Land Subsidence of Java North Coast Observed by SAR Interferometry

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Abstract. Land Subsidence became recent issue in environmental management in Indonesia. Large cities in Indonesia, especially in Java Island, are well known to suffer from fast rate land subsidence such as Jakarta, Bandung, and Semarang. However, the phenomena is presumed to also happen in other cities which have large industries and located on the deposit or clay soil layer. The effect of land subsidence may be different in some location, but the coastal zone will have more impact since land subsidence will also induce tidal flood and may cause land area reduction. In this study, we use more than 70 Sentinel-1 data, range from year 2016 to 2020 to map the land subsidence in the Java North Coast. The interferograms are selected based on Small Baseline Subset (SBAS) algorithm. National Digital Elevation Model (DEMNAS) is used in differential InSAR process. Our result shows that many cities along the Java North Coast suffer land subsidence. Jakarta, experience has maximum subsidence more than 5 cm/year. In Central Java, Pekalongan experience up to 7 cm/year of land subsidence, while Semarang and Demak has subsidence rate up to 8 cm/year.

1. Introduction
Java island is the most populated island in Indonesia, and the location of several main cities of Indonesia such as Jakarta, Surabaya, Semarang, Bandung, and Jogjakarta. Population wise, there are more than 145 million peoples based on 2015 National Survey held by Indonesian Bureau of Statistics. The number depict almost half of the total of Indonesian population, and the fact that both population and development are more concentrated in the North Coast of Java, make this region is very important for Indonesia. However, cities located along the region are prone to the risks caused by environmental changes such as coastal flooding, mangrove loss, and coastal abrasion [1]. Some study also reveal that this region also suffer from land subsidence such as Jakarta [2] and [3], Semarang [4] [5], and some other cities [6].
Geologically, the North Coast of Java is formed by the deposition of sediment or alluvial plain, consist of unconsolidated clay, silt, sand, and gravels of Quaternary age [7].
USGS explain land subsidence as a gradual settling or sudden sinking of earth’s surface which caused by removal or displacement of subsurface material such as water, gas, oil compaction, and loading. The cause of land subsidence can be both natural [8] and anthropogenic, although the study of land subsidence in some cities along the Java North Coast suggest that it mostly driven by anthropogenic activities. Furthermore, land subsidence is considered to be a disaster since it caused both economic loss [9], [4], and natural degradation in large scale [10] [11]. Despite its consequences, many people do not realize the risk because land subsidence affect relatively large area and happened at a slow rate in long term. The risk is realized after the impacts comes to the surface such as infrastructure damage [12], worsen of flood [4], sea water intrusion, and soil quality degradation [13]. The economic loss caused by land subsidence is enormous, such as in Semarang it is estimated to caused loss about 3.5 trillion rupiahs or about 270 million USD [14] [15], and the loss in Bandung is estimated to be around 180 million USD [4].

2. Method

2.1. Data
In this study, we use SAR Sentinel-1 data provided by European Space Agency (ESA) which can be accessed publicly. We choose 70 data from 500 available ascending data in 4 tracks covering Java Island. The average data for each track is about 14 to 16 data, chosen every 3 months of data acquisition to make the computation effective without losing the deformation signal. The acquisition is taken from late 2016 for 2 tracks, while other tracks start from January 2017, to mid-2020.

2.2. InSAR Data Processing
Interferogram generations are done using GMTSAR [16]. We generate 214 interferograms, with average of 51 interferograms for each track. Height correlated tropospheric signal is removed by model the signal by third-order 3D polynomial curve plane [17]. However, due to relatively flat area, the remaining error still affect the interferograms and will be corrected further during time series inversion because the atmospheric error is uncorrelated in time [18]. The Line of Sight (LOS) Displacement and LOS velocity is obtained by interferogram stacking method [19]. Interferogram generation is constrained by perpendicular baseline length below 200 meter, and temporal baseline below 365 days, and then each pixel of every interferogram is evaluated by their coherence value. All pixels have coherence below 0.4 is rejected to make sure its reliability. Due to temporal decorrelation and rapid seasonal vegetation cover changes in the study area, the coherence value in the area is relatively low with average coherence about 0.1. Figure 2 below show the coherence value in track 54. The coherence condition in other tracks is similar since the vegetation
and surface characteristic is relatively homogeneous in the North Coast of Java. The C-band system also contribute to decorrelation because it is more sensitive to surface changes and vegetation cover compared to L-Band use by ALOS-PAL SAR as demonstrated by [6]. However, the access to Sentinel-1 C-band SAR data which made public, prove the dataset to be much more popular to be used more widely.

![Figure 2: Average coherence over the area of Track 54](image)

All interferograms are unwrapped using Minimum Cost Flow (MCF) method provided on SNAPHU software [20]. To speed up phase unwrapping process, we also perform nearest neighborhood interpolation on low coherence pixels prior to phase unwrapping process [21]. The unwrapped interferograms are then resampled and geocoded down to a ground resolution of about 60 meters.

3. Result and Discussion

Our result show that there are at least three cities suffer from land subsidence in relatively large area in each city. Those cities are Jakarta, Semarang and Pekalongan (Figure 3). The result of each city will be described and discuss on each sub chapter.

![Figure 3: The Location of the prominent land subsidence in the north coast of Java Island as observed from SAR data processing](image)

3.1. Jakarta

Jakarta is the capital city of Indonesia. It is the center for both government and business, as well as the main gate to Indonesia. The rapid development of Jakarta in the last 50 years, make the surrounding
area such as Bekasi, Bogor, Tanggerang and Depok was also affected. With population reach more than 25 million peoples in 2016, Jakarta-Bogor-Depok-Tangerang-Bekasi (Jabodetabek) area is expected to be one of the largest megapolitan city in the world. Beside the population number, Infrastructure development and new industrial area required huge carrying capacity from surrounding area. Access to clean water is one of the most notable problem facing by people in Jakarta and its surrounding area. The limited capability from the government to provide clean water both for household and industry usage, force people to use ground water extensively. Based on observation from 2000 to 2005 in monitoring wells placed in Jakarta, all of them shows the groundwater decreasing level [22].

As can be inferred from figure 1, geologically, Jakarta is dominated by quaternary sediment. This geological condition and excessive ground water exploitation in Jakarta known to caused land subsidence, especially in the northern part of Jakarta. In 1995, [2] report that in the period of 1974 to 1990, the subsidence observed in the northern coast of Jakarta can reach 0.7 meter. The study and monitoring then continued by using geodetic method such as precise leveling, GPS, and InSAR [23] [24] [3]. All study report subsidence rate can reach up to 10 cm/year.

In this study, we report the recent land subsidence going on in Jakarta. We found that the land subsidence continuing with cumulative LOS displacement up to 15 cm, with rate 5 cm/year (Figure 4). The spread of subsidence still dominated in the northern coast of Jakarta, and area in West Jakarta. Land subsidence also broaden to the buffer city of Jakarta, such as Tangerang in the west and Bekasi in the east. We found the rate is much smaller than had been reported in the previous study [6] [24]. However, much recent study provided by JICA [25] shows similar result of subsidence rate using ALOS-PALSAR data.

![Figure 4: Land subsidence in Jakarta and its surrounding area (right), and subsidence profile along the line track, lighter color represents earlier data acquisition (2017) and darker color represent recent data acquisition (2020) (left)](image)

3.2. Semarang

As the capital city of Central Java Province, Semarang has become home to 1.6 million peoples. It is one of the largest cities located in the northern coast of Java after Jakarta and Surabaya. Semarang divided into two distinct morphology, coastal lowlands and alluvial deposit in the north-east side, and much more hilly and rough topography in the south-east. Geologically, Semarang formed by three main lithologies, volcanic rock in the southern part, sedimentary rock, and alluvial deposit more in the north coast part (Figure 1).

Like Jakarta, Semarang also suffer from land subsidence. This later confirmed by leveling measurement by [26] and reveal the subsidence rate up to 12 cm/year. In 2007, the land subsidence rate in Semarang reported to be as high as 16.5 cm/year [27]. However, different result was also reported by [4] and [5] which report the maximum rate to be around 10-11 cm/year.

The cause of land subsidence in Semarang is triggered by excessive ground water exploitation and damage on groundwater recharge area [26] [4]. Both studies also report the consequences of land
subsidence, such as damage on infrastructure and sea water inundation. However, for Semarang case, the land subsidence is not solely blame to ground water exploitation, but also from natural compaction which contribute up to 2.2 cm/year [8].

Our result shows that the land subsidence continuing in Semarang, and the cumulative LOS displacement from 2017 to mid-2020 can reach 24 cm, or the average rate of 8 cm/year (Figure 5). Interestingly, the maximum displacement not happening in near the coast as in previous study [6], but more to the south. The extension of land subsidence area in Semarang also observed from our result, confirming previous study done by [5]. Outside Semarang city, land subsidence also extends to Kendal City in the west, and Demak in east side of Semarang City.

![Figure 5](image)

**Figure 5** : Land subsidence in Semarang and its surrounding area (top), and subsidence profile along the line track, lighter color represents earlier data acquisition (2017) and darker color represent recent data acquisition (2020) (bottom)

### 3.3. Pekalongan

Pekalongan located about 80 km in eastern side of Semarang and passed by logistic to and from Jakarta. Administratively, Pekalongan in this context covers both Pekalongan City and Kabupaten (Regency) Pekalongan. It is one of the main industry areas in Central Java, along with history of batik production. Geologically, most of Pekalongan located in alluvial plain in the north, while in the southern part, it divided into quaternary volcano in the southwest, and anticlinorium in the south east part [7].

Environmental issue in the region had drawn more attention from peoples as well as the government since the last decade. The local mass media reported about the worsen of sea water inundation for long time, and later they also report land subsidence phenomena in Pekalongan. The land subsidence Pekalongan was reported to have rate about 3 cm/year [28] to 10 cm/year [6]. The land subsidence in Pekalongan affected tidal flood significantly and projected to cause increasing in flood depth up to 132 cm in 2050 [29].
Our result shows recent subsidence in Pekalongan using Sentinel-1 SAR data. The land subsidence continues with cumulative LOS displacement reach 22 cm from 2017 to mid-2020, or with rate up to 7 cm/year (Figure 6). The land subsidence occurs both in Pekalongan city and Pekalongan Regency, although geologically, it occurs in the alluvial plain. The area of affected by land subsidence in Pekalongan like what have been reported by [6].

![Figure 6](image)

**Figure 6**: Land subsidence in Pekalongan Regency (top), and subsidence profile along the line track, lighter color represents earlier data acquisition (2017) and darker color represent recent data acquisition (2020) (bottom)

4. **Conclusion**
We processed Sentinel-1 SAR data from 2016 to min 2020 in four different tracks to cover all north java coast. Using time-series processing manner, we manage to obtain subsidence rate and land deformation changes both spatially and in time. Our result shows that there are three prominent cities along northern coast of Java suffer from large land subsidence, they are Jakarta, Semarang, and Pekalongan. In Semarang, the area affected by land subsidence widen both to Kendal Regency in the east, and to Demak Regency in the south. Semarang also have fastest subsidence rate up to 8 cm/year, followed by Pekalongan with rate up to 7 cm/year, then Jakarta with rate up to 5 cm/year.

Further study and continuous monitoring of land subsidence in the north coast of Java still need to be continued in the future with better algorithm and more data. Other geodetic method such as GNSS method and leveling is suggested to perform to verify the InSAR method. Government intervention and strong regulation is needed to slow or stop land subsidence, which from various study conduct in the land subsidence area, the major cause of subsidence is excessive ground water exploitation.

5. **References**

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