Land Subsidence Monitoring in Semarang and Demak Coastal Areas 2016-2017 Using Persistent Scatterer Interferometric Synthetic Aperture Radar

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Abstract. Land subsidence is a problem faced in coastal areas of Java Island especially coastal areas of Semarang and Demak that caused by various natural and human factors. One method that can be used for this is by utilizing the method of Persistent Scatterer Interferometric Synthetic Aperture Radar (PS-InSAR). PS-InSAR is a remote sensing technique that is the development of the DInSAR method that can monitor the movement of the ground surface that allows users to perform regular measurements and monitoring of fixed objects on the surface of the earth. One of PS-InSAR method is Standford Method of Persistent Scatters (StaMPS). StaMPS identify and extract the deformation signal even in the absence of bright scatterers. StaMPS is also applicable in areas undergoing non-steady deformation, with no prior knowledge of the variations in deformation rate. In addition, this method can also cover a large area. From the PS-InSAR method can be known the impact on the existing area in Semarang and Demak region per year from 2016 to 2017 by utilizing the image of Sentinel-1A. The result of PS-InSAR is done comparison of result from GNSS survey data.

Keyword: Land subsidence, GNSS survey, PS-InSAR

1. Introduction

Coastal areas are potential areas to be managed well, especially in terms of natural resources, causing most of the densely populated settlements in coastal areas. The pattern of land use in coastal areas that ignore the environment such as land use that is not appropriate and exceeds the carrying capacity of land result in environmental degradation. Degradation of environmental quality will result in the lives of people who depend on the coastal areas, especially the northern coast of Java [1]. As a result of the existence of these symptoms can be possible coastal areas often occur land subsidence caused by various factors such as the loss of water catchment areas and excessive use of ground water resulting from the ongoing development.

There are several methods for identifying subsidence e.g. GNSS survey, Gravity survey, Levelling and InSAR [2]. One of InSAR method that has been developed is by utilizing PS-InSAR method. PS-InSAR is a remote sensing technique that is the development of the DInSAR method that
can monitor the movement of the ground surface that allows users to perform regular measurements and monitoring of fixed objects on the surface of the earth. It uses large stacks of Synthetic Aperture Radar (SAR) images and suitable data modelling procedures that allow the estimation of different parameters. These parameters include the deformation time series, the average displacement rates and the so-called residual topographic error. It has been successfully used in a wide range of applications mainly related to the fields of urban, peri-urban and built, subsidence and uplift, landslides, and geophysics [3]. Many PS-InSAR methods have been found, one of which is the method of Standford Method of Persistent Scatterers (StaMPS). StaMPS identify and extract the deformation signal even in the absence of bright scatterers. StaMPS is also applicable in areas undergoing non-steady deformation, with no prior knowledge of the variations in deformation rate [4]. In addition, this method can also cover a large area.

This method will identify land subsidence occurring in Semarang City and Demak District through the results of Mean LOS Velocity and Time-Series result. The result of land subsidence from PS-InSAR will be compared with the result of GNSS observation in Semarang [5] and Demak [6] that has been done in 2016 and 2017 spread in research area so that can know the difference of every point, standard deviation and mean difference between PS-InSAR and GNSS result. It is expected that the PS-InSAR method can assist in knowing the large land subsidence occurring in a region with wide coverage and can help GNSS survey.

2. Study Area and Method

2.1. Study Area

The study area covers the coastal area or the northern region of Semarang City and Demak Regency which is directly adjacent to the Java Sea. Figure 1 shows the location of the study based on the sub swath of the sentinel image 1 used.

![Figure 1. Study Area](image1.png)

The study area is also conducted based on the region conducted observation data using GNSS receiver in 2016 and 2017 as in Figure 2.
2.2. Persistent Scatterer Interferometry Synthetic Aperture Radar (PS-InSAR)

PS-InSAR is a remote sensing technique that is the development of the DInSAR method that can monitor the movement of the ground surface that allows users to perform regular measurements and monitoring of fixed objects on the surface of the earth [7]. Persistent Scatterer (PS) InSAR is an extension to the conventional InSAR techniques which addresses the problems of decorrelation and atmospheric delay [8]. Figure 3 illustrates the principle of PS-InSAR which works on a distributed scatterer of radar SAR acquisition to obtain a Persistent Scatterer to reduce and eliminate the effect of decorrelation to 0.

Figure 3. Phase Simulations for Distributed Scatterer and Persistent Scatterer

One of the developing PS-InSAR methods Standford Method of Persistent Scatterers (StaMPS) which identify and extract the deformation signal even in the absence of bright scatterers. StaMPS is also applicable in areas undergoing non-steady deformation, with no prior knowledge of the variations in deformation rate [4]. Many of the imagery that has been used in this method such as ERS-1/2, ALOS PALSAR, ENVISAT and one of the most recent is Sentinel-1. Sentinel-1 is the latest radar image of the ESA (Europe Space Agency) that is fully operational every day using C-band sensor with the shortest revisit time than other radar imagery that is useful to better support a variety of areas such as marine monitoring, ground monitoring and disaster response [9]. Sentinel -1 Synthetic Aperture Radar (SAR)
with four modes of acquisition. Sentinel 1 image used is Sentinel-1A image with type Interferometric Wide Swath (IW) and Level – 1 Single Look Complex (SLC) with complex data such as amplitude and phase from June 2016 to June 2017 with monthly data interval. The process of StaMPS method using Sentinel-1A image includes the things shown in Figure 4 below.

![Persistent Scatterer Workflow Diagram](image)

**Figure 4.** Persistent Scatterer Workflow

2.2.1. **Interferogram Generation**

The interferogram generation process includes the following [10].

- **TOPSAR Split**

  The TOPSAR Split operator provides a convenient way to split each subswath with selected bursts into a separate product. The user may select the desired subswath with desired bursts and polarisations. The subswath used is determined based on the study area.

- **Apply Precise Orbit**

  The orbit state vectors provided in the metadata of a SAR product are generally not accurate and can be refined with the precise orbit files which are available days-to-weeks after the generation of the product. The orbit file provides accurate satellite position and velocity information. Based on this
information, the orbit state vectors in the abstract metadata of the product are updated. Sentinel-1A precise orbits are produced a few weeks after acquisition.

- Master Selection
  The master image is selected such that the dispersion of the perpendicular baseline is as low as possible. The master image is selected maximizing the stack coherence of the interferometric stack. The "optimal" master implies improved visual interpretation of the interferograms and aids quality assessment. The result of the master selection will be the images defined as master and slave like in Table 1.

| Sensor     | Acquisition | Master / Slave | Track | Orbit | B⊥ (m) | Delta fDC (Hz) |
|------------|-------------|----------------|-------|-------|--------|----------------|
| Sentinel-1A| 16 Nov 2016 | Master         | 76    | 13973 | 0.00   | 0              |
| Sentinel-1A| 14 Apr 2016 | Slave          | 76    | 10823 | 216.00 | 1.7            |
| Sentinel-1A| 08 May 2016 | Slave          | 76    | 11173 | 192.00 | 7.2            |
| Sentinel-1A| 01 Jun 2016 | Slave          | 76    | 11523 | 168.00 | 1.75           |
| Sentinel-1A| 19 Jul 2016 | Slave          | 76    | 12223 | 120.00 | 6.81           |
| Sentinel-1A| 12 Aug 2016 | Slave          | 76    | 12573 | 96.00  | 2.24           |
| Sentinel-1A| 26 Sep 2016 | Slave          | 76    | 13273 | 48.00  | 5.01           |
| Sentinel-1A| 23 Oct 2016 | Slave          | 76    | 13623 | 24.00  | 0.16           |
| Sentinel-1A| 10 Des 2016 | Slave          | 76    | 14323 | 24.00  | -0.92          |
| Sentinel-1A| 27 Jan 2017 | Slave          | 76    | 15023 | 72.00  | 0.6            |
| Sentinel-1A| 21 Apr 2017 | Slave          | 76    | 15723 | 120.00 | 3.86           |
| Sentinel-1A| 03 May 2017 | Slave          | 76    | 16248 | 156.00 | 2.15           |
| Sentinel-1A| 20 Jun 2017 | Slave          | 76    | 16423 | 168.00 | 7.02           |

- Coregistration
  A coregistration algorithm is developed based on the amplitude to estimate the gap positions between two images having a good correlation. The function which connects master image to the slave images is estimated by the inverse least squares method. After that each image is sampled by report to the master image. Finally, the interferograms are constructed by making the difference between the phase of the slave images and the phase of the master image.

- TOPSAR Deburst
  Images for all bursts in all sub-swaths of an IW SLC product are re-sampled to a common pixel spacing grid in range and azimuth. Burst synchronisation is ensured for both IW and EW products of Sentinel-. In the range direction, for each line in all sub-swaths with the same time tag, merge adjacent sub-swaths. For the overlapping region in range, merging is done midway between subswaths. In the azimuth direction, bursts are merged according to their zero Doppler time.

- Interferogram Formation and Topographical Phase Removal
  The formation of an interferogram is calculated by pixel by pixel from two organized images. In addition, a topographic phase removal process has been performed to eliminate the topographic phase of the interferogram phase to obtain differential and phase phases from other signals such as atmospheric phase and systematic phase of the orbits used.

- Export Gamma Format
  Export Gamma Format is the process of converting the process data to gamma format. Gamma format is in order to run mt_prep_gamma script in StaMPS process. Converted files are results of
interferogram formation and topographic phase removal and TOPSAR deburst results. In addition, additional data include elevation data from interferogram and longitude and latitude files for geometric correction and PS Candidate Selection.

2.2.2. StaMPS Processing

PS processing in StaMPS was performed in eight main steps. The first step consists of an initial PS pixel candidates selection by using the amplitude dispersion index. Then the phase stability of PS candidate pixel was determined by estimating the phase noise value for each candidate pixel in every interferogram. After that, pixels were selected on the basis of their noise characteristics, dropping those that are due to signal contribution from neighboring ground resolution elements and those deemed too noisy. Then, selected PS pixel candidates were corrected for spatially-uncorrelated look angle error (SULA) to estimate the phase due to deformation. Then, a 3D phase unwrapping method was performed on the selected PS for converting wrapped phase into unwrapped phase. The following step consists of estimating the spatially correlated look angle error (SCLA) simultaneously with master atmosphere and orbit error (AOE), which will be subtracted from the wrapped phase. At the final stage, the obtained wrapped phase was unwrapped once again and used later to estimate the Mean Line of sight velocity (MLV) in mm per year [11].

3. Results

3.1. Mean LOS Velocity

Based on the result of PS-InSAR StaMPS method happened uplift and land subsidence in study area. Land subsidence is -10.16 cm and the uplift is 5.38 m based on PS-InSAR result. Both of these results are results based on the known WGS84 ellipsoid reference height of DEM in which the sea region has elevation. So on PS-InSAR result in marine area there are also PS-InSAR points. The results can be seen in Figure 5 for MLV, Figure 6 for standard deviation and Figure 7 for krigging interpolation result based on study area.

**Figure 5.** Mean LOS Velocity of PS-InSAR Result

**Figure 6.** Standard Deviation of PS-InSAR Result
Analysis for Mean LOS Velocity (MLS) interpolation show Semarang and Demak tend to subsided with the average value land subsidence value in each district shown in Table 2.

### Table 2. Characteristics of Land Subsidence at Semarang and Demak

| No. | District          | Maximum (cm) | Average (cm) | Minimum (cm) |
|-----|-------------------|--------------|--------------|--------------|
| 1   | Gajahmungkur      | 3.047        | 1.707        | 0.667        |
| 2   | Candisari         | 2.738        | 1.573        | 0.586        |
| 3   | Semarang Selatan  | 2.566        | 1.292        | -0.946       |
| 4   | Ngaliyan          | 4.661        | 2.453        | -0.422       |
| 5   | Semarang Barat    | 3.606        | 0.696        | -5.143       |
| 6   | Semarang Tengah   | 1.756        | -1.545       | -5.986       |
| 7   | Semarang Timur    | 0.876        | -4.460       | -8.041       |
| 8   | Semarang Utara    | 0.201        | -4.113       | -9.231       |
| 9   | Tugu              | 4.057        | 0.548        | -4.148       |
| 10  | Pedurungan        | 2.512        | -5.366       | -10.245      |
| 11  | Gayamsari         | 0.838        | -4.179       | -8.403       |
| 12  | Genuk             | -4.795       | -8.020       | -10.239      |

Based on MLV interpolation results, the largest land subsidence occurred in Pedurungan with a decrease value -10.245 cm and Genuk with a decrease value -10.239 cm.

### 3.2. Time Series

Time Series has a function to know the movement that occurs both land subsidence and uplift on every month that made a slave image based on the master of 16 November 2016. The following is the result of time series in Figure 8 for CTRM and Figure 9 for PRWS.
Based on the result of the time series it is seen that the CTRM and PRWS decrease every month.

3.3. **Comparison PS-InSAR and GNSS Survey**

The comparison of PS-InSAR and GNSS survey data indicates that the study area has spatial variation of land subsidence seen in Table 3.

**Table 3. Comparison of PS-InSAR and GNSS Observation Data**

| No. | Point | Latitude | Longitude | GNSS Survey (cm) | PS-InSAR (cm) | Difference (cm) |
|-----|-------|----------|-----------|------------------|---------------|-----------------|
| 1   | N259  | -6.984   | 110.410   | -9.250           | 5.720         | 14.97           |
| 2   | SMK3  | -6.995   | 110.431   | -1.570           | 0.898         | 2.468           |
| 3   | SPO5  | -6.989   | 110.423   | -8.970           | 0.904         | 9.874           |
| 4   | CTRM  | -6.972   | 110.442   | -13.220          | -5.175        | 8.045           |
| 5   | K371  | -6.979   | 110.377   | -13.660          | 2.436         | 16.096          |
| 6   | KOP8  | -6.973   | 110.415   | -33.580          | -2.486        | 31.094          |
| 7   | PRWS  | -6.936   | 110.499   | -12.631          | -7.443        | 5.188           |
| 8   | GEMA  | -6.918   | 110.515   | -0.057           | -5.741        | -5.684          |
| 9   | BDN1  | -6.921   | 110.489   | -14.928          | -5.785        | 9.143           |

| Mean (cm) | 11.304 |
| S. Deviation (cm) | 3.266 |
Results from PS-InSAR compared with GNSS data had an average difference of 11.304 cm and a standard deviation of 3.266 cm. These results indicate that the GNSS survey data in which some GNSS measurement points are decreasing actually increases in PS-InSAR results.

4. Conclusion

Persistent Scatterer (PS) InSAR is an extension to the conventional InSAR techniques which addresses the problems of decorrelation and atmospheric delay whose results can cover a very large area. The result of PS-InSAR can be mean LOS velocity and time series, both of which are very effective in monitoring geodynamics especially land subsidence and uplift but the results of PS-InSAR are still far different from the results of GNSS survey data. The mean LOS velocity is used to describe the moving average within a specified time interval and the time series is used to explain the temporal movement at each time interval.

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