Investigation of Potential Landsubsidence using GNSS CORS UDIP and DinSAR, Sayung, Demak, Indonesia

B D Yuwono¹, Y Prasetyo¹, and L J F Islama¹

¹Diponegoro University, Indonesia

Email: bdyuwono92@gmail.com

Abstract: The coastal flooding induced by land subsidence is one of major social problems in the coastal area of Central Java, especially North Demak. Recent advance technology Global Navigation Satellite System Continuously Operating System (GNSS) and Differential Synthetic Aperture Radar Interferometry (DInSAR) is already increased our capability to identify of land subsidence processes. DInSAR required not only availability of good quality input data but also rigorous approaches. In this research we used DInSAR analysis with focusing on landsubsidence phenomena. Tests were done with geodetic GPS survey with GNSS CORS UDIP as base station. Performance assessment of development method was conducted on study area affected by land subsidence. The results of this study indicate land subsidence spreads in study area with varying degrees of subsidence.

Keywords: GNSS CORS, DInSAR, Land Subsidence

1. Introduction

Land subsidence is definite as downward displacement of the land surface relative to certain reference surface, such as mean sea level (MSL) or reference ellipsoid. Land Subsidence mainly caused by the combination of natural consolidation of alluvium soil, excessive groundwater extraction and loading constructions [1]. Natural-anthropogenic hazard occurs quite many in large urban and the coastal area including coastal Semarang Demak [2].

There are several methods for identifying subsidence e.g. GPS [1], Gravity survey [3], Levelling and InSAR [4]. This research mainly discuss about identify subsided area in Sayung using DInSAR and GPS method. The use of SAR interferometry technique can explore and map deformation area especially land subsidence with good precision. SAR techniques have been tools successfully applied for the study deformation as for example in Jakarta [5], Semarang [6].

2. DInSAR Monitoring of Height Change

2.1. Study Area

Demak is one of the regencies located in central java province. Demak Regency has an area of 897.43 km². Geographically Demak Regency is located at 6°43'26" - 7°09'43" LS and 110°48'47" BT (Wikipedia, 2015) Demak Regency is bordered by Java Sea in the west, Regency of Jepara in the north, Regency of Kudus in the east, and Regency Grobogan in the southeast The coastal area of Sayung District Demak is...
often affected by tidal floods or better known as rob floods. The rob flood is an ever-present phenomenon in the northern Demak district since 1997. The flood of rob in the village Bedono has drowned 2 villages namely Tambaksari and Senik [7].

2.2. DInSAR

Deformation especially landsubsidece phenomenon can be studied by using geodetic method, e.g Global Positioning System (GPS), Differential Interferometri Aperture Syntetic Radar (DinSAR). Both methods have been utilized to study landsubsidene in Jakarta, Semarang, Bandung and Surabaya [8]. This research had been done by using both method In order to compare and to complete each other, because each of method has disadvantages.

Sentinel-1 is the first satellite series of seven satellite missions launched as part of the Copernicus program. Copernicus is the new name of GMES (Global Monitoring for Environment and Security), an earth observation program initiated by the European Commission (EC) and the European Space Agency (ESA). This observation program aims to provide accurate, timely and accessible information to improve environmental management, understand and mitigate the impacts of climate change and ensure civilian security [9].

Sentinel-1 has four observation modes. The main modes are Interferometric Wide-swath (IW) mode, and Wave mode (WV). It also features Stripmap (SM), Extra Wide-swath (EW) modes for data continuity reasons and usage requirements for certain situations.

![Figure 1. Mode Operation of Sentinel-1 (ESA, 2012)](image)

The basic concept of the InSAR and DInSAR methods is to utilize coherence (the measure of correlation or suitability for the phase information of the corresponding signals) in phase measurement to obtain distance difference and distance change from two or more SAR images having complex values from the same area. If there are two images in a single complex observation format of the same area then the phase information of the two images in the form of such complex numbers can be combined. The result of this phase difference produces a phase difference image called interferogram, where the fringes indicate all relative geometry information [10].

In this research there are two pairs of images were processed. The first was Master 29 October 2015 and the second was Slave 29 October 2016. In this case, the subsidence is derived using differential method, and data SRTM was used for generating the DEM for the area. In the interferogram, the phase difference is described as the distance difference measured by the line of sight (LOS) radar and includes
topography, orbit shifts, surface deformation and atmospheric effects [11]. The phase difference in the interferogram can be written by the following equation I:

\[
\varphi = \varphi_{\text{topo}} + \varphi_{\text{defo}} + \varphi_{\text{atm}} + \varphi_{\text{orb}}
\]  (1)

\(\varphi\)  = Difference Phase \\
\(\varphi_{\text{topo}}\) = Topographic Phase \\
\(\varphi_{\text{defo}}\) = Deformation Phase \\
\(\varphi_{\text{atm}}\) = Atmosphere Phase \\
\(\varphi_{\text{orb}}\) = Orbit Phase

DInSAR is the process whereby the phase component caused by ground surface displacement is extracted by somehow eliminating or minimizing the phase difference magnitudes attributable to other sources. [12].

This research is done in accordance with the figure 2. With using DInSAR and GPS method including data collecting, data processing and data analyzing. It would be compared result deformation in both methods.

Figure 2. Research methodology
2.3. Baseline Estimation

At this stage, the image pair is evaluated to select the best image pair. As can be seen in Figure III.3, information obtained is acquisition date, sensor mode, perpendicular and temporal baseline, estimation of coherence model and Doppler centroid frequency difference between the two images. However, the coherence information (γ) obtained is not the result of the calculation of complex data but the calculation of the metadata of both images. So the coherence value will be different after further processing.

2.4. Coregistration

At this stage, the image pair is evaluated to select the best image pair. As can be seen in Figure III.3, information obtained is acquisition date, sensor mode, perpendicular and temporal baseline, estimation of coherence model and Doppler centroid frequency difference between the two images. However, the coherence information (γ) obtained is not the result of the calculation of complex data but the calculation of the metadata of both images. So the coherence value will be different after further.

2.5. Interferograms

If two images exist in a single complex observation format from the same area, then the phase information of the two ideals in the form of such complex numbers can be combined. The formation of the interferogram is done by computing the complex form of the conjugate complex product (∗) between the main image of C1 (master) with the second image of C2 (slave), through the following relationship [13].

\[ I = C_1 \cdot C_2 \]  \hspace{1cm} \text{(2)}

\[ \phi^\Delta = \arctan \frac{\text{Im} (C_1 \cdot C_2^*)}{\text{Re} (C_1 \cdot C_2^*)} \]  \hspace{1cm} \text{(3)}

\[ \gamma = \frac{\sum C_1 \cdot C_2^*}{\sqrt{\sum C_1^* \cdot C_2^*}} \]  \hspace{1cm} \text{(4)}

I = Interferogram \hspace{1cm} I_m = Komponen imaginer \hspace{1cm} \gamma = coherence.
C1 = Master \hspace{1cm} \text{Re} = \text{real component} \hspace{1cm} \phi^\Delta = \text{different phase}
C2 = Slave

In addition to forming interferogram, equation 2 \hspace{0.5cm} in this stage also carried out the process of coherence formation. This coherence value (γ) is closely related to the match that will occur between the master image and the slave image. The higher the value of the coherence the greater the compatibility of the two images and the smaller the coherence value the lower the match rate of the two images. This coherency value estimate is expressed in equation 4. Coherence between C1 and C2 is defined as [13].

The coherence value (γ) of an image pair has a range of values from 0-1. If the image pair is really identical then the value γ = 1 and vice versa if the image pair is different or the image is only a noise then γ = 0. In this study the determined coherence limit is 0.2 which refers to the minimum value of the formation of the surface of the digital model in Set by ESA. The author does not set a smaller value because generally PMT in Semarang city is not too large to cause the coherence value is below the value of 0.2. In addition fringes also cannot be formed if the coherence is too small where the fringes appearance is required for the next stage. Interferogram can be distributed by removing the topographic phase. Topographic phase removal operations in SNAP software will create an interferogram simulation based on the DEM reference and substrate the topographic phase of the processed interferogram. This
stage will produce an interferogram with deleted topography and an additional topographic phase channel such as Figure 3 and Figure 4.

![Figure 3. Before topographic removal](image1.png)  ![Figure 4. After topographic removal](image2.png)

2.6. Phase Unwrapping

Interferogram is a different phase information. This information is directly related to the form of topography. This information is limited between 0 and 2π, thus raising the ambiguity problem in calculating the phase cycle required to obtain the correct phase [13]. To solve this ambiguity is the processing of phase unwrapping, ie to obtain the absolute phase, through the relationship of formula (5).

\[
\text{abs} = \hat{\phi} + k \cdot 2 \pi
\]

\[
(5)
\]

abs = fase absolut and \( \hat{\phi} = \) relative phase

2.7. Surface Deformation

After importing the results of phase unwrapping data, the next step is to change the phase to shift to determine the Los quantity. The result of the phase change process to the shift. Results from DInSAR processing shown in Figure 2 show Sayung district tend to subsided with a max value of 4.7 cm in the village Pilangsari with the lowest magnitude value in the village Sayung. The magnitude of the decline varies in every region of Sayung district.

![Figure 5. Ground Deformation observed by DInSAR](image3.png)
2.8. Global Positioning System Survey

Global Positioning System (GPS) surveying methods were used to observe the location, extent, and magnitude of the vertical land-surface changes in the Northern Sayung Demak [2]. GPS measurements made at 7 geodetic monuments in 2015 and in 2016. Monuments were located in Sidodadi, Gemah, Tugu, Purwosari, Bedono and Timbulsloko. Distribution of GPS Survey is shown at figure 6. GPS surveys were conducted in May – June 15, and the second observation in April - May 2016. GPS survey done using dual frequency geodetic-type GPS receivers Hiper II and Hiper Gb.

![Figure 6. GPS Distribution Survey (Yuwono, 2017)](image)

2.9. GPS Data Processing

Based on ellipsoidal height differences defined from GPS processing between two consecutive observations, epoch can be calculated. To obtain subsidence rate it should be defined in different epoch. This research was based on the GPS Surveys conducted in 2015 and 2016 Periods.

For statistically [2] check the significance of land subsidence values, It used the general linear hypothesis test (11) Reference Height change defined as dhij and its rate dhij at each station are derived using the following relation.

\[
\begin{align*}
\text{dhij} & = \text{dh(tj)} - \text{dh(ti)} \\
\text{dhij} & = \frac{\text{dhij}}{\text{tj} - \text{ti}} \\
\text{Null hypothesis } H_0 & : \text{dhij} = 0 \\
\text{Alternative hypothesis } \text{dhij} & \\n\text{Test statistic is } t & = \frac{\hat{\Delta}d_{h_y}}{\sigma(d_{h_y})}
\end{align*}
\]

if Ho is true. The null hypothesis is rejected if.
At a confidence level of 99% (i.e. \( =1\%\)), the critical value is \( t_{1\%,005}=2.576 \). The Estimated land subsidence at several locations in Sayung Demak is given in Table 1.

**Table 1. Landsubsidence Observation GPS Survey (Yuwono, 2017)**

| Station | Years | Landsubsidence | t-test |
|---------|-------|----------------|--------|
|         | h 2015 | h 2016 | Dh\(_{12}\) cm | s(Dh\(_{12}\)) (mm) | 12 cm | t-test |
| WNSR    | 27.8   | 27.72  | -8.1           | 5                  | -8.4  | -16.3 |
| SIDO    | 27.1   | 26.99  | -11.9          | 4.9                | -12.2 | -24.1 |
| GEMA    | 27.45  | 27.33  | -12.3          | 4.9                | -12.6 | -24.9 |
| TUGU    | 27.62  | 27.56  | -6.5           | 5                  | -6.8  | -13.1 |
| TMBL    | 27.28  | 27.16  | -11.7          | 5                  | -12   | -23.6 |
| SURO    | 27.04  | 27.04  | 0.3            | 4.9                | 0.3   | 0.7   |

Result from the GPS observation show that subsid ence area has distributed in spatial variation, ranging between 0.3 cm to 12.6 cm (see table 1). Base on the result in table 1, it could be statistically concluded that with 99\% confidence lever there were significant ellipsoid changes observed by GPS surveys at all the stations during the period between 2015 and 2016 except suro. Figure 7 shows that the Middle region on Sayung district indicates higher rates of subsidence compare to it north region.

![Figure 7. Ground Deformation in Sayung Demak Observed by GPS (Analysis 2017)](image)

### 3. Result and Discussion

Figure 8 and Figure 9 shows the section profile of the DInSAR in the north area of Sayung. They indocate taht subsidence in Sayung is generally occurring with the maximum rates of about 4.7 cm. The
results are more or less similar with the aforementioned results derived by other methods. There are should be noted that the uplift presence in figure 8 is mostly caused by the very low correlations of images, and the uplift presence should not be considered as a 'real' uplift.

![Figure 8. Section of Landsubsidence](image)

![Figure 9. Profile subsidence](image)

Analysis for DInSAR processing show Sayung district tend to subsided with the average value shown in tugu village with the subsidence level 3 cm.

**Table 2. Characteristics of landsubsidence at Sayung Demak (Analysis 2017)**

| No. | Village  | Average (cm) | Minimal (cm) | Maximal (cm) |
|-----|----------|--------------|--------------|--------------|
| 1   | Jetaksari| 0.01         | -2.17        | 2.34         |
| 2   | Loireng | 0.04         | -3.37        | 3.23         |
| 3   | Gemulak | 0.02         | -3.18        | 2.39         |
| 4   | Sidogemah| 0.08        | -3.13        | 2.64         |
| 5   | Purwosari| -0.01       | -3.65        | 2.75         |
| 6   | Sariwulan| 0.01        | -2.86        | 3.05         |
| 7   | Bedono  | 0.00         | -2.96        | 2.77         |
| 8   | Timbulskoko| 0.00        | -2.77        | 2.80         |
| 9   | Tugu    | -0.03        | -2.71        | 3.07         |
| 10  | Sidorejo| 0.00         | -2.26        | 3.20         |
| 11  | Banjarsari| 0.01       | -2.73        | 2.12         |
| 12  | Dombo   | 0.04         | -2.03        | 1.75         |
| 13  | Surodadi| 0.01         | -2.23        | 1.73         |
| 14  | Bulusari| 0.01         | -2.46        | 2.12         |
| 15  | Perampelan| 0.02      | -2.09        | 1.73         |
| 16  | Karangasem| -0.03      | -2.43        | 2.49         |
| 17  | Kalisi | 0.00         | -2.05        | 2.81         |
| 18  | Sayung | 0.03         | -1.53        | 2.09         |
| 19  | Tambakroto| -0.02      | -2.78        | 2.78         |
| 20  | Pilangsari| -0.15      | -4.57        | 2.71         |
The comparison of DInSAR and GPS observations indicates that the study area has spatial variation of land subsidence. The subsidence value of DInSAR and GPS has not shown correlation, due to different observation time intervals, data accuracy, and accuracy typical of limitation seen in Table 3.

Table 3. Subsidence level observed by GPS and DInSAR (Analysis 2017)

| No | Village | Latitude | Longitude | GPS (cm) | DInSAR (cm) |
|----|---------|----------|-----------|----------|-------------|
| 1  | WNSR    | -6.936   | 110.499   | -5.29    | -0.50       |
| 2  | TMBL    | -6.894   | 110.510   | -4.74    | -2.00       |
| 3  | GEMA    | -6.918   | 110.515   | -5.87    | -1.50       |
| 4  | SIDO    | -6.935   | 110.515   | -8.37    | -2.80       |
| 5  | SURO    | -6.879   | 110.521   | -0.66    | -3.00       |
| 6  | TUGU    | -6.908   | 110.522   | -5.07    | -1.00       |
| 7  | DADI    | -6.869   | 110.527   | 2.078    | -1.00       |

Standard Deviation 0.95
Average Difference 1.68

4. Conclusion

Land subsidence characteristic in Sayung can be estimated by using geodetic measurement techniques such as DInSAR and GPS. And each method has strengths and limitation. It cannot be stated that the existence of land subsidence in Demak is due to a fairly short range of observations. It is necessary to study land subsidence through periodic measurement in the long term so that will give better conclusion about deformation was occurred.

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