction.

In the study area, there is CC02 Van Quan construction at the time of storage on March 19, 2013 (Table 2). These values are predicted to subsidence according to the radar image processing timelines, which results in the value of subsidence measurement and timeline (Fig. 2).

Table 2. Building subsidences CC02-Van Quan-Ha Dong

No.	Subsidence (mm)	Measure day (from the completion of roof construction)
1	0.00	19/3/2013
2	-2.47	01/10/2013
3	-4.82	19/2/2014
4	-6.46	08/8/2014
5	-7.12	14/11/2014

Source: Collected Data from Contract Number: 280/2010/HDTV (04/10/2010) cooperate Housing and Urban Development Corporation with HUD-CIC construction

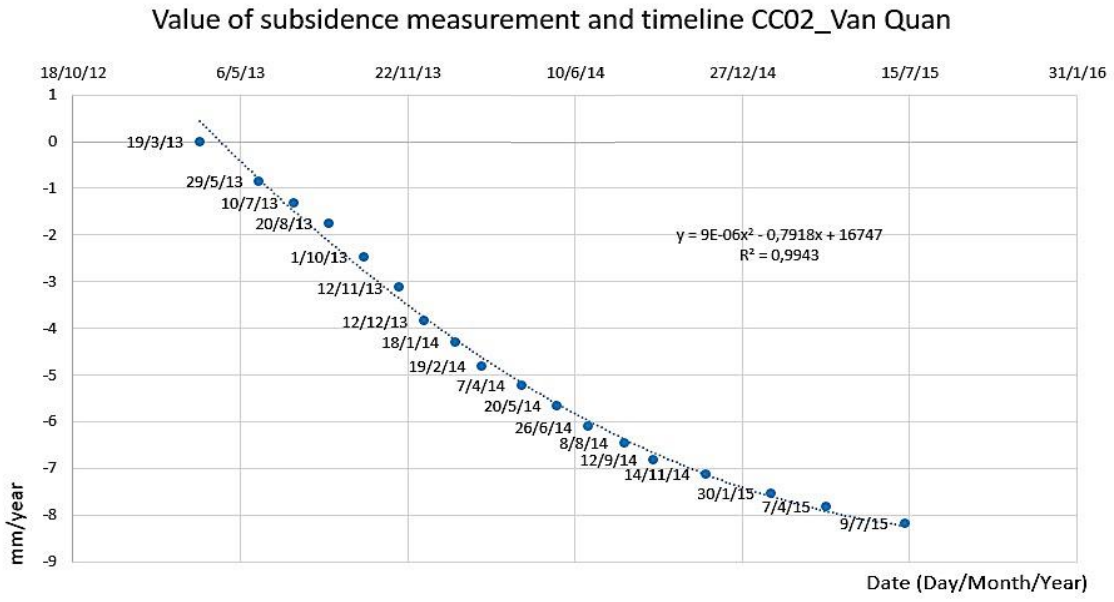


Figure 2. Value of subsidence measurement and timeline CC02-Van Quan

3.2. Methodology

3.2.1. Synthetic Aperture Radar Interferometry method

Synthetic Aperture Radar Interferometry can be determined by extracting phase information from pair of interferometry images that allows measure the deformation of terrain surface by formula:

$$\varphi_{interferometry} = \varphi_{topo} + \varphi_{defo} + \varphi_{atm} + \varphi_{noise}$$

In the interferometric phase of the radar image pair, including the terrain phase, the land deformation phase, the atmospheric phase due to the latency of the signal when passing through the atmosphere, other phase noise such as the reduction of geometric correlation or the baseline of the image pairs, correlation decline due to time, thermal noise,...

Phase deformation is calculated by the formula:

$$\varphi_{defo} = \frac{4\,\pi\Delta r}{\lambda}$$

Researching the central area of Hanoi city with Terrasar-X image with a wavelength of 3.1cm is processed through the PSInSAR method. This method works when a set of radar images is large enough. A master SAR image is selected and then all the remaining images are registered under this master image. The process of PSInSAR processing is shown in Fig. 3.

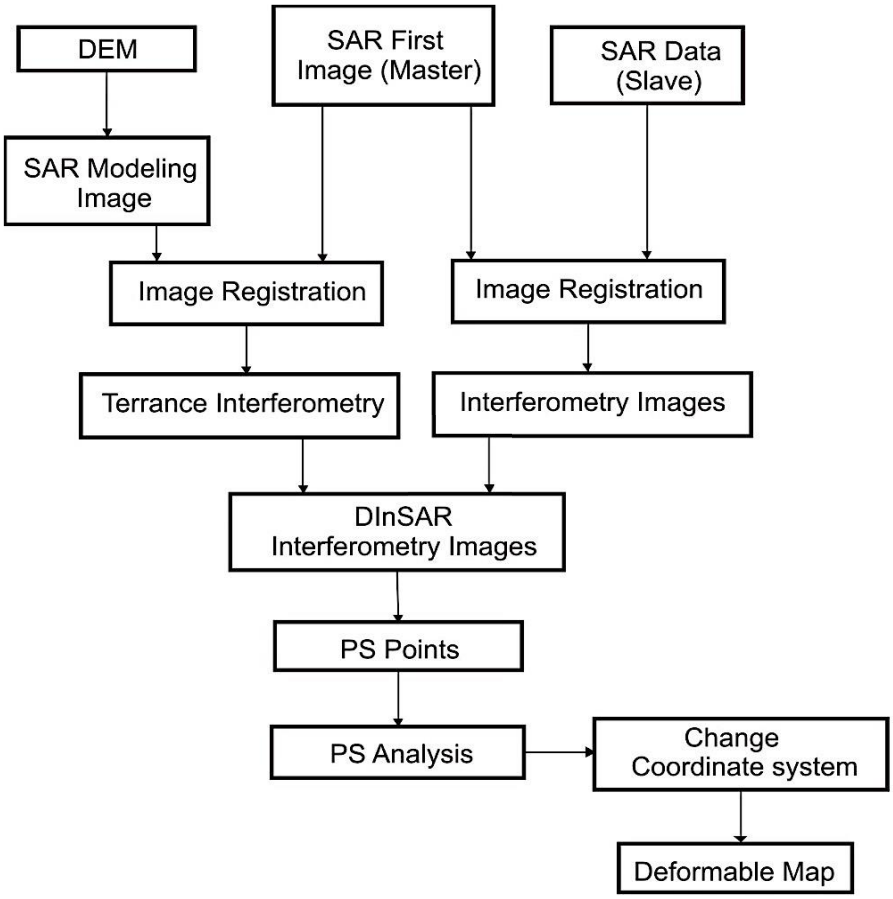


Figure 3. PSInSAR workflow

Image registration includes two steps: preliminary registration with 1-pixel accuracy and accurate registration with approximately 1/8-pixel accuracy. The step with the SLC image is a complex image data consisting of two bands: the band contains amplitude information and the band contains phase information. Preliminary registers use the image amplitude component to eliminate the difference in image registration at a pixel. After registering the image, the two images will be registered in one or two pixels in both horizontal and vertical directions. The result of coregistration showed that the quality of the images is quite high (Fig. 4).

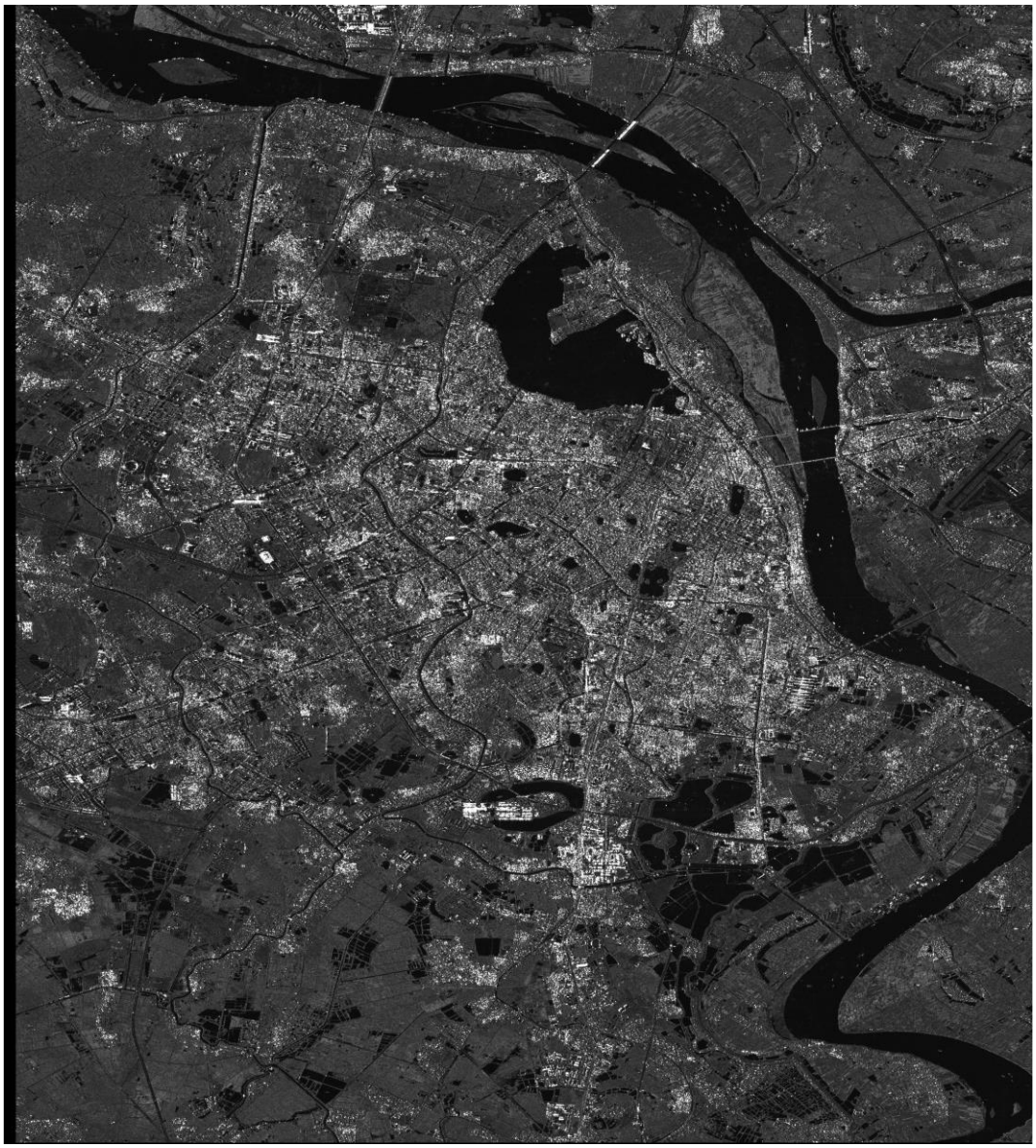


Figure 4. SAR intensity images in the central area of Hanoi

Terrain interferometry: Process execute Master image with simulated SAR image (processed from DEM). Two SAR images incorporate complex interference SAR images

including elevation components and deformed components of objects. Complex interferometry images are created by the multiplication of each complex pixel of the first image with the same complex pixel of the second image. Similarly, the terrain interference processing step of the interferometric image processing step is done by combining the master image with the slave image (Fig. 5). The coherence of images greater than 0.7 in the residential area (Fig. 6, 7).

Process PSInSAR by combining topographic interferogram with the interferometry image file processed above to select PS points, these steps are processed by Sarscape. Figure 8 showed the interferogram of Terrasar-X images in Central of Hanoi.

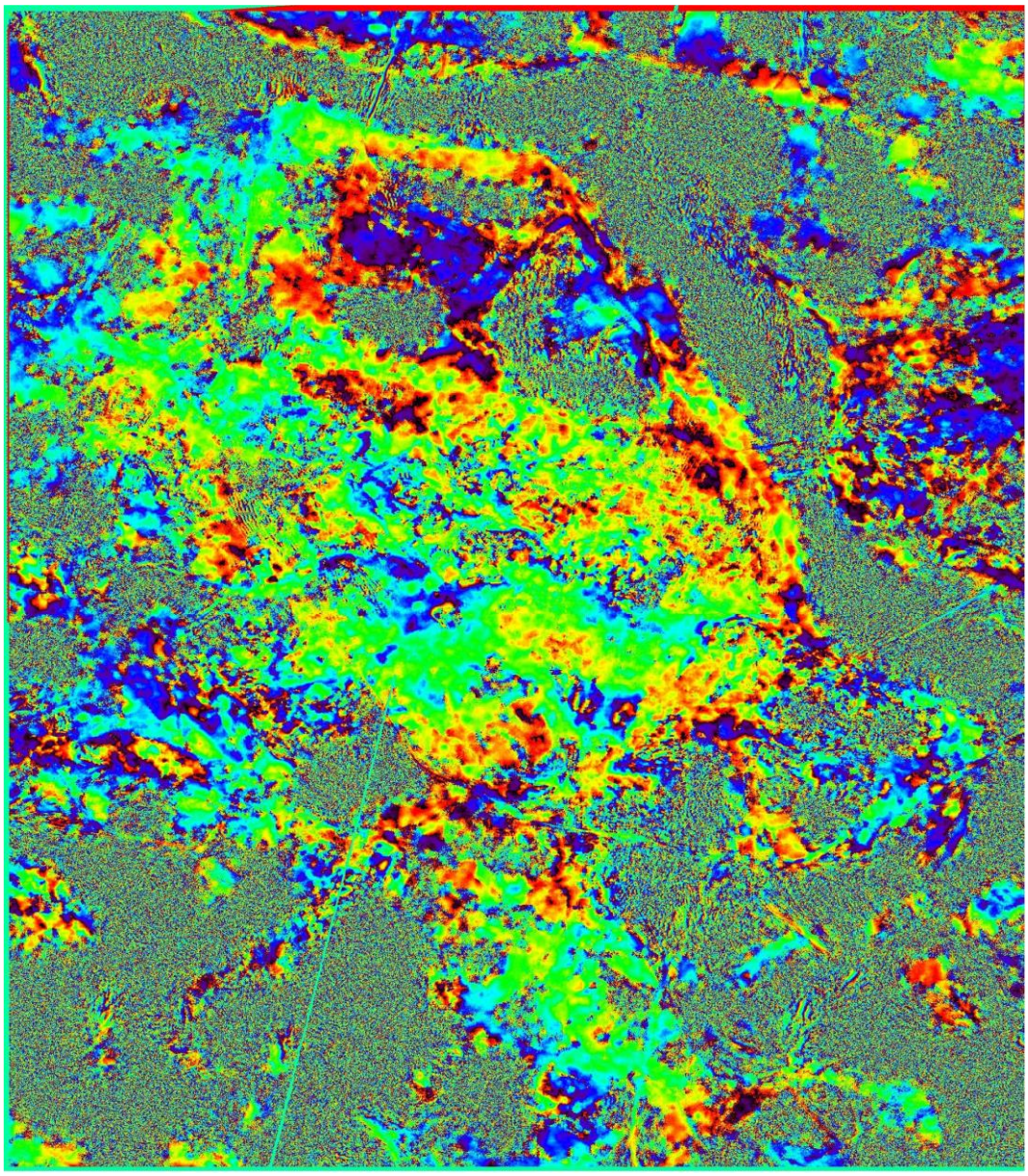
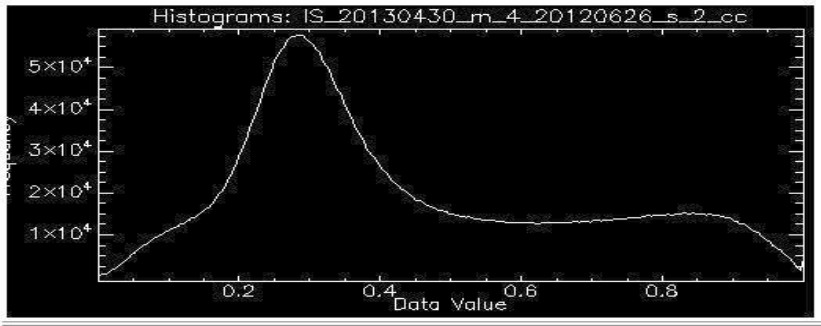


Figure 5. Radar interferometry



Select Stat

Filename: F:\PSTSX_HN2017\Tsx_PS_processing\work\work_interferogram
Dims: Full Scene (5,040,000 points)

Basic Stats	Min	Max	Mean	Stdev
Band 1	0.000012	0.999999	0.437551	0.236561

Histogram	DN	Npts	Total	Percent	Acc Pct
Band 1	0.000012	252	252	0.0051	0.0051
Bin=0.00392	0.003934	330	582	0.0066	0.0117
	0.007855	505	1087	0.0102	0.0219
	0.011777	769	1856	0.0155	0.0373
	0.015698	1092	2948	0.0220	0.0593
	0.019620	1465	4413	0.0295	0.0887
	0.023541	1847	6260	0.0371	0.1259

Figure 6. Histogram of Coherence

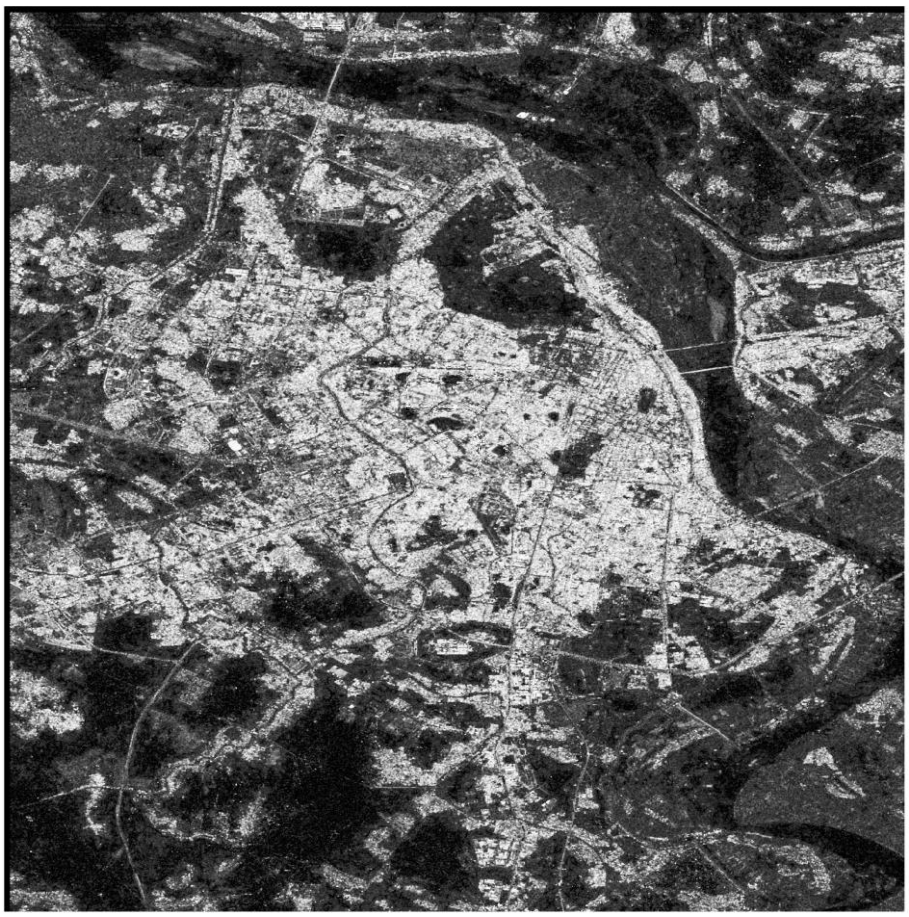


Figure 7. Coherences

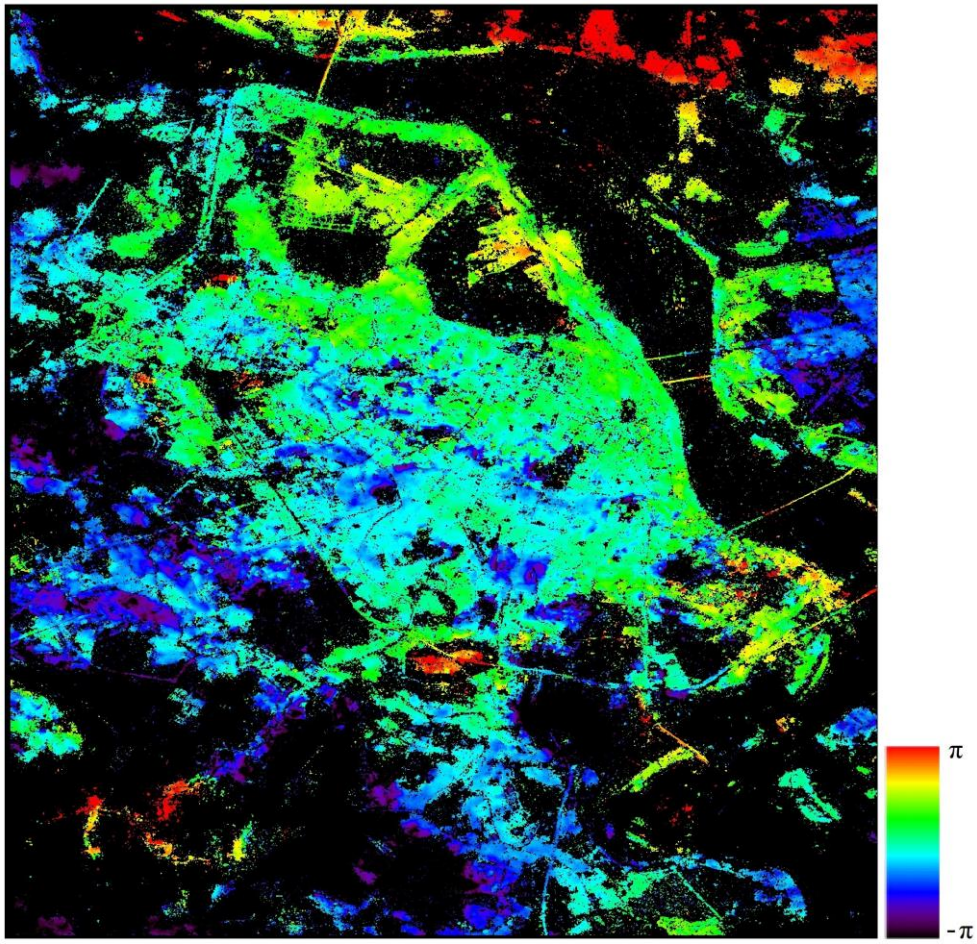


Figure 8. The results of Phase unwrapping

3.2.2. Leveling method

In monitoring, measuring subsidence can use some methods

- Leveling survey method.
- Trigonometrical survey
- Short sighting geometry method.

In the above methods, the leveling survey method is highly accurate, but the measuring device is complicated, bulky and the performance is not high. The trigonometrical survey method has high performance but low accuracy. Compared with the above two methods, the short sighting geometry method has outstanding advantages as follows:

- High accuracy, ensuring an accurate reflection of the subsidence of the project.
- Compact measuring machine, high working efficiency.
- Strict measurement process, ensuring the elimination of systematic errors.

With these advantages, high measuring short sighting geometry method is the main method used in monitoring subsidence currently.

In this study, the data of subsidence measurement is observed through the method of measuring the short-sighted geometry, this method is based on the benchmark and the observation points on the built work, conduct the measurement. subsidence of works with 15 cycles, requires the accuracy of the settlement of Class II, the number of benchmark measurements is 35.

4. Result and Discussions

4.1. Calculation of subsidence by interferometric SAR data in the downtown area of Hanoi

Study subsidence in the central area ofHanoi city with Terrasar-X image data with 3.1cm wavelength by PSInSAR method, the result obtained 817,414 PS points for the value of average subsidence speed in the period of 2013 to 2015. Notably, the area has subsidence less than -10mm per year with a large area mainly in Ha Dong and Hoang Mai districts and some small subsidence areas in the central districts of Hanoi (Fig. 9).

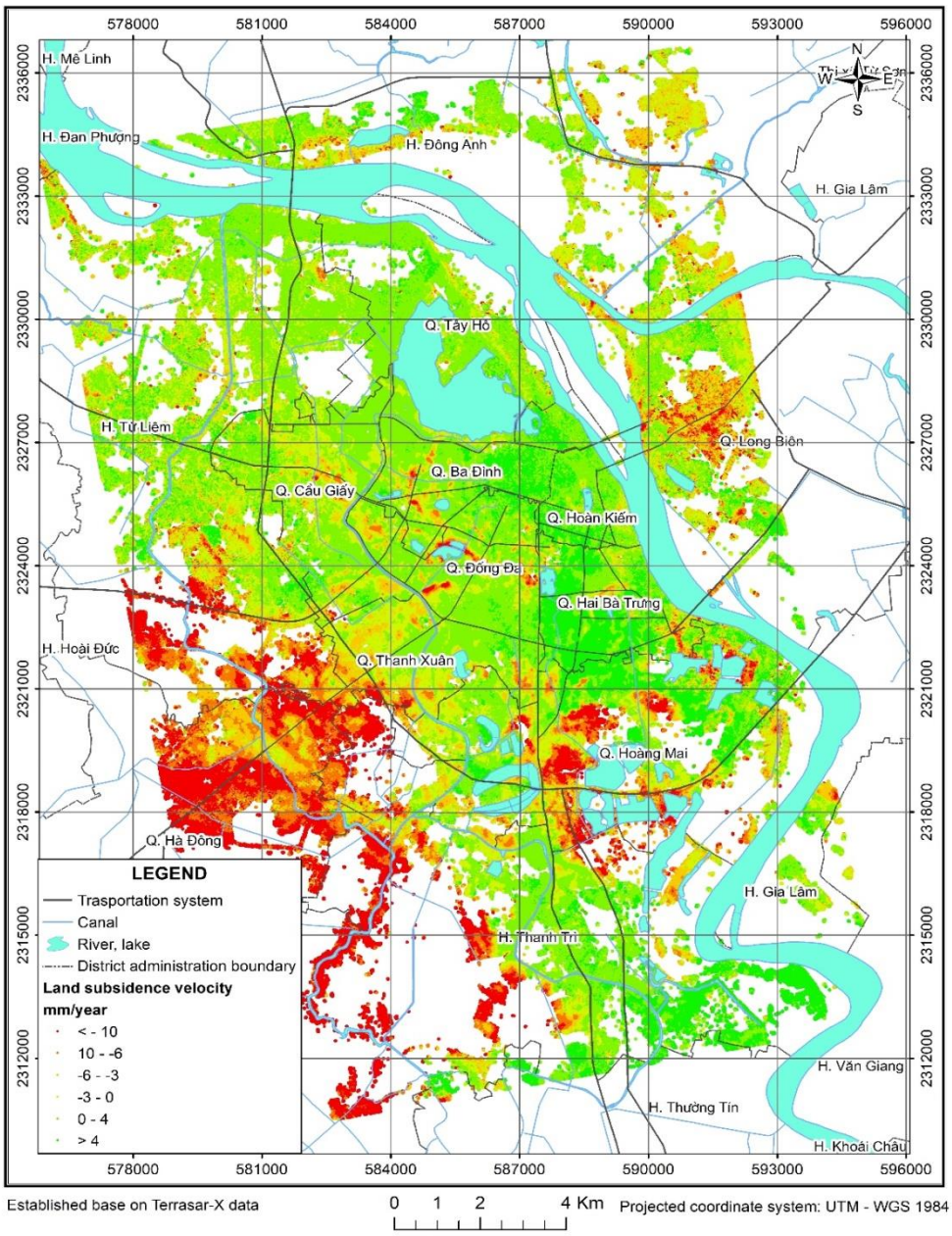


Figure 9. Land subsidence map in the Central are of Hanoi from 2012–2015

As in previous studies, this study shows places which have a high velocity of subsidence.

Ha Dong district area: This is the area which is the largest subsidence and subsidence area in the study area. The area with subsidence velocity is less than -10mm / year and from -6 to -10mm / year accounts for most of the area (Fig. 10).

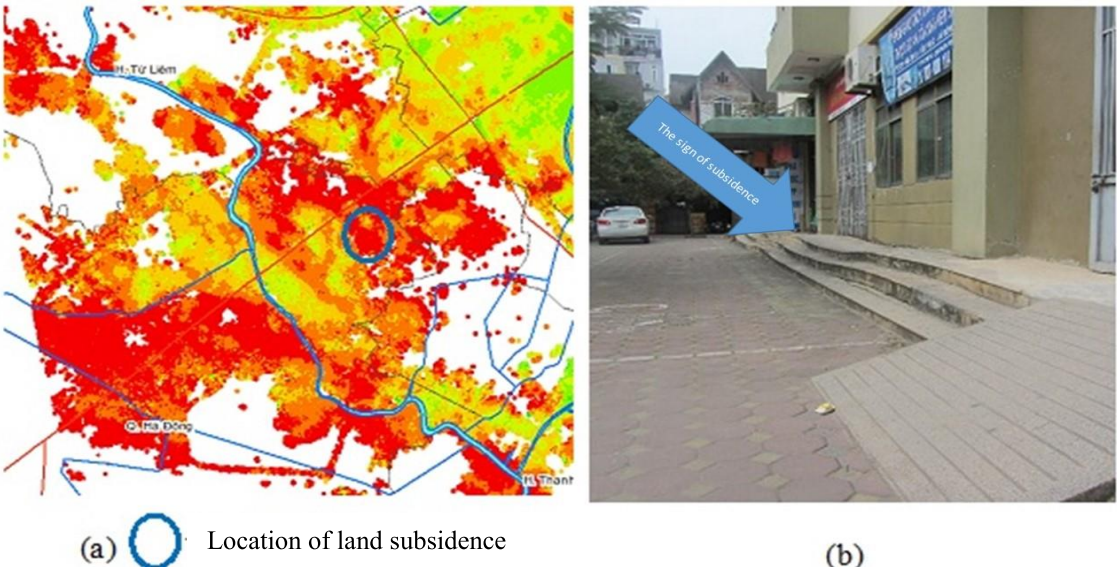


Figure 10. (a) Current situation land subsidence in Ha Dong District; (b) House subsidence in Van Quan-Ha Dong

Hoang Mai District area subsides on residential areas, high buildings in Thinh Liet Ward, Phap Van area, averaging in this area less than -10mm/year (Fig. 11). The appearance of tilting the subsidence of buildings is serious (Fig. 12).

Figure 11. Current situation land subsidence in Dong Tau urban area and X2A resettlement area in Hoang Mai District

Figure 12. (a) Subsidence in Dong Tau urban area; (b) Subsidence in X2A resettlement area

Some strong subsidence areas with small acreage such as Hoang Cau area, Dong Da district, some areas of Hai Ba Trung district, Ngoc Lam ward area, Bo De ward of Long Bien district.

Besides, with a larger area of research than other studies, this study has discovered new areas with large subsidence rates in the region such as Vinh Tuy Ward's area, Thanh Tri ward of Hoang Mai district (Fig. 13).

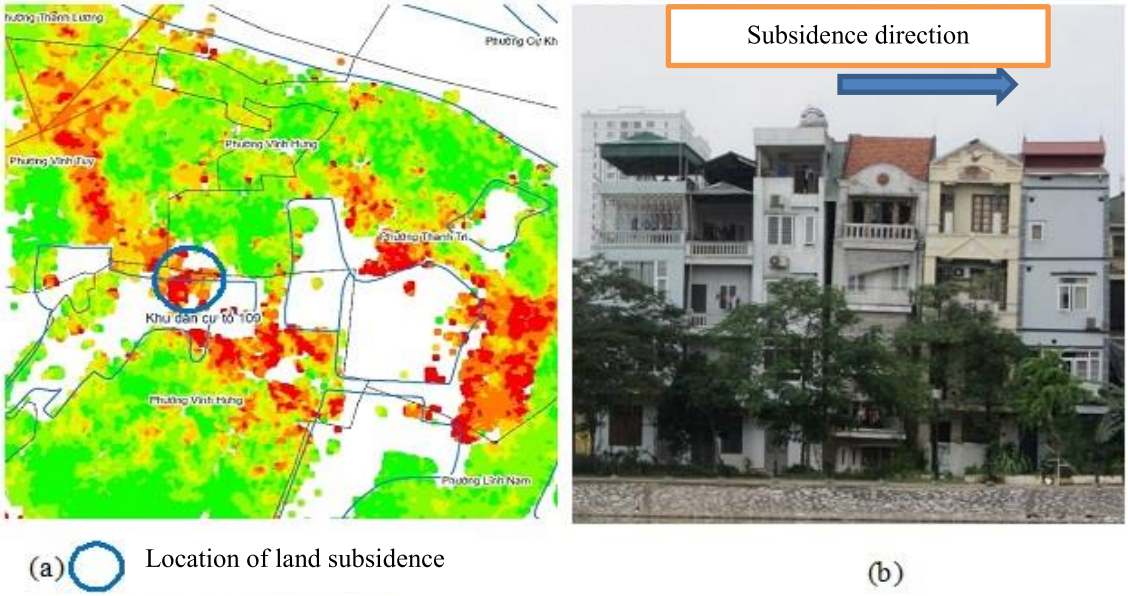


Figure 13. (a) Current situation land subsidence in Vinh Hung Ward, Thanh Tri ward, Hoang Mai District; (b) Land subsidence at Residential area 109

The survey results of this subsidence area show that the area is seriously subsiding, some houses are in the serious state that people have to move (Fig. 14).

Figure 14. Serious subsidence threatens people's lives in Vinh Hung Ward, Thanh Tri ward, Hoang Mai District

The field survey of the two areas shows that with the post-compacted pile foundations, the entire ground surface around the house is subsided causing serious distortion of the house steps, the ground surface around this building is significantly reduced by the time,

Beside of two large subsidence areas, Vinh Hung ward and Thanh Tri ward's area in Hoang Mai district also has subsidence with a settlement rate greater than -10mm / year. Strong land subsidence in this area focuses on construction located in the former ground of ponds and rice fields. All buildings in the raft foundation area are enormously tilted (Fig. 15, 16).

Figure 15. Subsidence between House number 130 and 131 in Vinh Hung Ward, Hoang Mai District: (a) Separation in horizontal direction, (b) deviation in depth of the houses

Figure 16. Inclined House in Vinh Hung Ward, Hoang Mai District (House number 130)

4.2. Correlation between interferometric SAR subsidence and surveying subsidence from building

In addition to finding more serious subsidence areas, this study has calculated the correlation between the results of the InSAR technique and the results of measuring subsidence by Subsidence measurement that there have been no studies done before.

Correlation is calculated between two series of radial subsidence calculation data and the subsidence of the building with a timeline calculated from the time of the building was finished construction roof (Fig. 17). This is to ensure the observation period subsidence still ensures construction when interferometric radar processing does not lose correlation.

Figure 17. Location map of PSInSAR points belonging to CC02-Van Quan project

In this study, we calculated the correlation between interferometric radar subsidence and the settlement of the construction carried out with CC02 Van Quan construction located in the subsidence area. This is a project in the study area which has subsidence measurement data and a subsidence value from the InSAR method (Fig. 18).

The correlation between of the subsidence by InSAR and subsidence of CC02 Van Quan building in the period from April 30, 2013, to October 19, 2015, shows that the value of settlement from InSAR method to the value of construction subsidence has a correlation coefficient R2 = 0.94 (Fig. 19).

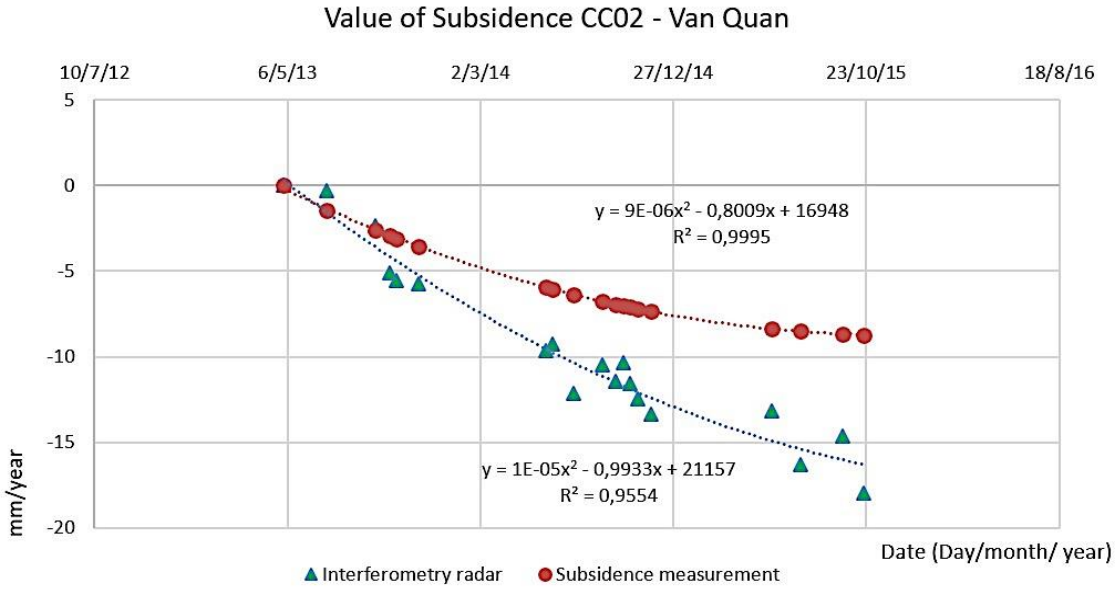


Figure 18. The correlation between interferometric radar subsidence and the settlement of the construction carried out with CC02 Van Quan

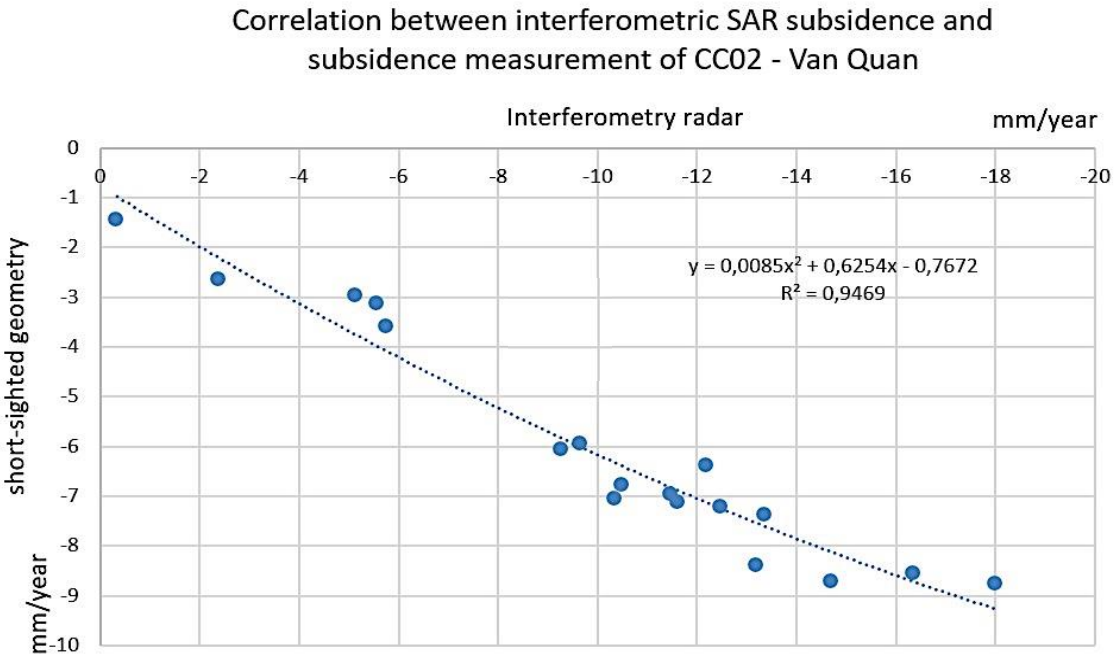


Figure 19. The result of the correlation between the results of calculation of subsidence by InSAR and subsidence of CC02 Van Quan building

Evaluate the correlation between the subsidence value of the PSInSAR method and the value of the subsidence measured from building survey has a high correlation coefficient. However, the series of subsidence values of the two methods are not

approximated, the subsidence value from the calculation of the PSInSAR is greater than the value of subsidence measurement cause of noise factors and atmospheric environment preventing the phase signal reception that makes interferometric phase receive not only topographic phase also phase delay when transmitting signals.

In order to study ground deformation from InSAR method with high precision results need to eliminate phase caused by noise sources and atmosphere. However, it is initially shown that the settlement calculation from the PSInSAR method allows determining the area of subsidence in time with reliable and fast results compared to other methods.

5. Conclusions

SAR data with the X-band and PSInSAR allows the study of terrain deformation in a tropical climate country like Vietnam. The results of research from the X-band radar data allows an analysis of average annual subsidence rate quickly, determination of the distribution of subsidence points and area of subsidence provides us a useful data source serves to monitor and predict the subsidence of the land surface.

Land subsidence calculation results for the period of 2012-2015 with Terrasar-X image data in the center of Hanoi City has described exactly the area that has average annual subsidence velocity less than -10 mm/year in Hoang Mai Dist., Ha Dong District.

In addition to areas of subsidence similar to previous studies, the study found some areas with large subsidence such as subsidence in Vinh Tuy Ward's area, Thanh Tri ward of Hoang Mai district. Correlation between the calculated subsidence from Terrasar-X images and the measuring subsidence of CC02 Van Quan Ha Dong located in the area of subsidence with time observation from 03/2013 to 7/2015 has correlation coefficients R2 of 0.94 which has confirmed the method allows research and development according to the area and time with fast and reliable results. To have a higher accuracy in research results we must research more intensively to eliminate the interferogram from noise phase as well as the influence of the atmosphere when transmitting and receiving the backscatter signal.

Combining the research and development of radar interferometry by some monitoring methods for measuring subsidence in the field will help us track the ground subsidence phenomenon effectively and accurately.

However, for areas of land subsidence, further studies on the causes and factors causing the phenomenon of subsidence will make predictions and remedies to deal with this phenomenon.

Acknowledgments

The authors would like to thank the Vietnam National science project DTDL.2012-T/28 for supplying TerraSAR data. We thank HUD-CIC construction and investment consultants joint stock Company for supplying Subsidence measurement data of CC02 Van Quan construction. And we would like to thank three anonymous reviewers who had substantial contributions to improve the quality of the manuscript.

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