YANGON SURFACE DISPLACEMENT AS DETECTED BY INSAR TIME SERIES ANALYSIS

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ABSTRACT: This paper presents Yangon's surface displacement during the period between April 2012 and April 2014 as detected by InSAR time series analysis. The persistent scatterer InSAR (PSI) is one of InSAR time series analysis technique, and we apply this method to analyze a suite of 15 Radarsat-2 SAR images. The revealed pattern of displacement in line-of-sight direction suggests that the surface motion is caused by non-seismic activities. We then convert the line-of-sight to vertical motion. The vertical displacement rates are between +55 and -74 mm/year. Most areas between Yangon River and Ngamoeyeik creek appear to be stable. Fast uplift of the rates +25 to +30 mm/year are presented in West Yankin area. The true causes of these upward motions are presently unknown. Subsidence is revealed in North Dagon Township on the east side of Ngamoeyeik creek. The area between Dagon University and East Dagon Industrial Zone is heavily subsiding at the rate between -50 and -65 mm/year. The cause of this subsidence is likely groundwater extraction. At present, validation of InSAR result with leveling or other ground-based measurements cannot be made due to the unavailability of data. However, the results demonstrate the potential of InSAR as a space-based geodetic tool for change monitoring.

1. INTRODUCTION

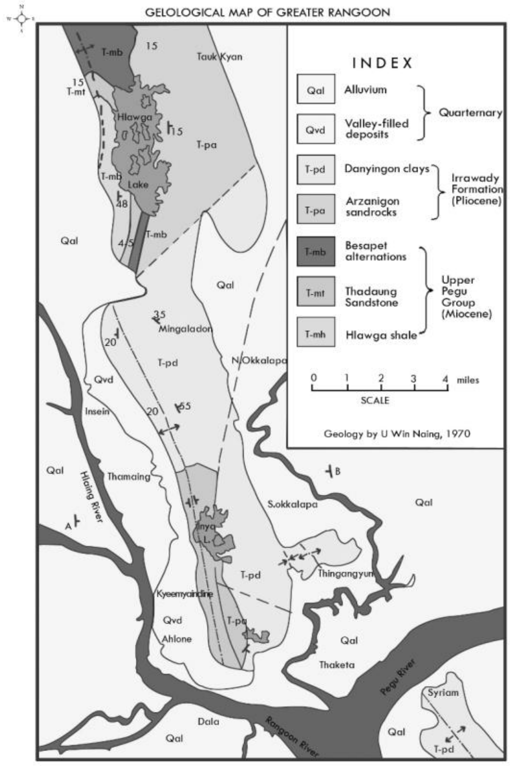
Yangon is the largest, most populated and urbanized city in Myanmar which has an area about 598.75 km^2 in 2008 (Zin, 2006). There are thirty-three townships in Yangon city. Yangon is located in lower Myanmar at the convergence of the Yangon and Bago Rivers about 34 km away from the Gulf of Martaban at latitude 16.80 and longitude 96.15. The population of Yangon, as estimated in 2012 is 4.6 million (Source: Ministry of National Planning and Economic Development). However, some article reports that Yangon has reached its population of about six million people. Thus, the investigation by using InSAR for the potential of surface displacement monitoring in the area is crucial because of the unavailability data based on other ground-based measurement. The review of ground water situation is also important due to the fact that it is the main cause of surface displacement. Nonetheless, the groundwater data in the area is still in the beginning phase of scientific study to inform the public the more information or details about groundwater situation in Yangon.

1.1 Geology of Yangon

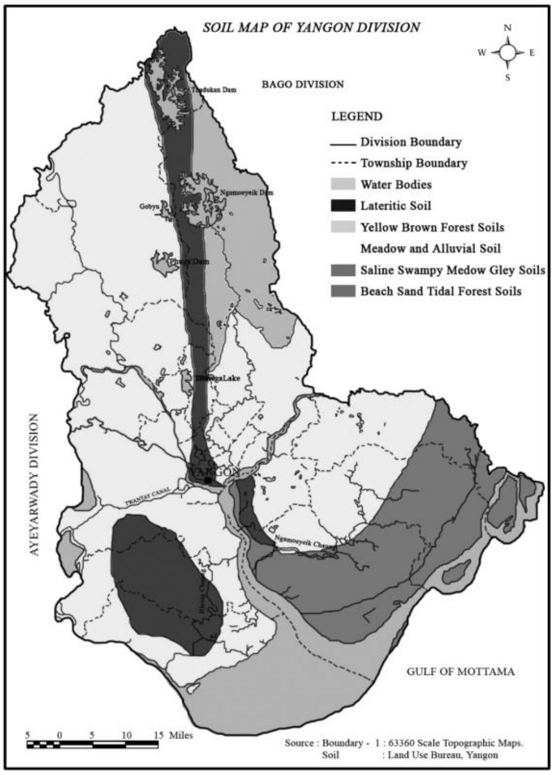
Yangon area is underlain by alluvial deposits, the non-marine fluviatile sediments of Irrawady Formation, and hard, massive sandstone of Pegu Series. The alluvial deposits are composed of gravel, clay, silts, sand and laterite, which lies upon the eroded surface of Irrawady Formation at 4.6 m above mean sea level. The central part of Yangon area is occupied by the anticlinal ridge as a backbone, 30 m above mean sea level and covered with sands, sand rock, soft sandstones, shale, clays, and lateritic of Irrawady Formation. The hard compact sandstone and shale of Pegu series can be found at the northwest corner of Hlawga Lake with NNW–SSE strike dipping to the east (Figure 1a). Alluvial deposits are found in the surrounding areas of the ridge whereas lateritic soils can be found along the ridge (Figure 1b). In the geological map, two anticlines can be seen trending NNW-SSE direction and are cut by NNE-SSW trending transverse fault (Aung, 2011). From the geological point of view, it can be concerned for the initial review of faster displacement possibility in some area such as in the eastern part of the city where the top soil is clays.

1.3 Yangon Groundwater Resources

Exploitation of ground water resource is one of an important issue because it can be a main cause of land subsidence as occurred in many cities around the world. The information from Yangon City Development Committee (YCDC) mentioned that they can supply 160 m gallons of water a day in the city, but many citizens rely on their surface and private tube-wells which are installed to extract groundwater. In the case of controlled operation, the water supplies come from two main sources; reservoir water from Hlawga Gyobu Pugyi and Ngamoeyeik reservoirs and groundwater from YCDC's tube-wells as well as from rainwater, lakes and ponds.



a. Geological map



b. Soil map (Source: Land Use Bureau of Yangon)

Figure 1 Geological and soil map of Yangon (Aung, 2011).

Generally, the extraction of groundwater in the city depends on population growth, residential expansion, and industrial development. Since the supply of piped water by YCDC was not enough, it has accelerated the demand of water resulting in groundwater over extraction. According to this reason, there is a possible crisis in Yangon in the future because the city's population will increase drastically. The private own tube/dug-well is increasing while the ground water controlling policy (Burma Underground Water Act of 1930) (JICA, 2001) is not sufficient at present. However, there has not been reported yet about land subsidence caused by groundwater over extraction. Monitoring of both groundwater use and land subsidence, therefore, needs to be considered.

1.3 Satellite datasets

Radarsat-2 images acquired in ascending orbit in F2N beam-type have been used in this study. The orbital sense is in ascending orbit. The antenna pointing is in the right direction with horizontal transmit and receive polarization (HH), and the incidence angle is 39.92 degrees at image center. Azimuth angle is 315.09 clockwise degrees from true north at image center. The master image is fixed on 04 April 2013 by maximizing the (predicted) total coherence of the interferometric stack, and optimizing of the perpendicular baseline, the temporal baseline, the mean Doppler centroid frequency difference, and thermal noise (Hooper, 2006). The time series data has been constructed from 09 April 2012 until 23 April 2014 which is 2 years time span totaling fifteen images. Information of the slave images of each pair, including date of acquisition, interval time, and perpendicular baseline ($B_\perp$) with the master image are shown in Table 1 and Figure 2.

Table 1 Parameters of Radarsat-2 SAR images (Path = 1, Row = 1) used for PSI analysis.

Image	Degree	Date	$B_\perp$ (m)	B_{temp} (Days)
1	29.594	09-Apr-2012	284	-360
2	25.167	20-Jun-2012	313	-288
3	24.361	07-Aug-2012	380	-240
4	26.700	24-Sep-2012	-109	-192

Image	Degree	Date	$B_\perp$ (m)	B_{temp} (Days)
5	22.477	11-Nov-2012	57	-144
6	21.781	29-Dec-2012	-88	-96
7	20.178	15-Feb-2013	-112	-48
8	22.046	11-Mar-2013	-64	-24
Master Image	29.989	04-Apr-2013	0	0
10	26.225	22-May-2013	177	49
11	25.726	30-Nov-2013	124	241
12	23.554	17-Jan-2014	45	289
13	26.464	11-Feb-2014	147	314
14	27.349	30-Mar-2014	46	361
15	29.638	23-Apr-2014	95	385

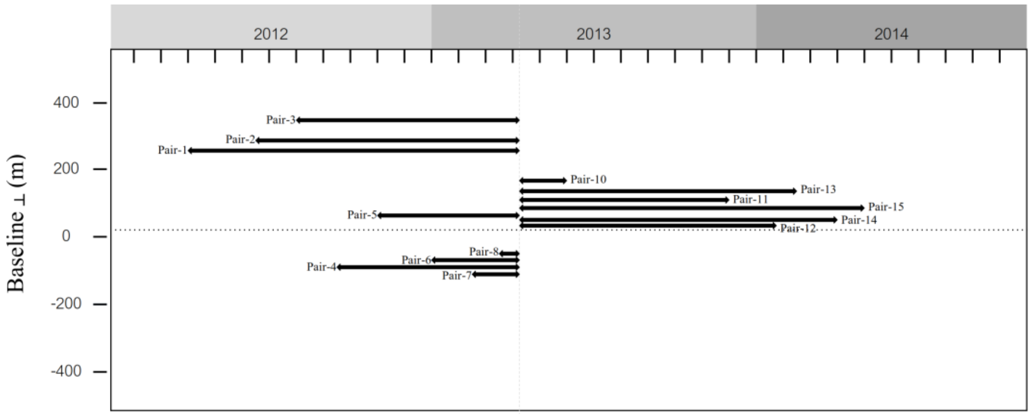


Figure 2 Image pairs used for PSI analysis in this study. All images are acquired by satellite Radarsat-2 in the descending orbit Path = 1, Row = 1. Cross axle: acquisition time; vertical axle and the number in parentheses: perpendicular baseline ($B_\perp$) in meter. Considering the baseline condition and time span, the master image is fixed on 04 April 2013. The maximum perpendicular baseline is 380 m of pair-3.

2. METHODOLOGY

The first algorithms of PSI technique were developed by Ferretti et al. (2000) and (2001). Similar processing strategies have been developed by Crosetto et al. (2003), Lyons et al. (2003), Werner et al. (2003) and Kampes (2005). These methods have been very successful for InSAR analysis of radar scenes containing large numbers of man-made structures. One of the limitations of these methods is the PS selection strategy, which relies heavily on amplitude variation to detect a stable network. These algorithms may fail to detect PS when the number of images is limited or when the PS has low amplitude. Hooper et al., (2004, 2007) overcomes this limitation by using both amplitude and phase analysis to determine the PS probability for individual pixels. This method does not require any a priori assumptions about the temporal nature of the deformation for PS selection. This is achieved by using the spatially correlated nature of deformation rather than requiring a known temporal dependence. Thus, it can provide reliable deformation measurements even when applied to mountainous areas (Hooper, 2006).

Stanford Method for Persistent Scatterers (StaMPS) is a software package that implements PSI method, and it is developed by Hooper et al., (2004, 2007). Through the years this software was further developed at the University of Iceland, Delft University of Technology and currently University of Leeds. StaMPS use the interferograms as computed using DORIS. All the software is open source and free for non-commercial applications. The main processes include: Raw data process, SAR image process, differential interferometry process, PS selecting, intersection of PS and phase extracting, phase unwrapping, DEM error correcting, atmospheric filtering. The SAR image and differential interferometry process were done by DORIS software; all PS processes were done by StaMPS software.

3. RESULTS AND DISCUSSION

The study applies PSI to analyze a suite of 15 Radarsat-2 SAR images. The method can detect 78,420 pixels that can serve as monitoring points (Figure 3).

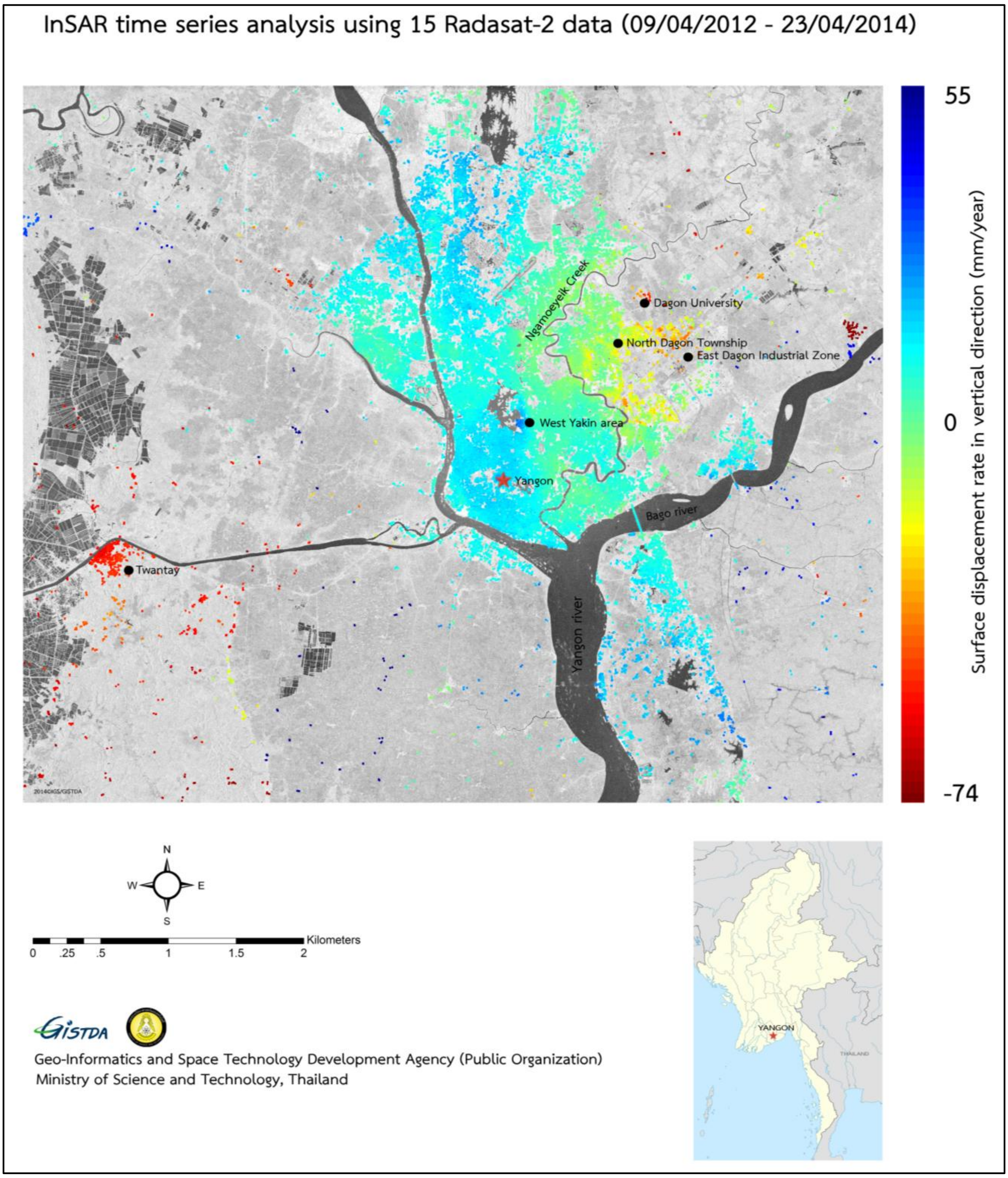


Figure 3 The surface displacement rate of the processed PSI in Yangon area. Rate in positive with cold colors represents land uplift and rate in negative with warm colors represents land subsidence in vertical direction.

The displacement pattern indicates that the observed motion is caused by non-seismic activities. By using the cosine of incidence angle of each pixel, we can convert the line-of-sight to vertical motion. The vertical displacement rates are between +55 and -74 mm/year. Most areas between Yangon River and Ngamoeyeik creek appear to be stable including Yangon city center. In the West Yankin area, InSAR can detect fast uplift of the rates +25 to +30 mm/year, but unfortunately the true causes of these upward motions are presently unknown. Subsidence is revealed in North Dagon Township on the east side of Ngamoeyeik creek. We also found that the area between Dagon University and East Dagon Industrial Zone is heavily subsiding at the rate between -50 and -65 mm/year (Figure 4). The cause of this subsidence is likely groundwater extraction. However, the more details investigation should be considered for future study.

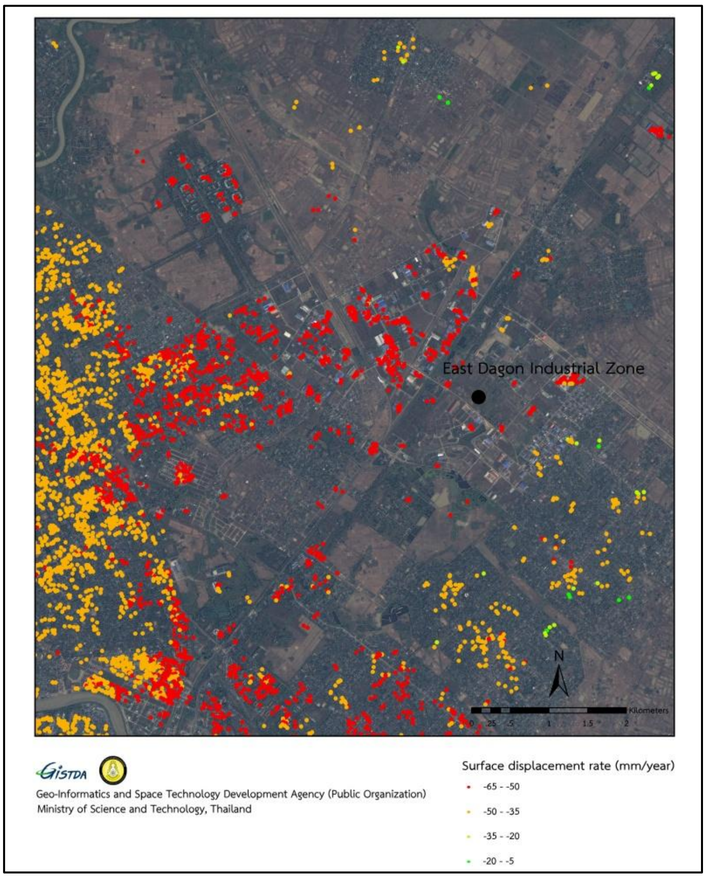


Figure 4 Surface displacement rate and PS distribution at East Dagon Industrial Zone using Thaichote satellite image as a background to visualize.

The average pixel density in the study is approximated 30 PS per km^2 and added in the urbanized zone which can serve as the observation points. We calculate the standard deviation of mean displacement using percentile bootstrap method (Efron and Tibshirani 1986). Most of the estimated displacement rates from InSAR processing have standard deviations around 1.5 mm/year especially in the east side of Yangon River (Figure 5).

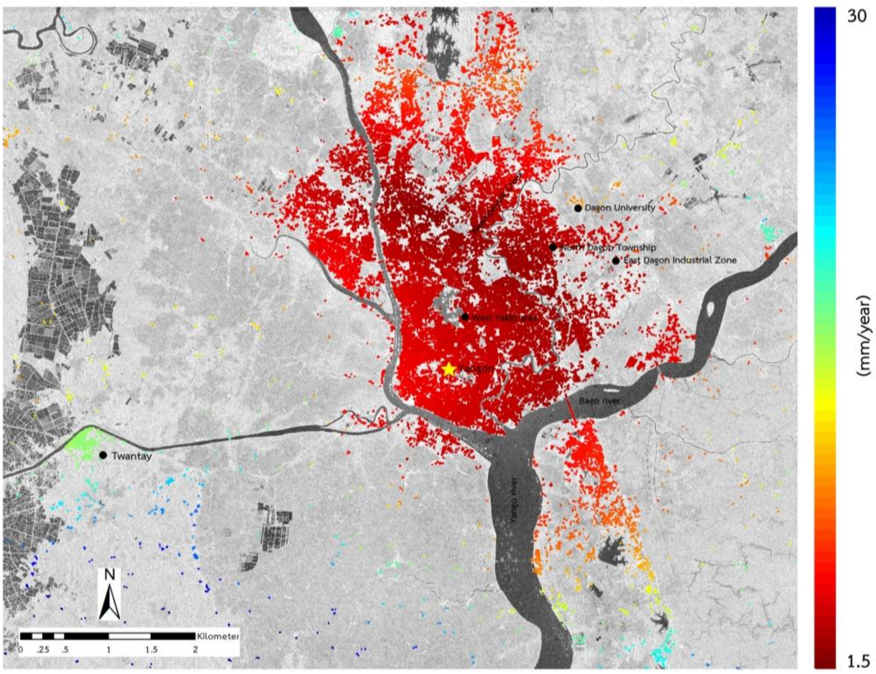


Figure 5 Standard deviations of mean rates.

It can be confirmed that both atmospheric signal and unwrapping errors have a negligible contribution in the rate estimation. However, there are areas in the southwest and Twantay where the standard deviations are up to 30 mm/year. This may be caused by atmospheric artifacts, unwrapping errors, or real deviations of the subsidence in these areas from linear behavior. The rates obtained for these areas should be considered and carefully utilized with concern.

4. CONCLUSION

At present, validation of InSAR result with leveling or other ground-based measurements cannot be made because of the unavailability of data. However, there was great potential for land subsidence to occur in Yangon if too much water was taken from wells, or if groundwater supplies were unable to keep up with demand from a growing population. The geology of the soil under Yangon is ‘alluvium’, which is susceptible to land subsidence. There was no official government body tasked with monitoring land subsidence in Yangon, and no information whether it might have already occurred in some parts of the city. Current groundwater use in the country has not reached critical levels, but the issue should be considered for the future plan. InSAR, a space-based geodetic tool, can be the potential measurement for change monitoring in the area where no other techniques can be applied or in the case of initial phase before accessing to the area for field surveying. The collection of time series data is still important for future monitoring.

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REFERENCES

Aung, H., 2011. Potential Seismicity of Yangon Region (geological Approach). Advances in Geosciences: Solid Earth (SE), 26, 139.

Crosetto, M., Arnaud, A., Duro, J., Biescas, E. and Agudo, M., 2003, Deformation monitoring using remotely sensed radar interferometric data. In Proceedings of the 11th FIG Symposium on Deformation Measurements, Santorini, Italy.

Efron, B. and Tibshirani, R., 1986, Bootstrap methods for standard errors, confidence intervals, and other measures of statistical accuracy. Statistical Science, Vol. 1, No. 1, pp. 54-77.

Ferretti, A., Rocca, F., and Prati, C., 2000, Nonlinear subsidence rate estimation using permanent scatterers in differential SAR Interferometry. IEEE Transactions on Geoscience and Remote Sensing, 38(5): 2202-2212.

Ferretti, A., Prati, C. and Rocca, F., 2001, Permanent scatterers in SAR interferometry. IEEE Transactions on Geosciences and Remote Sensing, 39(1): 8-20.

Hooper, A., Segall, P. and Zebker, H., 2007, Persistent scatterer interferometric synthetic aperture radar for crustal deformation analysis, with application to Volcáno Alcedo, Galapagos. Journal of Geophysical Research, 112(B07407), doi:10.1029/2006JB004763.

Hooper, A., 2006, Persistent Scaterrer Radar Interferometry for Crustal Deformation Studies and Modeling of Volcanic Deformation. PhD thesis, Stanford University, 3219289, 124p.

Hooper, A., Zebker, H., Segall, P., and Kampes, B., 2004, A new method for measuring deformation on volcanoes and other natural terrains using InSAR persistent scatterer. Geophysical Research Letters, 31(L23611).

JICA (Japan International Corporation Agency), 2001-2002, “The Study on Improvement of water supply System in Yangon City in The Union of Myanmar”, Final Report.

Kampes, B.M., 2005, Displacement Parameter Estimation Using Permanent Scatterer Interferometry. PhD thesis, Delft University of Technology, The Netherlands.

Lyons, S., and Sandwell, D., 2003, Fault creep along the southern San Andreas from interferometric synthetic aperture radar, permanent scatterers, and stacking. Journal of Geophysical Research, 108(B1): 2047-2070.

Werner, C., Wegmuller, U., Strozzi, T. and Wiesmann, A., 2003, Interferometric point target analysis for deformation mapping. In Proceedings of the International Geoscience and Remote Sensing Symposium (IGARSS), 21-25 July 2003, Toulouse, France.

Zin, N.M., 2006, Frauke Krass, Hartmut Gaese, Mi Mi Kyi, ed. Megacity yangon: transformation processes and modern developments. Berlin: Lit Verlag. p. 264. ISBN 3-8258-0042-3.