JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
ISSN: 2339-076X (p); 2502-2458 (e), Volume 8, Number 2 (January 2021): 2587-2593
DOI:10.15243/jdmlm.2021.082.2587

Research Article

Utilization of Sentinel-1 satellite imagery data to support land subsidence analysis in DKI Jakarta, Indonesia

Mohammad Ardha[1*], Argo Galih Suhadha[1], Atriyon Julzarika[1], Fajar Yulianto[1], Dipo Yudhatama[1], Rofifatuz Zulfa Darwista[2]

[1] Remote Sensing Application Center, Indonesian National Institute of Aeronautics and Space, Indonesia
[2] Geodesy and Geomatics Engineering Study Program / Institute Technology of Bandung, Indonesia

[*]corresponding author: mohammad.ardha@lapan.go.id

Received 11 November 2020, Accepted 7 December 2020

Abstract: Land subsidence had been a significant problem in DKI Jakarta and Semarang, with at least 20 kilometres of roads affected. Repairing them will require at least US $ 1 million per kilometre. Land subsidence monitoring has been carried out using terrestrial methods (GPS and levelling), which are believed to have a high degree of accuracy. The high accuracy of the terrestrial method results in a lack of precision over a large area. On the other hand, remote sensing technology as a non-terrestrial method has developed to monitor land subsidence which can produce high precision over a large area. This study aimed to test the Sentinel-1 satellite data using the Differential Interferometric Synthetic Aperture Radar (DInSAR) method in monitoring land subsidence in DKI Jakarta. DInSAR is a method in Remote Sensing that utilizes radar sensors to analyze the phase differences of a SAR data pair that have different times of capture and have been catalogued to obtain displacement along the area of collection. The results showed that the North Jakarta area experienced the highest land subsidence in the entire Jakarta area. The annual average rate from 2017-2019 is 3.4 cm. The value of 3.4 cm is the average value of all samples in the North Jakarta area. The second area where high land subsidence is West Jakarta, where the maximum amount value of subsidence is 2.8 cm. The accuracy-test results with the MONAS test point showed that the difference between field data and DInSAR results was ± 6.5 cm. The results of this research indicate that the DInSAR method is quite capable of describing land subsidence in the DKI Jakarta area with a relatively good level of precision.

Keywords: *DInSAR, Jakarta, land subsidence, remote sensing, Sentinel-1*

To cite this article: Ardha, M., Suhadha, A.G., Julzarika, A., Yulianto, F., Yudhatama, D. and Darwista, R.Z. 2021. Utilization of Sentinel-1 satellite imagery data to support land subsidence analysis in DKI Jakarta, Indonesia. J. Degrade. Min. Land Manage. 8(2): 2587-2593, DOI: 10.15243/jdmlm. 2021.082.2587.

Introduction

Land subsidence has been one of the main problems in urban Indonesia in recent years. In Jakarta and Semarang, there are at least more than 20 kilometres of roads are affected by land subsidence (Abidin et al., 2011). Land subsidence has resulted in cracks in housing, buildings, roads, the sinking of bridges and dams, drainage problems, etc. As a result of land subsidence, it will cost at least US $ 1 million to upgrade the bridge and repair damaged roads every 10 kilometres (Andreas et al., 2017). Land subsidence can occur due to several reasons, both natural and non-natural. Natural subsidence can be caused by geological factors such as volcanic activity, tectonics, geological cycles, etc. Meanwhile, non-natural aspects can occur due to human intervention because of the withdrawal of liquid from the ground (such as groundwater and oil), the extraction of solids from the ground (such as mining), and heavy loads on lands (such as building structures and settlements (Whittaker and Reddish, 1989). Land subsidence that is allowed to occur will cause inundation and tidal flooding in the lowlands, reduce groundwater in an area, and the most extreme impact is the damage of buildings on the land (Marfai and King, 2008).

The high population movement rate from cities to villages has resulted in rapid population growth (Harahap, 2013). DKI Jakarta, as the capital city of Indonesia, has problems related to population. The population in Jakarta is around 10 million people, causing residents to need settlements to live in, which causes rapid settlement growth. One of the impacts of this rapid settlement growth is groundwater, which causes a decrease in the DKI Jakarta area's groundwater level.

The landform condition in DKI Jakarta is structured by alluvial landforms in the Jakarta area, especially in the northern part (Cyntia and Pudja, 2018). The alluvial landform is characterized by the presence of soil sediment carried from the upstream river in the area above it, to be precise, in the upper Ciliwung River with the characteristic of the existing landform volcanic fan. The alluvial landform condition is characterized by its youthful soil characteristics and is prone to collapse due to soil conditions (Cyntia and Pudja, 2018).

Based on the explanation above, research related to land subsidence in Jakarta is needed. Some of the activities carried out to examine the subsidence of groundwater levels are by using the levelling method (Marfai and King, 2008), the microgravity method, and the global positioning system (GPS) (Abidin et al., 2013). Several studies have several constraints, namely the level of data precision in a large area. As one of the most developed sciences, Remote Sensing can be used as an alternative to obtaining information about the subsidence of groundwater levels (Fárová et al., 2019). Several methods can be used to monitor groundwater fall, including Persistent Scatter Interferometry (Ferretti et al., 2011), Small Baseline Subset (SBAS) method (Chang et al., 2010). The DInSAR method can obtain information related to groundwater table subsidence quickly and accurately (Strozzi et al., 2001). The DInSAR method is used to see changes in the existing baseline in SAR data so that phase differences can later be reduced to displacement.

Sentinel-1 Single Look Complex (SLC) is one type of data in the Sentinel-1 satellite used in the DInSAR method. The SLC data from Sentinel-1 is used to make interferometry, which can then be performed for vertical deformation analysis using the DInSAR method (Fárová et al., 2019). In simple terms, DInSAR is a remote sensing technique that utilizes radar sensors to analyze the phase difference of a SAR data pair with different taking times that have been catalogued to obtain displacement along the line of sight (LOS) (Liu et al., 2015)

This paper focuses on using SAR data using the DInSAR method for land subsidence in Jakarta. A study that examined this method has been carried out by (Abidin et al., 2013). They reported that during the period of 1974-2010 Jakarta experienced land subsidence by 3-10 cm. The availability of Sentinel-1 data in the Jakarta area with a long temporal can be used for deformation to no small extent, so the vertical deformation analysis method using the DInSAR method is used.

The purpose of this study was to gather information on the lowering of groundwater levels in Jakarta using the DInSAR method and the results of the RMSE accuracy test against other secondary data so that the RMSE value was obtained. This study is expected to provide solutions for vertical deformation values based on the DInSAR method with Sentinel-1 imagery in Jakarta with a large area.

Materials and Methods

Description of the study area

The study area is in the province of DKI Jakarta which is located at 5°19′12″ - 6°23′54″ S and 106°22′42″ - 106°58′18 E (Figure 1). Geologically, the study area is in a basin area with sequential rock arrangements from young to old composed of alluvium, alluvium fan, coastal embankment deposits, Banten Tuff to the Serpong Formation (Listyono et al., 2016).

This study activity used a pair of Sentinel 1 data, namely, on August 21, 2017, and August 19, 2019, a 2-year time span was taken to see changes with a greater time span for data coverage. Other data used were observation data on groundwater monitoring test points and water basin subsidence land (MONAS) obtained from Geodetic GPS measurements by the Geological Agency. Flow chart of the study is presented in Figure 2.

Data processing and analysis

Before using Sentinel 1 Image must be corrected first if we want to use, for example, to land-use classification, vegetation monitoring, disaster events, and others. Corigestering data on Sentinel 1. The purpose of corigestering is to make the two SLC data into one by stacking and resampling using SLC reference data (Syahreza et al., 2018). After the corigestering stage is complete, the next step is enhanced spectral diversity to correct the residual errors that remain in the coregistration correction process and meet the requirements for TOPS progress (Qin et al., 2018).

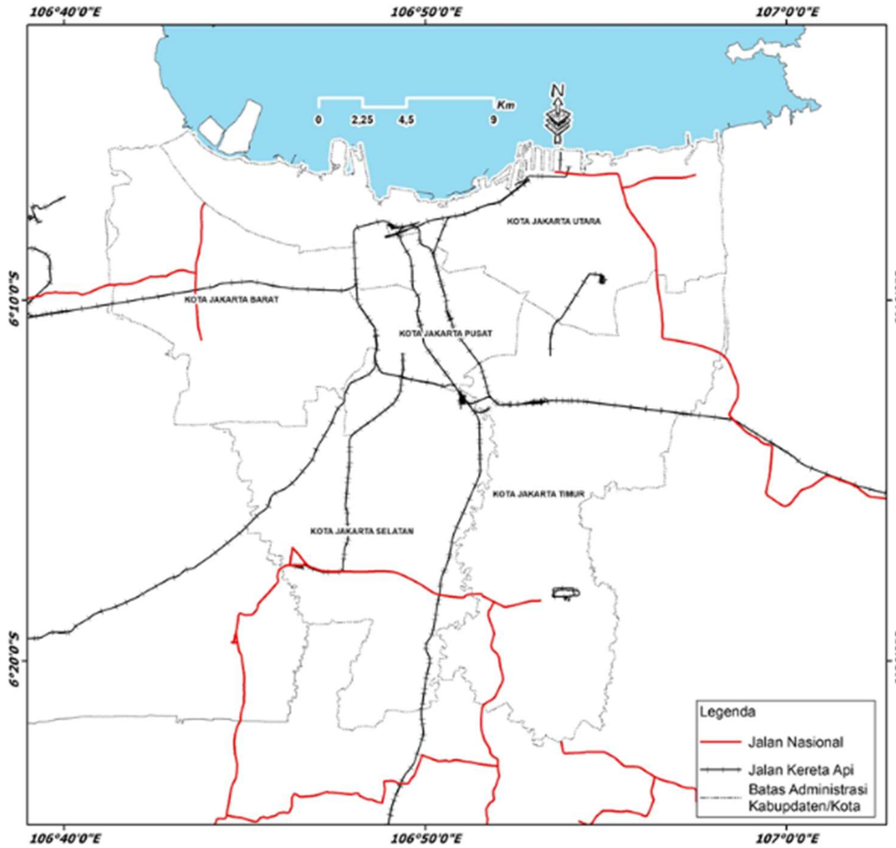

Figure 1. Study area in Jakarta (Source: Administration Boundary, BIG).

These two processes are the stages that are carried out in the coregistering process, which is required at the beginning of processing. When the coregistration step is complete, the next step is to use the interferogram. The Interferogram stage is used to eliminate phases on a flat earth surface with no height or topographic surface (Ai et al., 2008). After the interferogram processing results, there are still some disturbances or noise that need to be eliminated. Several steps are useful for removing noise, namely topography phase removal, which is helpful in eliminating phase information that experiences noise in the area by generating an interferogram from two pairs of SLC data. The next stage was to carry out the TOPS Deburst stage, which aims to eliminate the seamlines between bursts on Sentinel 1 data, so the results are smoother and cleaner as has been done by (Tzouvaras et al., 2020), where his research conducted TOPS Deburst on coherence product results. Then the filtering phase process with the Goldstein method, which aims to improve the accuracy of phase unwrapping. The Goldstein method is widely used because it is a fast process and refines the intensity of the Fourier transform, which overlaps with the interferogram patch (Song et al., 2015). The last stage was phase unwrapping, which aims to eliminate the ambiguity value of the phase. And the last processing of SAR data was a phase to displacement, which aims to obtain information on the Los Displacement. The value of this Los displacement was changed to vertical displacement with the formula applied to the Los Displacement value. The verification of displacement detection from DInSAR has used field measurement points from the MONAS geodetic GPS (23 points) with displacement values per year and the SHP for the administrative boundaries of DKI Jakarta Province. The verification test calculated the Root Mean Square Error (RMSE) value, which is a statistical test to determine the relationship between two values using equations. The RMSE value getting closer to zero means that it has good linearity, so away from 0 implies that the two data groups relationship is quite far. In this RMSE calculation, we compared the displacement value processed by the InSAR method on SNAP with the MONAS displacement data measured using GPS. MONAS data were considered to be the correct measurement.

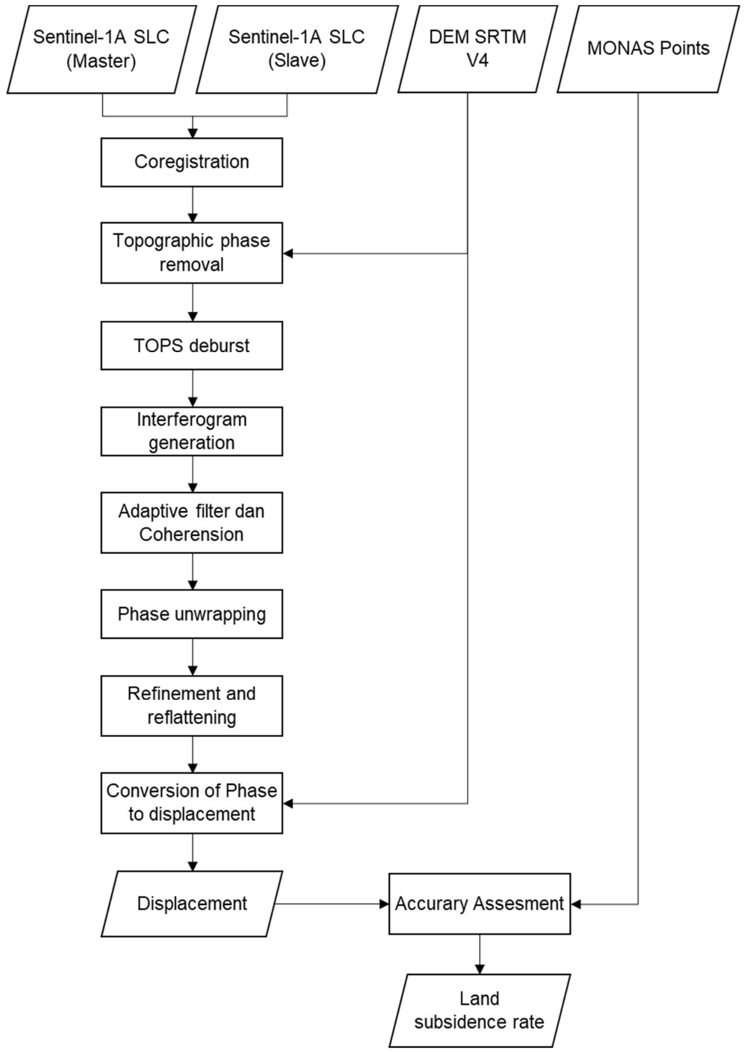

Figure 2. Flow chart of the study.

The number of points tested was 63 points (before clip) and 37 points (after clip).The RSME was calculated using the following equation,

$$\mathrm{RSME} = \sqrt{\frac{\sum_{i=1}^{n}(\mathrm{Pi} - \mathrm{Oi})^2}{n}}$$

where:

P_i = displacement value with diNSAR
O_i = displacement value in MONAS dana
n = sample test

Results and Discussion

The results of this study can be seen in Figure 3. The results of this processing were interpolated so as to produce a pixel size of 15 m in the groundwater level reduction data using 2 pairs of data, namely data for 2017 and data for 2019. Then from the 2-year data, the annual average was taken to be compared with the data from MONAS. The method of collecting point values in DInSAR processed data was obtained using the zonal statical method. This method uses the average value at each point that has been buffered as far as 15 m. the value selection of 15 m is based on the IW mode swept width of 5 x 20. The value of the Zonal Statical Table was taken the average value at each point from the MONAS data. The following Table 1 shows the results of the value of land subsidence in the area in the City of Jakarta.

Based on the average land subsidence value in the municipality of Jakarta, the North Jakarta area has the highest land subsidence in the entire Jakarta area. The average annual rate from 2017-2019 is 3.4 cm. The value of 3.4 cm is the average value of all values in the North Jakarta area. Based on research conducted (Ramadhanis et al., 2017), the area of land subsidence in North Jakarta has a high spatial correlation with built-up land, settlements, and transportation facilities. Apart from North Jakarta, the area that has experienced high land subsidence is West Jakarta. The result from the table that the maximum average value in West Jakarta has a value of 2.8 cm. Based on the map's appearance, it is shown that it is near Soekarno Hatta Airport to lower the groundwater level in West Jakarta. It happens because the area is quite aggressively carrying out development.

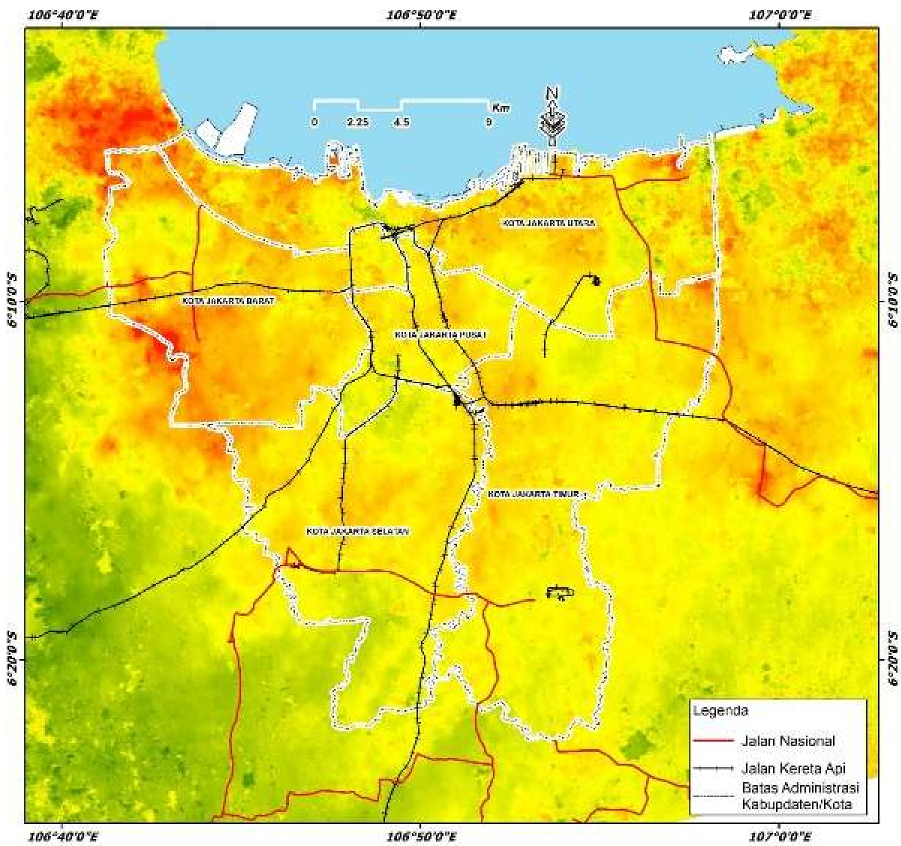

Figure 3. diNSAR result data from 2017-2019.

Table 1. The average value of land subsidence rate in the DKI Jakarta.

City	MAX (m)	MIN (m)	MEAN (m)
West Jakarta	-0.0284142	-0.0041615	-0.0151952
Central Jakarta	-0.0093872	-0.00159568	-0.00389577
South Jakarta	0.00184288	0.016214933	0.0090289
East Jakarta	-0.0138908	-0.0093139	-0.0116630
North Jakarta	-0.0345189	-.006438376	-0.01612811

The results presented in Table 2 show that the areas of North Jakarta and West Jakarta have the most massive land subsidence. Several studies have stated that land subsidence in Jakarta is caused by several factors, including excessive groundwater extraction. A study on the correlation between groundwater extraction and its relationship with land subsidence conducted by Abidin et al. (2010) indicated that from observational data in 2002-2007 there is a correlation between land subsidence and a decrease in groundwater level in Jakarta. In addition to the decrease in groundwater level, land subsidence in Jakarta also occurs due to massive construction in the Jakarta area such as building construction and coastal reclamation which causes land subsidence (Rahman et al., 2018). This is in line with the results of information about research conducted using the dinSAR method. Overall, it can be said that the relationship between lowering the groundwater table and the extraction of groundwater, and development in Jakarta has a significant correlation.

Table 2. The average value of RMSE calculation in DKI Jakarta.

Location	Decrease per year (MONAS data)	Decrease per year (dinSAR)	Decrease Monas – Decrease (dinSAR)
Kemayoran, Jiung (Kem Tower)	-0.04	-0.00469361789	-0.035306382
Ancol, Pademangan	-0.05	-0.01288910986	-0.03711089
Cakung	0.01	-0.00465695071	0.014656951
Marundra, Cilincing	-0.03	0.00363732999	-0.03363733
Kayumanis	-0.11	-0.00694544427	-0.103054556
Pulo Mas, Cempaka Putih	-0.02	0.00079784162	-0.020797842
Jl. Raya Joglo Jakarta Barat	0.02	-0.01301908703	0.033019087
Tongkol, Jl Tongkol No 4 BKAT	-0.03	-0.00555214084	-0.024447859
Nizam Zachman	-0.02	-0.00387489749	-0.016125103
Benda, Husein Sastranegara	0.01	-0.01420711447	0.024207114
Kamal	-0.07	-0.00558955770	-0.064410442
Kali Deres	-0.04	-0.00865894510	-0.031341055
Vittoria Residence	-0.02	-0.00246280021	-0.0175372
Pantai Indah Kapuk	-0.08	-0.01725945715	-0.062740543
Kebon Jeruk	0.02	-0.00515691377	0.025156914
Hotel Ciputra	-0.07	-0.00208077615	-0.067919224
Senayan	-0.06	0.00153460990	-0.06153461
Muara Angke 2	-0.07	-0.00321918819	-0.066780812
Lebak Bulus, Jakarta Selatan	-0.07	0.00810746694	-0.078107467
Bintaro Permai	0.18	0.00092144071	0.179078559
Cibubur, Jakarta Timur	-0.12	0.007082207	-0.127082207
Ceger, Jakarta Timur	0.07	0.004169022	0.065830978
Halim, Jakarta Timur	-0.02	-0.005892137	-0.014107863

Conclusion

The results of this study showed that several areas in DKI Jakarta experienced a decrease in groundwater level, namely North Jakarta by 3.4 cm per year and West Jakarta by 2.8 cm per year. In North Jakarta, the decline in groundwater levels occurs due to the intense development in the North Jakarta area and accompanied by coastal abrasion which causes the land to decline; this also applies in the West Jakarta area where land subsidence occurs due to a large number of housing in the West Jakarta area. The RMSE value is ± 6.5 cm from the test between field data and DInSAR data.

Acknowledgements

This paper is a part of the research activities entitled "Utilization of Sentinel-1 satellite imagery data to support land subsidence analysis in DKI Jakarta, Indonesia". This research was funded by the budget of DIPA LAPAN activities in 2020, Remote Sensing Application Center, Indonesian National Institute of Aeronautics and Space (LAPAN). Thanks go to Dr. M. Rokhis Khomarudin (Director of Remote Sensing Application Center, LAPAN) who has supported the implementation of this research. We also acknowledge to Prof. Dr. Dony Kushardono, M.Eng. who has assisted the author by providing research-related clues, and Jansen Sitorus, M.Si for helping us to provide references for other research.

References

Abidin, H.Z., Andreas, H., Gamal, M., Gumilar, I., Napitupulu, N., Fukuda, Y., Deguchi, T., Maruyama, Y. and Riawan, E. 2010. Land subsidence characteristics of the Jakarta basin (Indonesia) and its relation with groundwater extraction and sea level rise. In: *Groundwater Response to Changing Climate* (pp.113-130), doi: 10.1201/b10530-11.

Abidin, H.Z., Andreas, H., Gumilar, I., Fukuda, Y., Pohan, Y.E. and Deguchi, T. 2011. Land subsidence of Jakarta (Indonesia) and its relation to urban development. *Natural Hazards* 59(3): 1753-1771, doi: 10.1007/s11069-011-9866-9.

Abidin, H.Z., Andreas, H., Gumilar, I., Sidiq, T.P. and Fukuda, Y. 2013. Land subsidence in the coastal city of Semarang (Indonesia): characteristics, impacts and causes. *Journal of Geomatics, Natural Hazards and Risk* 4(3): 226-240, doi:10.1080/19475705.2012.692336.

Ai, B., Liu, K., Li, X. and Li, D.H. 2008. Flat-earth phase removal algorithm improved with frequency information of interferogram. *Geoinformatics 2008 and Joint Conference on GIS and Built Environment: Classification of Remote Sensing Images*, 7147(May 2014), 71471A, doi: 10.1117/12.813247.

Andreas, H., Usriyah, Abidin, H. Z. and Sarsito, A.D. (2017). Tidal inundation ("Rob") investigation using time series of high resolution satellite image data and from in situ measurements along the northern coast of Java (Pantura). *IOP Conference Series: Earth and Environmental Science* 71(1), doi: 10.1088/1755-1315/71/1/012005.

Chang, C., Yen, J., Hooper, A., Chou, F. and Chen, Y. 2010. Monitoring of surface deformation in Northern Taiwan using DInSAR and PSInSAR techniques Monitoring of Surface Deformation in Northern Taiwan Using DInSAR and PSInSAR Techniques. *Terrestrial Atmospheric and Oceanic Sciences* 21(3): 447-461, doi: 0.3319/TAO.2009.11.20.01(TH).

Cyntia, C. and Pudja, I.P. 2018. Subsidence analysis in DKI Jakarta using Differential Interferometry Synthetic Aperture Radar (DInSAR) method. *Sustinere: Journal of Environment and Sustainability* 2(3): 118-127, doi: 10.22515/sustinere.jes.v2i3.48.

Fárová, K., Jelének, J., Kopačková-Strnadová, V. ands Kycl, P. 2019. Comparing DInSAR and PSI techniques employed to Sentinel-1 data to monitor highway stability: A case study of a massive Dobkovičky landslide, Czech Republic. *Remote Sensing* 11(22): 1-23, doi: 10.3390/rs11222670.

Ferretti, A., Fumagalli, A., Novali, F., Prati, C., Rocca, F. and Rucci, A. 2011. A new algorithm for processing interferometric data-stacks: SqueeSAR. *IEEE Transactions on Geoscience and Remote Sensing* 49(9): 3460-3470, doi: 10.1109/TGRS.2011.2124465.

Harahap, F.R. 2013. The impact of urbanization on urban development in Indonesia. *Society* 1(1): 35-45, doi: 10.33019/society.v1i1.40 (*in Indonesian*).

Listyono, G.M., Arfiansyah, K., Natasia, N., Alfadli, M.K. and Pranantya, P.A. 2016. Quaternary sediment lithofacies in DKI Jakarta area. Bulletin of Scientific Contribution: Geology 14(1): 89-96 (*in Indonesian*).

Liu, Y., Huang, H. and Dong, J. 2015. Large-area land subsidence monitoring and mechanism research using the small baseline subset interferometric synthetic aperture radar technique over the Yellow River Delta, China. *Journal of Applied Remote Sensing* 9(1), 096019, doi: 10.1117/1.jrs.9.096019.

Marfai, M.A. and King, L. 2008. Tidal inundation mapping under enhanced land subsidence in Semarang, Central Java, Indonesia. *Natural Hazards* 44(1): 93-109, doi: 10.1007/s11069-007-9144-z.

Qin, Y., Perissin, D. and Bai, J. 2018. Investigations on the coregistration of Sentinel-1 TOPS with the conventional cross-correlation technique. *Remote Sensing* 10(9): 1-23, doi: 10.3390/rs10091405.

Rahman, S., Sumotarto, U. and Pramudito, H. 201). Influence the condition land subsidence and groundwater impact of Jakarta coastal area. *IOP Conference Series: Earth and Environmental Science* 106(1), doi: 10.1088/1755-1315/106/1/012006.

Ramadhanis, Z., Prasetyo, Y. and Yuwono, B. 2017. Analysis of spatial correlation of impact of land subsidence on floods in North Jakarta. *Jurnal Geodesi Undip* 6(3): 77-86 (*in Indonesian*).

Song, R., Guo, H., Liu, G., Perski, Z., Yue, H., Han, C. and Fan, J. 2015. Improved goldstein SAR interferogram filter based on adaptive-neighborhood technique. *IEEE Geoscience and Remote Sensing Letters* 12(1): 140-144, doi: 10.1109/LGRS.2014.2329498.

Strozzi, T., Wegmüller, U., Tosi, L., Bitelli, G. and Spreckels, V. 2001. Land subsidence monitoring with differential SAR interferometry. *Photogrammetric Engineering and Remote Sensing* 67(11): 1261-1270.

Syahreza, S., Fadhli, Saepuloh, A., Jefriza, and Lateh, H. 2018. Combining the Sentinel-1A/B DinSAR Interferometry to detect deformation associated with Pidie Jaya earthquake. *Journal of Physics: Conference Series* 1120(1), doi: 10.1088/1742-6596/1120/1/012021.

Tzouvaras, M., Danezis, C. and Hadjimitsis, D.G. 2020. Small scale landslide detection using Sentinel-1 interferometric SAR coherence. *Remote Sensing* 12(10), doi: org/10.3390/rs12101560.

Whittaker, B.N. and Reddish, D.J. 1989. *Subsidence: Occurrence, Prediction and Control*. Publisher Elsevier, ISBN 0444872744, 9780444872746, 528 pages.