Application of Different Coherence Threshold on PS-InSAR Technique for Monitoring Deformation on the LUSI Affected Area During 2017 and 2019

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Abstract. Difficulties encountered in the DInSAR technique is the temporal and geometric decorrelation. This method's main objective is to identify a single-pixel called Permanent Scatter (PS) over a long-time-interval and for a wide-angle of view variation. In this study, we aim to use the PS-InSAR technique to monitor land surface changes in the LUSI mud volcano area with coherence threshold difference analysis using the Sentinel 1A data set using SARPROZ as a tool. The land surface change that is our focus is west and east of the LUSI. Sentinel 1A data processing with different coherence threshold, affecting the number of PS points formed. Based on Fisher's test on each coherence threshold showed that cumulative displacement and velocity did not differ significantly. During the 3 years since 2017 - 2019, the West LUSI region experienced average cumulative subsidence of -47.95 mm with an average velocity decline of 19.20 mm/year. The East LUSI region experiences average cumulative subsidence of 60.86 mm in the year, with an average velocity decline of 24.37 mm/year. The results of subsidence and velocity in this study are still in the line of sight (LOS).

1. Introduction

Sidoarjo Mudflow (LUSI) is when mud and gas eruptions emerge from the earth towards the surface. LUSI mud volcano in Porong District, Sidoarjo, East Java, Indonesia, began erupting on May 29, 2006. Synthetic Aperture Radar Interferometry (InSAR) is a remote sensing technique that is widely used to obtain accurate surface deformation (sub-centimeter) measurements over large areas [1]. LUSI research using various SAR data and techniques such as ALOS PALSAR with the Interferometry method [2], Differential Interferometry (DinSAR) [3], repeat-pass InSAR [4], Multitemporal InSAR [5] and combining GPS and InSAR [6] in seeing the deformation that occurred in the LUSI region.

Deformation can be interpreted as a decrease in soil surface or ground surface movement caused by various factors or triggers that cause changes in both position and dimension. Deformation is characterized by gradient tensor displacement [7]. In the general case, deformable objects move relative to each other. Distance, time, and temporal variation are based on all deformation theories obtained based on temporal variations of metrics or coordinates [8]. Ground or surface deformation is
the situation when the land surface changes horizontally and vertically. It is caused by many factors such as earthquakes, landslides, surface loads, groundwater extraction, and geological induced caused [9]. The deformation is easily monitored if a short loop cycle of the radar image is available. Therefore, the Sentinel-1 mission, which has a recurring 12-day cycle for each observation, is very suitable for deformation studies which can support this research in implementing ground change monitoring [10].

One of the main difficulties encountered in the DInSAR technique is the temporal and geometric decorrelation. This method's main objective is to identify a single-pixel called Permanent Scatter (PS) over a long time interval and for a wide-angle of view variation [11]. The development of the PS-InSAR method is based on the DInSAR technique, which in principle, the technique is unique, covers a wide coverage area for the implementation of deformation observation and measurement applications [12]. The purpose of applying the PS-InSAR method at the beginning of the study was to identify single coherence pixels starting from several SAR images separated by a large baseline to obtain DEM accuracy up to sub-meters and the movement of the earth's surface in low coherent areas based on pixel bases - pixels. In summary, it aims to detect and observe shifts in residential areas with an accuracy of up to centimeters annually [13]. The formation of an interferogram from each image will produce a phase difference where this phase difference can indicate the initial identification of changes in the earth's surface, which is the research subject. A perfect relationship has a correlation coherence of 1, a coherence of 0.75, and 0.5 are considered as strong and moderate relationships, respectively. Besides, weak coherence has a value of less than 0.25. When the coherence drops to a value less than 0.5, it means that the correlation is lower than the supposed relationship [14].

The East Java Basin developed as a back-arc basin due to the subduction of the Australian oceanic plate in the northwest under the Sunda continent during the late limestone period. The main extensional tectonic system applies during the initial tertiary time caused by complex interactions between the Australian, Eurasian, and Pacific plates. This subduction creates an extensional graben system and the development of basin cracks [15]. From the perspective of geodynamics, the eastern tip of Java Island's position is also very vulnerable to earthquakes. Some earthquakes have been recorded from May 2006 to 2017 [16]. Sidoarjo is included in the Kendeng Basin, which is the Central Depression Zone of Java due to the collision of Eurasian plates with Indo-Australian plates so that many faults are still active. There is a sliding fault in the Kendeng Zone series with the southwest-northeast direction, the Watukosek fault. This fault extends past Mojokerto, Gresik, to Madura's western part and causes other faults [17].

The interferogram covering the first four months to 4 October 2006 and the next 46 days between 4 October 2006 and 19 November 2006 showed at least 70 cm and 80 cm. Possible causes of subsidence, namely the effect of loading erupted mud, making cylindrical mud channels, and reducing the pressure and depletion of material in the depths of the earth [2]. LUSI between 2006 and 2011 from the time series analysis that occurred in the eruption zone. The results showed that the decline occurred in the west of the eruption center and around the vent. The total LOS changes observed reached up to 200 mm [18]. Surface deformation analysis suggests the exponential decay of pressure in the mud source but does not limit the location, geometry, and evolution of possible erupting sludge and liquid sources. To map surface deformation, researchers used multitemporal InSAR. They analyzed L-band data sets with good populations obtained by ALOS between May 2006 and April 2011 with average subsidence of 100 mm/year [16]. In this study, we aim to use the PS-InSAR technique to monitor land surface changes in the LUSI mud volcano area with a coherence threshold difference analysis using Sentinel 1A [19] data set process using SARPROZ [20–23]. The land surface change that is our focus is west [18][5] and east of the LUSI [2].
2. Data and Methodology

2.1. Study Area

Sidoarjo Regency is geographically located between 7°27′10.9″ Southern Latitude and 112°43′2.4″ East Longitude, with an area of territory 714,243 km². Sidoarjo Regency is bordered to the north by Surabaya City and Gresik Regency. In the east, it borders with the Madura Strait. In the south, it borders Pasuruan Regency, and in the boat, it borders Mojokerto Regency. LUSI eruption appeared in Porong Sidoarjo, which is located in the gas exploitation activities of PT. Lapindo Brantas. In this study, we limited the area of observation to 5 kilometers from the center of LUSI. The Alluvium Rock area of 686.89 km² is spread in all districts. Still, for the Pleistocene layer of the Patient Sedimentary rocks, there are only 6 districts: Sidoarjo, Budur, Park, Waru, Gedangan, and Sedati. In contrast, the layers of soil for Gray Alluvial soil are evenly distributed in 18 districts covering 470.18 km². As, Alluvial and Yellowish Brown soil layers only exist in 4 districts, namely Krembung, Balongbendo, Tarik, and Prambon 4.54 each; 27.95; 9.87 and 7.33 km². The Alluvial Hidromort soil layer covering 213.61 km² spreads in 8 districts, namely Sidoarjo, Budur, Candi, Porong, Tunggulangin, Jabon, Waru, and Sedati Districts. The dark gray soil area of 8.71 km² is in 2 districts, namely Budur and Gedangan Districts [24].

Figure 1. Location of LUSI Mud Volcano

2.2. Data

This study used Sentinel 1A Single Look Complex (SLC) imagery in the 2017 to 2019 recording year, 29 pairs of images with VV + VH polarization with descending direction. The selection of image pairs
(master and slave) is based on the perpendicular and temporal baseline Table 1. Sentinel-1 has an imaging mission to monitor sea ice zones and polar environments, map in support of human needs in monitoring the marine environment, monitor the risk of ground surface movement and map ground level: forests, groundwater, and agriculture. Sentinel-1 has better coverage capability than European remote sensing satellites (ERS-1 and 2) and Envisat Advanced SAR (ASAR). Compared to its predecessor, the Sentinel-1 mission represents a significant improvement in carrying the C-Band sensor [19].

2.3. PS-InSAR Processing

SAR data from March 16, 2017, to September 9, 2019, were analyzed using the PS-InSAR technique [13]. The SAR data stack consists of 30 SAR images from 2017 to 2019 with descending orbits. July 16, 2017, imagery is automatically selected as the master and pair of each SAR image shown in Figure 2. The PS-InSAR technique using Sentinel data has been carried out in various parts of the world, both in volcano monitoring, urban deformation, etc [21,25–30].

Table 1. The Perpendicular and Temporal Baseline of Sentinel 1A image

| Master     | Slave   | Bperp (m) | Btemp (d) |
|------------|---------|-----------|-----------|
| 16-Jul-18  | 11-Mar-17 | 18        | -492      |
| 16-Jul-18  | 4-Apr-17  | 24        | -468      |
| 16-Jul-18  | 10-May-17 | 67        | -432      |
| 16-Jul-18  | 3-Jun-17  | 44        | -408      |
| 16-Jul-18  | 9-Jul-17  | -29       | -372      |
| 16-Jul-18  | 2-Aug-17  | 36        | -348      |
| 16-Jul-18  | 7-Sep-17  | -30       | -312      |
| 16-Jul-18  | 13-Oct-17 | 68        | -276      |
| 16-Jul-18  | 18-Nov-17 | 10        | -240      |
| 16-Jul-18  | 12-Dec-17 | -28       | -216      |
| 16-Jul-18  | 17-Jan-18 | 10        | -180      |
| 16-Jul-18  | 22-Feb-18 | -5        | -144      |
| 16-Jul-18  | 18-Mar-18 | -14       | -120      |
| 16-Jul-18  | 23-Apr-18 | -10       | -84       |
| 16-Jul-18  | 29-May-18 | -21       | -48       |
|            |          |           |           |

| Master     | Slave   | Bperp (m) | Btemp (d) |
|------------|---------|-----------|-----------|
| 16-Jul-18  | 22-Jun-18 | 14        | -24       |
| 16-Jul-18  | 9-Aug-18  | -16       | 24        |
| 16-Jul-18  | 14-Sep-18 | 20        | 60        |
| 16-Jul-18  | 8-Oct-18  | -21       | 84        |
| 16-Jul-18  | 1-Nov-18  | 55        | 108       |
| 16-Jul-18  | 19-Dec-18 | -64       | 156       |
| 16-Jul-18  | 12-Jan-19 | 27        | 180       |
| 16-Jul-18  | 5-Feb-19  | -59       | 204       |
| 16-Jul-18  | 13-Mar-19 | 8         | 240       |
| 16-Jul-18  | 18-Apr-19 | 102       | 276       |
| 16-Jul-18  | 5-Jun-19  | -8        | 324       |
| 16-Jul-18  | 11-Jul-19 | -3        | 360       |
| 16-Jul-18  | 4-Aug-19  | 9         | 384       |
| 16-Jul-18  | 9-Sep-19  | 28        | 420       |
Figure 2. Pair of master and slave images which show the perpendicular and temporal baseline distribution

The interferogram represents the difference in each pixel phase between the two SAR acquisitions. In general, an interferogram will contain topographic and surface motion information [31]. Physical changes in the Earth cause the change in phase variation in the electromagnetic signal waves. However, to form an interferogram, at least two SAR data acquisition is required, a fundamental step before making an interferogram. Ideally, the following conditions must be met by the same sensor, the same area according to the same sensor location, and the same display geometry. To process the interferogram from SLC data, follow the equation [31].

\[
I = \frac{\sum f(M)f(S)\exp(2\pi i G)}{\sqrt{\sum f(M)^2}\sqrt{\sum f(S)^2}}
\]  

(1)

Where M (master), S (slave), I (interferogram function), and G (orbital and topographic phases) are implicit functions of the coordinates of image points on SAR. Filter f is designed to reduce the difference in radar signal response for each satellite track from the same plane. The phases formed in the interferogram have a range from 0 to 1, which is called coherence. Perfect coherence 1 will mean that each pixel agrees with each cell phase, an improbable situation if the cell contains more than one pixel. Values close to zero indicate meaningless phase measurements [32], so we apply the coherence threshold value of 0.25, 0.50, and 0.75 in the unwrapping process [14] to see ground-level changes each threshold of coherence at LUSI. Ferretti et al [11] recommend parameter formation of PS points with Amplitude Stability Index (ASI) values > 7.5 (Dispersion Index < 2.5) [21]. A pixel is defined as PS if the pixel phase is dominated by a stable scatterer [33]. Presented an index called Amplitude Dispersion Index that can be employed as an estimation for the phase stability in scatterers with high values of SNR [11]. In the formation of PS points, we use ASI parameter values with a value of 0.8 [31] to meet the formation of the ASI value > 0.75.
3. Experimental and Result

3.1. Interferogram and Unwrapping

Figure 3. Interferogram (a, b, c) and unwrapping (1, 2, 3) respectively coefficient threshold 0.25, 0.50, and 0.75

Differences in yield or differences in the land surface that occurred in the LUSI region with different coherence thresholds were not seen significantly [12] Figure 3. The interferogram and unwrapping results cannot be used as a reference to see the surface changes that occur.

3.2. PS-InSAR

Based on the parameters of PS point formation with an ASI value of 0.8, we get the number of Permanent Scatterers Candidate (PSC) points in Figure 4. around 3080 points before masks out with coherence threshold. After the mask out process using each coherence threshold parameters, we get several different Table 2. Different atmospheric conditions influence SAR at the time of acquisition. As water vapor delays the radar signal, the spatial variation in water vapor also causes differences in the delay of reflected waves throughout the SAR image. The APS is estimated to use a spatial-temporal filter. APS Estimates were removed from the results. The remaining phase is then used to estimate errors in topographic altitude and deformation velocity [28].

Table 2. PS Point Each Coherence

| Coherence Threshold | Total PS |
|---------------------|----------|
| 0.25                | 3052     |
| 0.50                | 2956     |
| 0.75                | 2945     |
Figure 4. Candidate point PS based on ASI value of 0.8

The point we chose in the West and East sections is based on research [2][17][5]. Based on Figure 5 and Figure 6, up to now, there is still subsidence and velocity in the East and West sections. This reinforces previous research, which states that this location is subsidence around the LUSI area.

Figure 5. PS Mean LoS Subsidence LUSI
3.3. Fisher Exact Test

To see whether the subsidence of each coherence threshold has different or equal decreasing values, we do a statistical test on each coherence threshold with the equation (2).

\[ F_{Score} = \frac{s_1^2}{s_2^2} \]  

(2)

S is the average standard deviation of PS formed at each coherence (0.25, 0.50, and 0.75), F is the calculated F value, which will be compared with the F table [34] with the degree of freedom 95%.

The acceptance of H0 satisfies the equation, so the coherence value that satisfies this equation means that there is no significant difference in the results of cumulative displacement and velocity at each different coherence. While the rejection of H0 will satisfy equality, the coherence value that satisfies this equation and its meaning is significantly different. We use a sample of 20 points formed around the western and eastern regions, which have a large range of cumulative subsidence Table 3. We get the following results in Table 4 and Table 5.

| Coherence Threshold | Velocity (mm/year) | Cumulative Subsidence (mm) | STDEV |
|---------------------|--------------------|---------------------------|-------|
| West 0.25           | -18.86             | -47.09                    | 2.47  |
| West 0.50           | -19.15             | -47.82                    | 2.38  |
| West 0.75           | -19.59             | -48.92                    | 2.39  |
| Coherence Threshold | Velocity (mm/years) | Cumulative Subsidence (mm) | STDEV |
|---------------------|---------------------|---------------------------|-------|
| East 0.25           | -24.75              | -61.81                    | 2.37  |
| East 0.50           | -24.18              | -60.38                    | 1.92  |
| East 0.75           | -24.18              | -60.38                    | 1.92  |

Table 4. Fisher exact test between difference coherence west region

| Coherence               | F Score | F Table | Hypothesis |
|-------------------------|---------|---------|------------|
| West 0.25 & West 0.50   | 1.08    | 3.11    | Accepted   |
| West 0.25 & West 0.75   | 1.07    | 3.11    | Accepted   |
| West 0.50 & West 0.75   | 1.00    | 3.11    | Accepted   |

Table 5. Fisher exact test between difference coherence east region

| Coherence               | F Score | F Table | Hypothesis |
|-------------------------|---------|---------|------------|
| East 0.25 & East 0.50   | 1.51    | 2.59    | Accepted   |
| East 0.25 & East 0.75   | 1.52    | 2.59    | Accepted   |
| East 0.50 & East 0.75   | 1.00    | 2.59    | Accepted   |

4. Conclusion

Sentinel 1A data processing with different coherence threshold, affecting the number of PS points formed. Based on Fisher's test on each coherence threshold showed that cumulative displacement and velocity did not differ significantly. During the 3 years since 2017 - 2019, the West LUSI region experienced cumulative subsidence mean at each threshold used of -47.95 mm with an average velocity decline of 19.20 mm/year. The East LUSI region experiences cumulative subsidence an average of -60.86 mm in a year with an average velocity decline of 24.37 mm/year. The results of subsidence and velocity in this study are still in the line of sight (LOS), so it is necessary to do a combination with GPS measurements as validation and further analysis in the eastern and western areas of the mud volcano LUSI and combining with ascending data for composite method.

5. References

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