Land Subsidence Monitoring by InSAR Time Series Technique Derived From ALOS-2 PALSAR-2 over Surabaya City, Indonesia

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Abstract Surabaya is the second largest city in Indonesia and the capital of East Java Province with rapid population and industrialization. The impact of urbanization in the big city can suffer potential disasters either nature or anthropogenic such as land subsidence and flood. The pattern of land subsidence need to be mapped for the purposes of planning and structuring the city as well as taking appropriate policy in anticipating and mitigating the impact. This research has used interferometric Synthetic Aperture Radar (InSAR) Small Baseline Subset (SBAS) technique and applied time series analysis to investigate land subsidence occured. The technique includes the process of focusing the SAR data, incorporating the precise orbit, generating interferogram and phase unwrapping using SNAPHU algorithms. The results showed land subsidence has been detected during 2014-2017 over Surabaya city area using ALOS-2/ PALSAR-2 images data. These results reveal the subsidence has observed in several area in Surabaya in particular northern part reach up to ~2 cm/ year. The fastest subsidence occurs in highly populated areas suffer vulnerable to flooding and sea level rise impact. In urban areas we found a correlation between land subsidence with residential or industrial land use. It concludes that land subsidence is mainly caused by ground water consumption for industrial and residential use respectively.

Keywords: Land Subsidence, Time Series, InSAR, PALSAR-2, Surabaya

1. Introduction

Surabaya which the second largest city in Indonesia with population more than 2.7 million people as well as the capital of East Java province is coastal city that has a delta system and located on low elevation (less than 10 meters above sea level). As the urban area Surabaya has potential antrophogenic hazard such as land subsidence, flood, inundation, drought, crack in the road and building damage. Land subsidence its self is the combination of the natural compaction of sediments, ground water extraction, geothermal fluids, coal, and other solids through mining; and underground construction. Therefore long-term land surface monitoring is needed for urban area to reduce economic loss and sustainable improvement. Most of the major land subsidence areas around the world due to the increasing use of ground water [1]. Even if the hazards associated with subsidence are different from those caused by sudden and catastrophic natural events like floods and earthquakes, because surface sinking is a slow event, expansive damage can occur. The pattern of land subsidence need to be mapped for the purposes of planning and structuring the city as well as taking appropriate actions in anticipating and mitigating the impacts. These characteristics can be determined by several measurements such as direct measurement, levelling, Global Positioning System (GPS), InSAR Interferometric Synthetic Aperture Radar (InSAR) and Gravimetry [2]. The application of satellite radar data have provided the ability to detect and monitor ground deformation with centimeter to milimeter precision at greater spatial detail and ability to cover remote area.

The objective of this study is to investigate surface elevation change of environmental in particular land subsidence episode between 2014 and 2017 in Surabaya city, Indonesia. To recognize the pattern characteristics of land subsidence, active remote sensing technique such as Synthetic Aperture Radar (SAR) has been widely implemented to characterize of urban area. The basic principle of SAR is Sensor emitted the pulse to the object and getting back reflection of electromagnetic waves from the object and calculated as phase differential.

Figure 1. Condition of Surabaya City over last 5 years.

2. Methodology

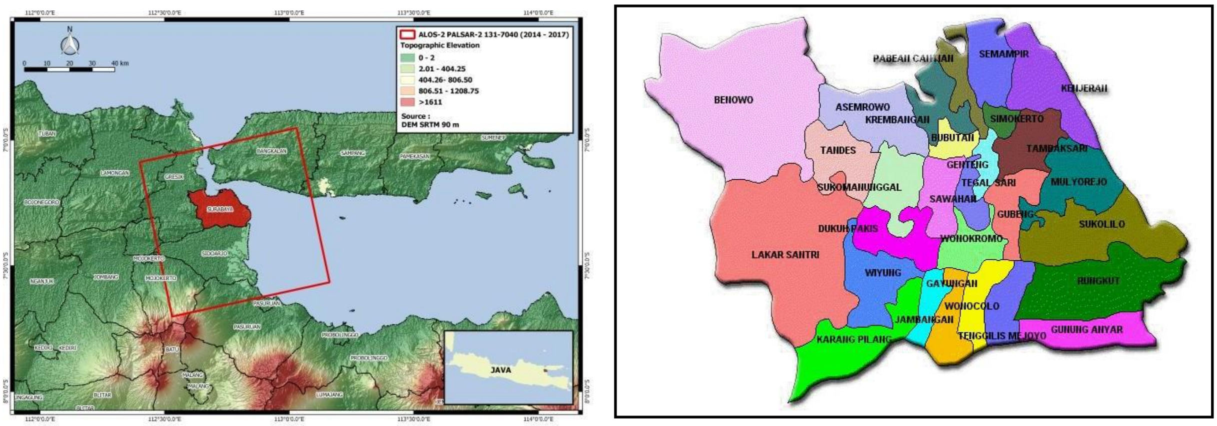
2.1. Study Area

Surabaya is located in the northern coast of Java island and mostof the area locates on low elevation between 3 up to 6 m above sea level. Surabaya also places around hill called Bukit Lindah and Gayungan on southwest direction with high elevation 25-50 meters above sea level. Total area cover of Surabaya is 33,306 Ha consists of 31 sub-districts and 160 urban villages. Alike a tropical city Surabaya has two seasons, dry and wet seasons. Between November up to April are months for dry season, July up to October for wet season, while month remaining for transition season. Temperature in Surabaya was 23.6 up to 33.8°C in daily average, maximum air moisture 92% and air pressure 1012.5 hPa. Looking into Surabaya topography, there are large area will be directly affected to impact of sea level rise. The following description of field survey was focused on the areas where those locate nearest distance from coastline. As defined by Local Government of Surabaya that the coastal area is the areas from shoreline continue to inland nearest coastal area. It may be consist of wet and dry land that still have affected by sea behavior.

Soil type in Surabaya was composed by alluvial deposit, which develop from river and coastal features. Mostly Brantas River and Rowo River affected the characteristic for river feature and some part area in east and north of Surabaya continue to along Madura Strait has coastal characteristic. It encompasses clay, silt and clay silty. A thin sheelfish layer was founded in some places. Geologic of

Municipality Surabaya consists of clay and sandy layer. Alluvial soil that susceptible for cropland dominated condition of soil. The soil was founded in west of Surabaya contain a highly lime soil that less open for plantation.

Based on geological study conducted by Geology Agency, the soil capacity in carring a building construction indicated that soil in Surabaya varies types and uneven spreading areas that differ capacity in place to place in old city part such as in the following districts of Wonokromo, Sawahan, Genteng, Tegalsari, Gubeng, tambaksari, Simikerto, Semampir, Paben Cantikan, Krembangan and Bubutan were classified a clay soil with 10-18 m depth [3]. The building foundation that would be constructed in this type soil has to be grounded on 25-30 m depth. The hilly area in west city mostly contain clay soil so the building foundation has to be grounded on 4 up to 10 mdepth.



(a) (b)

Figure 2. (a) Geographic location of Surabaya, Indonesia and red rectangle of PALSAR-2 image; (b) Administrative sub-district boundary of Surabaya.

2.2. Image Data Sets

The data used in this study is Phased Array Type L-band Synthetic Aperture Radar (PALSAR-2) sensor onboard of the Advanced Land Observing Satellite (ALOS-2) images. The ALOS-2 has worldwide observation scenarios for various missions, e.g., detection of deformation, monitoring forest change, and monitoring sea ice. Its precise orbit control and the gallium nitride (GaN) high- power transmitter/receiver enable accurate analyses in high spatial resolution. We used acquired data period from September 2014 to July 2017. These data sets were acquired in the ascending orbit with an off-nadir angle of 28.2°. Observation parameters for all the images were as follows observation mode Strip Map ; track 131 and right looking direction. These data were used to generate interferogram and to obtain line of sight (LOS) value. Table 1 shows the cover ranges of the ALOS-2/ PALSAR-2 data.

Table 1. List of ALOS2/PALSAR2 data

Satellite	Orbit	$B_{PERP\ (m)}$	Track	Off Nadir Angle	Acquisition Date	Look Direction
ALOS-2	Asc.	0 (M)	131	28.2°	20140916	Right
ALOS-2	Asc.	127.0	131	28.2°	20150707	Right
ALOS-2	Asc.	28.8	131	28.2°	20150915	Right
ALOS-2	Asc.	40.5	131	28.2°	20160202	Right
ALOS-2	Asc.	-37.1	131	28.2°	20160705	Right
ALOS-2	Asc.	-8.5	131	28.2°	20160913	Right
ALOS-2	Asc.	-121.2	131	28.2°	20170131	Right
ALOS-2	Asc.	-173.6	131	28.2°	20170704	Right

We used level 1.1 format data with spatial resolution reach up to 10 meters for strip map mode [4]. A Shuttle Radar Topography Mission-3 (SRTM-3) version-4.1 (90 m resolution) was used to eliminate the topographic phase, which was downloaded from public consortium for spatial information (CGIAR-CSI).

2.3. InSAR Technique

Interferometric synthetic aperture radar (InSAR) is a reliable microwave remote sensing technique using at least two or more SAR images acquired at different times to generate displacement maps to detect surface changes over a specific area. Most 2 last decades, InSAR has wide used to estimate surface deformation and has a remarkable achievement in geodynamics studies. In the SAR data processing, the interferograms are generated by combining two complex SAR images, the interferometric phase observation per resolution cell is composed by a number of contributors [5].

$$\phi_{int} = \phi_{topo} + \phi_{defo} + \phi_{orb} + \phi_{atm} + \phi_{scat} + \phi_{noise} \qquad (1)$$

where ϕ_{int} is interferometric phase, ϕ_{topo} is topographic phase, ϕ_{defo} is deformation phase due to the deformation in the radar line of slight, ϕ_{orb} is deterministic flat earth phase and the residual phase signal due to orbit in determination, ϕ_{atm} is atmospheric phase, ϕ_{scat} is phase due to a temporal and spatial change in the scatter characteristics of the earth surface between the two observation times, and ϕ_{noise} is phase degradation factors, caused by e.g., thermal noise, coregistration noise and interpolation noise. Furthermore InSAR approach, two SAR images from slightly different orbit configurations and at different times are combined to exploit the phase difference of the signals LOS (line of sight). InSAR is based on the phase difference which acquired from two different SAR acquisitions. By assuming that the scattering phase is the same in both images, the interferometric phase ϕ is a very sensitive measure of the range difference R2 - R1 i.e :

$$\phi = \phi_1 - \phi_2 = \frac{4\pi}{\lambda}\,(R2 - R1) \qquad (2)$$

Here, ϕ_1 and ϕ_2 are the phases of the first and second SAR images, respectively. R1 is the distance from the SAR to the scatterer by the first acquisition; R2 is the distance by the second acquisition; and, λ is the wavelength, as for L-band ALOS-2 data λ is 23.6 cm. The Small Baseline Subset (SBAS) method relies on an appropriate combination of differential interferograms produced by data pairs characterized by a small orbital separation (baseline) in order to reduce the spatial decorrelation phenomena [6]. Cumulative phase can be obtained by solving a linear least squares problem. Solves only for pixels with complete dataset, i.e. all interferograms and acquisitions are available. In a given pixel, the observation equation as showed :

$$\Phi ij = \sum_{n=i}^{j-1} \delta\varphi n \quad (3)$$

where Φ_{ij} is phase of the interferogram combining acquisitions *i* and j, $\delta_{\varphi n}$ is phase increment between acquisitions *n* and *n+1*. Interferograms having mutual small baselines combinations are created based on the available of image. However, this can produce different subsets of InSAR pairs connected in time and separated by large baselines. SBAS method allow to obtain surface deformation and to analyze their space time characteristics. The generation of a linear model will increase the sampling rate and allow the use of all acquisitions included in the different small baseline subsets [7]. While the usual approach to analyze phase differences in classical InSAR processing is to set a coherence threshold to reduce phase noise and preserve spatial resolution. The small baselines method searches to ease phase unwrapping by means of selecting small baselines interferograms and filtering the phases. It creates a network of interferograms to estimate heights and deformation with respect to one single master image [8]. We use multiple SAR acquisitions of the same area to perform time-series analysis based on SBAS method. Interferograms with a maximum spatial baseline of 2600 meter with respect to the first image are phase-unwrapped and inverted for the phase [9].

The first stage was focus to convert the raw data to SLC format and calibration. Furthermore the data was to form interferograms from single-look complex (SLC) images was applied for interferogram calculation. Then the Statistical-cost, Network-flow Algorithm for Phase Unwrapping (SNAPHU) package was used to unwrap phase [10]. At the last stage, the GIAnT was implemented to perform time series InSAR SBAS analysis. The ground displacement was also solved at this stage.

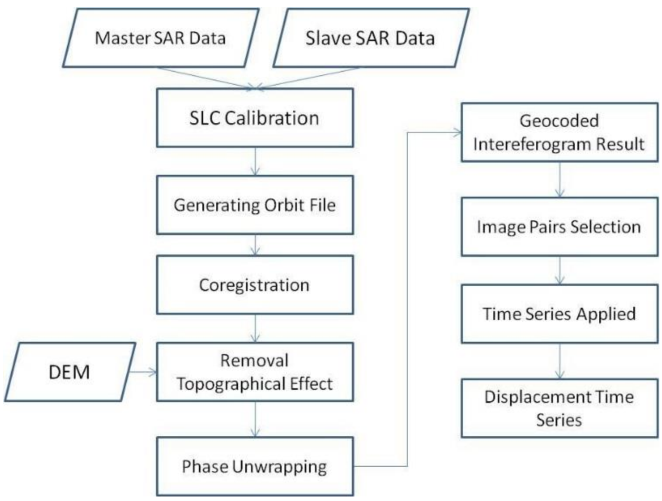


Figure 3. Flowchart of InSAR Time Series

3. Result and Discussion

We generated 28 interferogram results from all possible pairs of PALSAR-2 images. Some of the interfrogram images is shown by figure 4. In the interferogram processing not all produce good results, it can be due to unwrapping error and atmospheric effects on the image itself. Furthermore we continue to process time series data for Surabaya region by using GIAnT program [11]. In the SBAS method, we computed all interferograms and the wrapped phase was corrected for spatially- uncorrelated look angle error and noise associated with the master image. After unwrapping stage and filtering spatially correlated noise then it can be calculated mean of velocity line-of-sight (LOS).

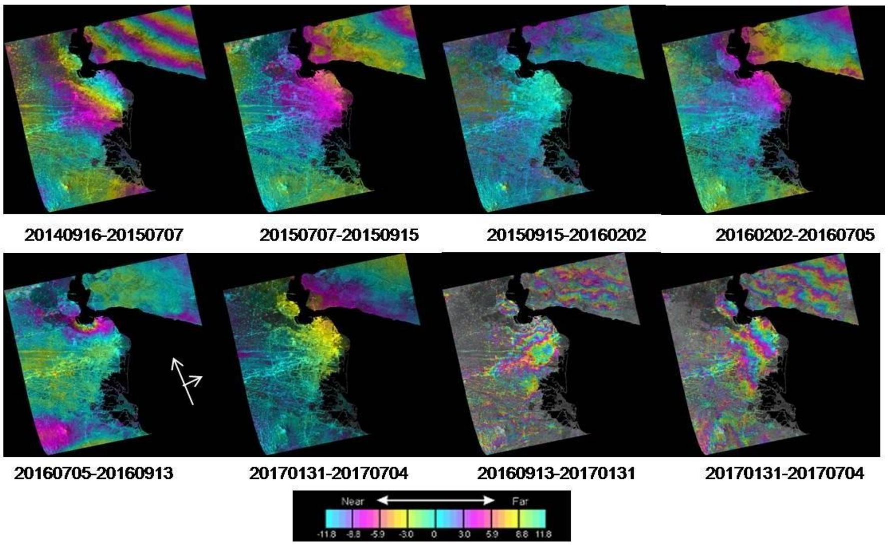


Figure 4. Interferogram Results

Figure 5 shows the surface deformation significant occured in northern part of Surabaya which is located in high density populated area. Value for each pixels from 2014 to 2017 with the deformation rates obtained in the interval 10 mm during 3 years. Finally, the results are mapped to geodetic coordinate system as shown figure below.

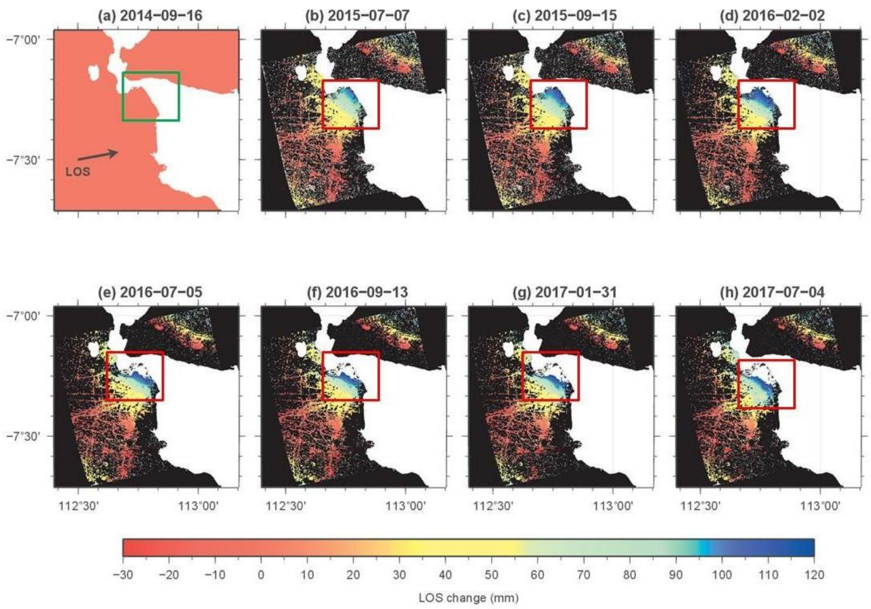


Figure 5. Surface Deformation Time Series Result

In order to make better interpretation, the processing was considered SBAS technique which is stable and calculate the differences respect to it. Therefore, blue areas mean deformation occured and uplifting respect to the mean deformation value. Taking into account that no uplifting is expected, we can consider that the light green areas are sinking slower than deep blue which is located in northern part of Surabaya. In other hand, we obtain the center of Surabaya to be subsiding with a rate of ~17 mm/year. We can also see the estimated deformation field which is not as smooth as expected probably due to unwrapping errors when the interferogram lacks of correlation. It can be seen at figure 5 that the oddity occurred in the 2014 to 2015 with the deformation value reach up to 10 cm on points A and 6 cm on point D. However, in the northern part (Kenjeran sub-district) subsidence reach up to 2.2 cm/ year and the southern part is more lower reach up to 0.6 cm/ year. Generally the coherence value of ALOS-2 images is better than ALOS but the temporal resolution is opposite for the area in Indonesia.

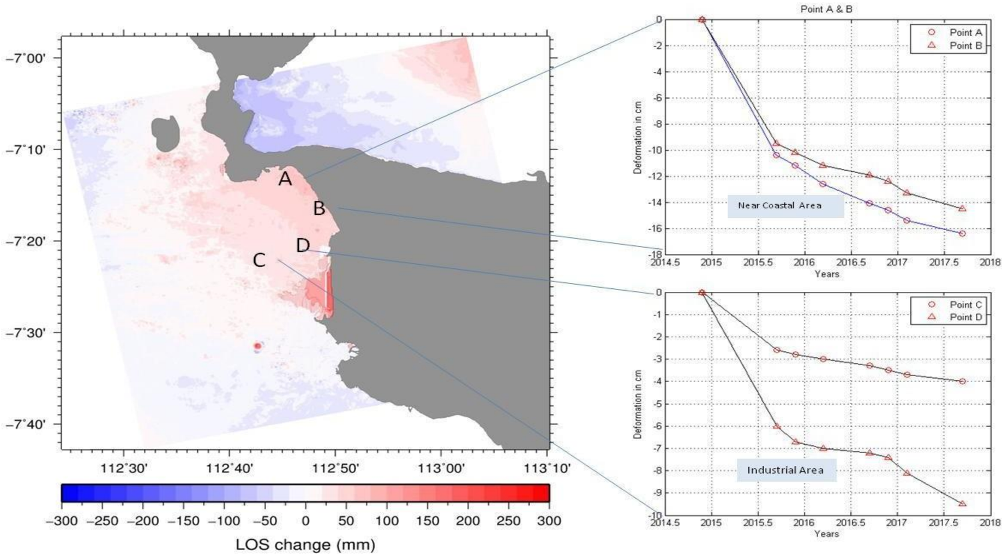


Figure 6. Plot of Specified Point in Surabaya

4. Conclusions

This work has presented an analysis of the ground subsidence phenomena in Surabaya City. The advanced multi-temporal InSAR technique is applied to this site using 8 ALOS-2 PALSAR-2 images acquired from 2014 to 2017. We identified a few locations undergoing subsidence at rates up to 2,2 cm/year. The average subsidence velocity map has been retrieved by Small Baseline technique processing to reduce spatial decorrelation characteristics among image itself. The urbanization and urban growth which have resulted in more groundwater extraction are mainly responsible for the subsidence in Surabaya. Subsidence in turn leads to flooding and water nuisance. From 2014 to 2017, the estimation of the average subsidence rate is ~1.7 cm/year with the maximum value up to ~2.2 cm/year, potentially suffering damages in the future.

After 3 years, in the regions along Kenjeran, Semampir, and Pabean sub-district the land had sunk up to ~6 cm. If not addressed, subsidence leads to an increase of inundation, both in frequency and spatial extent in particularly western part of Surabaya which is many inhabitant live. Regarding climate change, it can be confronted with flooding more often as a result of sea level rise mean rate up to 5.47 mm/year calculated in the period of 64 years (1925-1989) [12]. However, surface deformation will be correlated greater locally. Groundwater extraction for industrial use and residential consume are responsible for rapid subsidence. Therefore inundation will lead to an increase and will put coastal cities below relative sea level within decades. It is essential to consider human factors where the city is inhabited by more than 2.5 million people and subsidence directly impacts on urban structures and infrastructure. Furthermore, there could also be possible existence of other causes due to anthropogenic factors in almost all subsidence areas and natural factors such as tectonic processes in Southern of Surabaya. Future investigation can be improved by utilizing GPS technique in the significant deformation areas and monitoring long-time subsidence to achieve accurate result.

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