Land Subsidence Monitoring in Cepu Block Area Using PS-Insar Technique

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Abstract. Land subsidence can be caused by many factors, from natural through anthropogenic processes. Land subsidence due to anthropogenic factors results from such as fluid withdrawal, like oil and gas extraction. Cepu block is one of the oil and gas extraction areas that become Indonesia’s largest oil producer. This paper employs the Permanent Scatterers Interferometry Synthetic Aperture Radar (PS-InSAR) with C-Band Sentinel-1A imagery data to monitor the land subsidence phenomena. The PS-InSAR method is chosen because it can measure small movements in an area over time with millimeters DEM accuracy. The processing result showed deformation in the form of land subsidence in almost all of the blocks, except for Block D, with the mean velocity ranging from -27.75 to -9.78 mm/yr. An uplift phenomenon is also achieved in the eastern part of Block E. These PS-InSAR results are in the form of Line Of Sight (LOS). This paper correlates the land subsidence with geological maps to better understand the phenomena’ causes.

1. Introduction

Land subsidence has occurred in some cities in Indonesia, such as Semarang [1], Malang [2], Surabaya [3], and Jakarta [4]. Land subsidence is a hazard resulting in adverse impacts. It could lead to severe problems, for example, increasing the risk of flooding in coastal areas, cracking the buildings and infrastructures, destroying local groundwater systems, and generating tension cracks on land and reactivating faults [5]. Natural and anthropogenic processes can cause land subsidence. Natural land subsidence results either from isostatic sediment loading and natural compaction of Holocene deposits or tectonic and volcanic activities. Anthropogenic subsidence results from fluid withdrawal, solid withdrawal (tunnel construction or mining), surface water drainage charges, and sediment loading [6,7]. Human activities as fluid withdrawal are like groundwater extraction or oil extraction. One of Indonesia’s oil exploration area is Cepu Block. Located in Blora, Central Java, and Bojonegoro, East Java, the Cepu block is staying up to become Indonesia’s largest oil producer. According to Operation Manager of SKK Migas, Yani Abdurrahman, Cepu Block’s oil production could reach up to 225 thousand barrels per day, defeated Rokan Block in Riau, Sumatera. Based on these conditions, it is necessary to investigate the possibility of land subsidence occurring in this region.

However, up until now, there has been no large-scale, and high-precision monitoring carried out in this area. Therefore, to estimate the land subsidence in the Cepu Block area and investigatethe
possible causes, PS-InSAR would be ideal for applying. This technology has been used successfully in monitoring land subsidence studies due to oil exploration in several areas [8, 9, 10, 11]. PS-InSAR, developed by [12], requires many SAR scenes acquired over the same area. Typically a minimum of 15-20 images is needed to perform a C-band PS-I analysis [13]. The main goal of the PS-InSAR method is the identification of single coherent pixels, so-called Permanent Scatterers (PS). It starts by forming several SAR images separated by large baselines to get submeter DEM accuracy and terrain motion in low coherent areas on a pixel-by-pixel basis. A study showed that even if no fringes can be seen from generating single interferograms, reliable elevation and deformation measurements can be obtained on this subset of image pixels [12].

2. Data and Methodology

2.1 Study Area

The study area is Cepu Block, situated in between Blora, Central Java, and Bojonegoro, East Java Province. The Cepu Block area located at 6°55'15.6" – 7°17'45.6" S and 111°18'50.4" – 111°54'32.4" E. The total area of Cepu Block is 918.98 km².

Figure 1. Geographical Location of Study Area modified from Department Energy and Mineral Resources

2.2 Dataset Description

The SAR data used in this study were acquired by Sentinel-1A satellites, which have been freely available for the public at Copernicus. Twenty-one images were used with orbit 3, obtained from December 4, 2014, until December 2, 2019. The ground resolution of the sensor, in IW mode, is about 5m in range direction and 20 m in azimuth[14]. Compared to other acquisitions modes, IW uses TOPS, which requires extra data processing for image co-registration that needs to be very accurate to about 0.001 of pixel[15-18].

A Shuttle Radar Terrain Mission (SRTM) DEM versions 2.1 with 90m spatial resolution was used as external DEM to remove the topographic phase. Geological Maps of the Cepu Block was added to
understanding the possible causes of the land subsidence. List of Sentinel-1 images used in this study given in Table 1.

**Table 1. List of Sentinel-1A Images**

| Product Name                | Relative Orbit | Polarization | Direction |
|-----------------------------|----------------|--------------|-----------|
| S1A_IW_SLC_1SDV_20141204T220855_20141204T220928_003575_004381_A610 | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20150322T220851_20150322T220927_005150_0067DE_9569 | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20150602T220855_20150602T220930_006260_00815A_D0B0 | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20150906T220859_20150906T220934_007600_00A861_8191 | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20151211T220855_20151211T220929_009090_00CE6D_2C3B | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20160409T220852_20160409T220928_010750_0100CB_6986 | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20160807T220859_20160807T220934_012500_0138D8_FB62 | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20160924T220901_20160924T220936_013200_014FF5_7E0A | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20161205T220900_20161205T220936_014520_01708A_3CF2 | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20170404T220905_20170404T220932_016090_0164AC_92EF | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20170603T220908_20170603T220935_016875_01C114_48AE | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20170907T220913_20170907T220940_018275_01EBAE_A1CE | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20171212T220913_20171212T220940_019675_0216F4_1E0B | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20180318T220911_20180318T220938_020105_02433A_234A | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20180610T220915_20180610T220942_022530_0269E1_6C4C | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20180902T220920_20180902T220947_024325_028FC7_6617 | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20181207T220920_20181207T220947_024925_02BFE2_9F1F | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20190331T220917_20190331T220944_026325_02F17B_4E06 | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20190605T220921_20190605T220948_027550_031BE0_4918 | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20190921T220927_20190921T220954_029125_034EB3_1D7E | 3              | VV           | Descending |
| S1A_IW_SLC_1SDV_20191202T220926_20191202T220953_030175_0372C0_2E82 | 3              | VV           | Descending |

2.3 Data Processing

The stack of the images was processed using SARProz software, developed by [19]. The first step of the processing was dataset selection. A directory folder was selected, containing a stack of SLC (Single Look Complex) images format. The selected folder will automatically read the number of images and calculate the baseline to determine the master image. The second step is to SLC data processing. At this step, parameters such as polarization type and subswath area were defined. SARProz able to download orbit data satellites automatically in this step to remove the orbital phase. The area of interest was selected, and the co-registration process was started. The amplitude stability index was calculated to make a reflectivity map on preliminary analysis. External DEM was downloaded and geocoded by GCP’s point.

Interferogram images were generated from one master image and 20 slave images. The master image was selected concerning the geometric and temporal baselines at the barycenter of the distribution of normal and temporal baselines[14]. Some parameters, like flattening, multi looking, topographic removal, and unwrapping, were added to the InSAR parameter tool to generate interferograms. Interferograms contain information on the phase difference between master and slave. From this phase change, it will be known whether there is a change in the earth's surface or not.

Before deriving the final PS points, we must first select some pixels that will be able to be PSCandidate (PSC) based on the Amplitude Stability Index. Thus, a pixel that constantly has a similar amplitude during all acquisitions is expected to have small phase dispersions[14]. Amplitude stability index is used to select the PSC as written in [20]:

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Where $D_A$ represents amplitude dispersion, $\sigma_A$ represents the standard deviation of amplitude in time, and $\mu_A$ is the mean deviation of amplitude. PSC was selected in APS Estimation processing. In this study, we use 0.8 as the ASI’s threshold to select the first PSs as implemented in [20]. Based on this threshold, only a small number is chosen to be PSC and represents stable points during all acquisitions. Stable points are necessary to obtain a reference point used as a reference for the movement/displacement of the PS points later. In this stage, deformation velocity and residual topography were computed. Then the Atmospheric Phase Screen was estimated because SAR acquisitions are affected by different atmospheric conditions at the acquisition time[20]. The APS is then subtracted from the estimated linear model (displacement velocities and residual height).

After selecting the first order of PS selection, the next step was Sparse Points Processing to obtain the final PS points (second selection). The parameter used is the same as APS’s parameter, but the threshold is less strict (0.75) to get densified points. The estimated linear model was then recalculated with the same reference point for APS estimation to obtain deformation from final PS points. According to [21], only PS with coherence more than 0.8 were selected and geocoded. The measured PS points are estimated to the ground’s movement along Line Of Sight (LOS) direction.

3. Results and Discussion
3.1 APS Estimation Results
The first order PSs selection based on Amplitude Stability Index with threshold 0.8 generated 1,657 points in the area of interest. The reference points were selected in an area that consistently stable with high temporal coherence[22]. Figure 2 shows the PSCs scatter and the location of the reference point. The reference point was chosen at the number of sample 9100 and line 1031 with spatial coherence 0.44 and temporal coherence 0.94. The first’s linear model estimation shows in histograms in Figure 3 and Figure 5. The histograms’ peak in Figure 3 and Figure 4 should be 0, which indicates the reference point is on the ground and relatively stable, according to a pink circle in the histogram that is approximately situated in 0 mm based on the scalebar. Afterward, the APS was estimated and subtracted, the quality of the estimation was assessed from PSCs temporal coherence. If the coherence is high, it means the APS estimation is good [22], as given in Figure 5.
Figure 2. PSCs scatter plot. The red circle represents the reference point

Figure 3. Integrated Residual Height

Figure 4. Integrated Velocity
3.2 Sparse Points of Processing Results

The second-order PSs selection using the Amplitude Stability Index’s threshold 0.75 generated 8,397 points. The linear model then re-estimated after removing the APS and given in fig 6. Again, the peak of velocity and residual height should be at value 0, which means that most points have a zero relative velocity with the reference point, indicating that the reference point we selected is most likely stable[22]. The temporal coherence of the final PS should be high after parameter estimation and APS removal, as given in figure 7.

After obtained the final PS, only points with coherence more than 0.8 were used in the final deformation map. Afterward subset of the area of interest was conducted and resulted in 2,257 points.
Figure 8 shows the distribution of PS points that represents the velocity in the LOS direction. Plotting is done using GMT's software by [23]. The details about subsidence are described in figure 10. Deformation in the form of land subsidence occurred in almost all of the blocks, except for Block D. We assume that high vegetation in Block D caused the C-band radar signal cannot penetrate in that area. Therefore there are no PS points detected in this block. The highest subsidence occurred at Block A with the mean velocity rate reach up -27.75 mm/yr, followed by Block B with the mean velocity -10.81 mm/yr, block E with the mean velocity -10.76 mm/yr, and block C with the mean velocity 9.78 mm/yr. The subsidence in Block C occurred in the western part of the block. An uplift phenomenon is also achieved in the eastern part of Block E with the mean velocity rate up 9.90 mm/yr.

Figure 9. Cepu Block's Deformation Chart

3.3 Discussion
The result of the PS-InSAR processing revealed deformation in the form of land subsidence occurred in almost all the blocks. As it is shown in figure 11 by [24], Cepu and its surroundings are located in
Rembang Zone, North East Java Basin[25]. The North East Java Basin has experienced tectonic development in such a way and caused a tectonic compression regime to produce geological structure in the form of folds and faults in the North East Java Basin area. Both of these factors are significant factors of the petroleum system[26]. Besides that, many faults pass along the Rembang Zone, such as Muria faults, Pati faults, Baribis-Kendeng-Purwodadi faults, etc. as described in figure 12 [27]. The fault was also classified as active, as evidenced by several earthquake events on 18th and 25th December 2019. From the location of the epicenter, the earthquakes were located in Pati’s fault. So, due to some active faults near Cepu Block can trigger the earthquake and cause land subsidence as experienced in Block A, B, C, and the western part of Block E.

As shown in the geologic map (figure 13), we found a correlation between the land subsidence in some blocks. Alluvial’s layer was found in Block A and Block E. Alluvial is a kind of compressible deposits. In most cases, land subsidence results from the progressive compaction of compressible deposits. Compressible deposits refer to unconsolidated sediments with high initial porosity and compressibility and high organic content (clays, silts, peats, loose sand). Compressible deposits correspond to surficial deposits, often found near the mouths of rivers and along the bays[28]. Also, in Block A and Block E, we investigate that anthropogenic factors in crowded residence can cause land subsidence. In Block B and C were dominated by Wonocolo, Mundu, and Ledok formation. Ledok’s formation has a type of soil in the form of sandstone, which is more stable than alluvial soil types. Therefore the land subsidence occurred is not as large as in block A.

Figure 10. Regional Physiography of Java by [24]
4. Conclusion
We have presented the results of PS-InSAR processing and the geological background of Cepu Block. From the processing, we got land subsidence estimation in LOS direction occurred in Block A with the mean velocity rates up -27.75 mm/yr, followed by Block B, Block E, and Block C with mean velocity rate -10.81 mm/yr, -10.76mm/yr, and -9.78mm/yr. Many factors can cause land subsidence in Cepu Block. Land-forming structures are closely related to these phenomena. Natural
disasters such as earthquakes and geological structures such as active faults can also cause land subsidence.

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