Extensive Investigation of the Land Subsidence Impressions on Gedebage District, Bandung, Indonesia

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Abstract. Gedebage district is presently experiencing rapid and mass infrastructure development and becoming one of the developed districts in Bandung, Indonesia. A football stadium, several luxury housing, the grand mosque of West Java province, and a business center have been built in this district. However, it is well known that the Gedebage district has turned into one of the Bandung districts that suffers from land subsidence phenomena. Since 2000, the Gedebage district has suffered land subsidence at an average rate of 10 cm per year and becoming one of the fastest sinking districts in Bandung. This fast land subsidence phenomenon is suspected of affecting the infrastructure in this district. Therefore, this work aims to capture the current subsidence rate in the Gedebage district using the geodetic approach of the combination of the Global Navigation Satellite System (GNSS) with Interferometric Synthetic Aperture Radar (InSAR) and investigate the impact of land subsidence on infrastructures in Gedebage district. We use GNSS campaign datasets from the years 2016 and 2019. Each GNSS campaign was performed at least 10-12 hours of observations. We also utilize a similar period of 2016 to 2019 for the InSAR datasets. Utilizing both GNSS and InSAR datasets, we can capture the subsidence with the rate reaching 4 - 15 cm per year between 2016 and 2019, and it occurs uniformly in this district. The impact of land subsidence occurred in almost all urban areas in the Gedebage district. These impacts include cracks in buildings, bridges and roads, and also tilted buildings.

1. Introduction
Land subsidence disaster is a problem for big cities in Indonesia. This disaster has a long-term adverse effect on the people in the affected area. One of the areas affected by land subsidence is the Bandung Basin (Cekungan Bandung). Land subsidence in Bandung Basin has long been identified using Global Positioning System (GPS) data and Interferometry Synthetic Aperture Radar (InSAR) [1]; [2]; [3]; [4]; [5]. According to the findings of ten GPS surveys conducted between 2000 and 2012, many locations in the Bandung Basin experienced land subsidence, with an average subsidence rate of about –8 cm/year and a maximum subsidence rate of about –16.9 cm/year in a specific location and time span. [5]. Besides, several studies from the geological and geophysical aspects also show that there has been a decline in the Bandung Basin [6]; [7]. Groundwater extraction is believed to be one of the causes of land subsidence in the Bandung Basin.
[6]; [2]; [5], alongside other contributing factors such as natural compaction, building loads, tectonic activity [6] agricultural activities [9].

Land subsidence has various effects in the Bandung Basin, including cracks in buildings, infrastructure damage (roads and bridges), tilting and damaged buildings, and increased flooding inundation areas. Flooding occurs regularly in the Bandung basin during the year, with major flooding generally occurring after heavy rainfall. Flooding in the Bandung basin has resulted in significant economic losses [6]. One area that has experienced significant land subsidence is the Gedebage district in Bandung City.

Gedebage is a district in Bandung, where the plan is to create a Technopolis area that includes government centers, housing, recreation, sports, and a business center. In the future, the Gedebage is expected to become the center of information, communication, and technology (ICT) of Bandung.

Several things must be considered in relocating the city center to the Gedebage area. One aspect that must be considered is related to the disaster (hazard) at the Gedebage is the land subsidence phenomenon. Therefore, this work aims to capture the current subsidence rate in the Gedebage district using the geodetic approach of the combination of the Global Navigation Satellite System (GNSS) with Interferometric Synthetic Aperture Radar (InSAR) and investigate the impact of land subsidence on infrastructures in Gedebage district.

2. Method

2.1. Study Site

Gedebage is a district in Bandung City, West Java Province, Indonesia. Gedebage district has four villages: Rancabolang Village, Rancanumpang Village, Cisaranten Kidul Village, and Cimincrang Village. Administratively, the Gedebage district is placed in the eastern part of Bandung City. Topographically, the Gedebage district is positioned in a lowland area with a land elevation of 627 meters above sea level. With an area of 979,930 hectares, Gedebage is currently a district with a large agricultural area compared to other districts in Bandung City. The largest area of the paddy field is located in Cisaranten Kidul Village. However, the paddy field is decreasing significantly by the incessant conversion of land functions that mostly happen in Bandung. On the surface, the formation of Kosambi dominates the Gedebage area (which is primarily affected by land subsidence). Kosambi formation mostly consists of clay, siltstone, and sandstones compact with Holocene age [10]. Aerial map of Gedebage Subdistrict resulting from aerial photography using the Unmanned Aerial Vehicle (UAV) photogrammetry method is displayed in Figure 1.

2.2. Data Acquisition

GPS data used in this study consists of 2016 GPS data and 2019 GPS data. The data is taken from field surveys that have been conducted in 2016 and 2019. The interval from GPS data is 1 second, and the length observation is at least 10 to 12 hours. 18 GPS observation points are located at a number of points in Bandung Basin, including in Gedebage District. The GPS data is tied to CORS ITB which is located on the ITB campus.

InSAR data used in this study is Sentinel-1 data. Sentinel-1 is a series of earth observation satellites which use the SAR (Synthetic Aperture Radar) instrument launched by the European Space Agency (ESA). Sentinel-1 is designed to work in a programmed mode of operation to image all global terrestrial, coastal zones at high resolution.

The sentinel image used in this study consists of four images taken from different years. Interferometric Wide Swath Mode (IW) acquisition mode with Single Look Complex (SLC) format. The details of data collection can be seen in Table 1.

In addition, field surveys were also carried out both directly and using the web scraping method to identify and calculate the damage caused by subsidence.
Figure 1. Image map of the Gedebage District, Bandung, West Java, Indonesia.

Table 1. Interferograms master-slave pair selection

| Master date          | Slave date          |
|----------------------|---------------------|
| 12 October 2016      | 17 October 2017     |
| 17 October 2017      | 18 September 2018   |
| 18 September 2018    | 13 September 2019   |
2.3. **GPS and InSAR data Processing**

Dual-frequency geodetic-type GPS receivers were used to conduct surveys at all GPS stations. ITB1 was used as the reference point as its coordinates were assumed to not differ from time to time. The ITB1 station's coordinate is defined in ITRF 2008 epoch 2012 coordinate system, and the antenna is permanently attached to the roof of a building. Standard pillars or benchmarks were established at the monitoring points, and the monitoring was done periodically using sets of GNSS receivers attached to the tripod.

In GPS data processing, we implemented the radial GPS method and investigated the height variation at the monitoring points. Using this scenario, we obtained sets of coordinates relative to ITB1. Final precise ephemerises (SP3) were used for data processing. The differencing method and the use of dual-frequency measurements limit the influence of atmospheric biases, i.e., troposphere and ionosphere. To further minimize tropospheric impacts, residual tropospheric bias parameters for individual stations were estimated. The majority of the cycle ambiguities of the phase observations were successfully resolved during the processing of GPS baselines.

Sentinel-1 data are processed using the Differential Interferometry method. The acquisition time difference is set to be around one year in order to optimize the error to signal ratio in the unwrapped image. The interferograms are formed by the closest and sequential acquisition date, as listed in Table 1.

The topographic effect is eliminated by using 3-arc-second SRTM data. The phase unwrapping is done using SNAPHU routine [11]. We set the coherence value threshold to 0.4. We find that this threshold is suitable for the Bandung area to minimize the processing time but still yield good results confirmed by ground truth checks. The remaining atmospheric error is corrected using Generic Atmospheric Correction Online Service or GACOS [12]. The resulted from unwrapped interferograms are then georeferenced to produce a deformation map in Bandung.

2.4. **Accuracy Assessment**

The InSAR validation process was done by comparing the InSAR results with the estimated land subsidence from GPS data processing. Since GPS results are more reliable than InSAR and InSAR have a higher spatial resolution than GPS, combining the two methods will provide more accurate land subsidence information [6]. Thus, the InSAR validation procedure ensures the consistency of the estimated land subsidence map. Besides, field validation was carried out to see the damage in areas with significant land subsidence.

3. **Results and Discussion**

Processing of Sentinel master and slave image pairs in 2016 and 2017, 2017 and 2018, as well as 2018 and 2019, produces maps of land subsidence values in the Bandung Basin. The total land subsidence map for three years in the Bandung Basin is displayed in Figure 2. Kopo, Dayeuhkolot, and Gedeage are the three areas in the Bandung Basin suffering the most significant land subsidence. The average land subsidence in the region is 9.2 cm/year, 10.06 cm/year, and 13.51 cm/year, respectively.
As previously explained, the results of the InSAR method will be validated with GPS observation data. GPS is used as a validator because it has higher accuracy than InSAR. Meanwhile, InSAR results can be influenced by many factors, primarily image resolution, coherence level, and radar waves' ability to penetrate the earth's surface. The validation process is carried out by comparing the GPS results and the InSAR results at the GPS observation point. In this study, it can be ascertained that the ITB1 CORS, which is used as the GPS tie point, does not experience a shift due to land subsidence. Figure 3 shows a comparison of the results of subsidence from InSAR data and GPS data. In general, land subsidence resulted from the InSAR method with GPS gave similar results.
As explained above, the Gedebage Subdistrict area is one area in the Bandung Basin that has experienced the most considerable land subsidence. Figure 4 shows in more detail the subsidence that occurred in the Gedebage area. Land subsidence occurs in all urban villages with a reduction rate ranging from 4-15 cm per year. Several samples were selected to see the time series of subsidence in this area. The time series of each sample can be seen in Figure 5. Concluding from the land subsidence's pattern, land subsidence that occurs in Gedebage tends to be linear and has occurred to date. Rancabolang Village is the area with the most extensive land subsidence. However, Cisaranten Kidul Village underwent the largest land subsidence. Natural compaction and building loads are deemed to be the causes of land subsidence in the Gedebage Area. Land subsidence occurs in residential areas, roads and bridges, mosques, sports facilities, and business areas.
Figure 4. Total land subsidence in the Gedebage District for the period 2016-2019. Dot indicates the GPS Point.

Figure 5. Selected time series of land subsidence in Gedebage District, 2014-2019.
According to the in-situ observation field survey and web-scraping activities, several pieces of evidence of land subsidence in the affected area were identified. For example, cracks in houses, short houses (because the ground ahead was continuously raised), sloping houses, damage to infrastructure (roads and toll roads), and allegedly expanded the flood inundation area. The entire Cisaranten Kidul area has the most house damage and the longest road damage. Figure 6 and Figure 7 show the damage due to subsidence in Gedebage District.

Figure 6. Damage to roads and bridges due to subsidence in Gedebage District

Figure 7. Building damage due to land subsidence in Gedebage District
4. Conclusion

InSAR data processing shows that land subsidence occurs in all districts in Gedebage District, with subsidence rates reaching 4-15 cm per year. The results from GPS data processing show that the land subsidence rate in Gedebage reaches 9.96 cm per year. The pattern of land subsidence in the Gedebage district tends to be linear and is still happening today. Land subsidence occurs in strategic places such as sports facilities, major mosques, housing estates, roads, and bridges. In these locations, many damages can interfere with the function of these objects. In the future, this land subsidence disaster must be given special attention in the development process at Gedebage.

References

[1] Gumilar I, Abidin H Z, Andreas H, Sidiq T P, Gamal M, and Fukuda Y 2013 Land Subsidence, Groundwater Extraction, and Flooding in Bandung Basin (Indonesia) IAG Symp. 139 Earth on the Edge: Science for a Sustainable Planet Chris Rizos Pascal Willis (Eds) ISBN 978-3-642-37221-6.
[2] Abidin H Z, Andreas H., Gamal M, Wirakusumah A D, Darmawan D W, Deguchi T, and Maruyama T 2008 Land Subsidence Characteristic of The Bandung Basin, Indonesia, as Estimated From GPS and InSAR Journal of Applied Geodesy 2 167-177.
[3] Abidin H Z, Gumilar I, Andreas H, Murdohardono D, and Fukuda Y 2012 On Causes and Impacts of Land Subsidence in Bandung Basin, Indonesia Environmental Earth Sciences DOI 10.1007/s12665-0121848-z.
[4] Ge L, Man Ng A H, Li X, Abidin H Z, Gumilar I 2014 Land subsidence Characteristics of Bandung Basin as Revealed by ENVISAT ASAR and ALOS PALSAR Interferometry Remote Sensing of Environment 154 (2014) 46–60.
[5] Estelle C, Amelung F, Abidin H Z, dan Hong S H 2012 Sinking Cities in Indonesia: ALOS PALSAR Detects Rapid Subsidence Due to Groundwater and Gas Extraction. Remote Sensing Environment 29 266 – 278.
[6] Gumilar I, Abidin, H Z, Hutasoit L M, Hakim D M, Sidiq T P, Andreas, H 2013 Land subsidence in Bandung Basin and its Possible Caused Factors. Procedia Earth and Planetary Science 12 (2015) 47-62.
[7] Taufiq A 2010 Land subsidence study for Bandung and surrounding areas (case study area: Dayeuhkolot, Rancaekek and Cimahi) (in Indonesian) MSc Thesis, Bandung Institute of Technology (ITB) Bandung Indonesia
[8] Setyawan A, Fukuda Y, Nishijima J, and Kazama T 2015 Detecting Land Subsidence Using Gravity Method in Jakarta and Bandung Area, Indonesia. Procedia Environmental Sciences 23 (2015)
[9] Sidiq T P, Gumilar I, Abidin, H Z, Gamal M 2019 Land subsidence induced by agriculture activity in Bandung, West Java Indonesia IOP Conf. Series: Earth and Environmental Science 389 (2019) 012024. doi:10.1088/1755-1315/389/1/012024
[10] Hutasoit, L M 2006 Recharge Area and the Origin of Brackish Water in East Bandung: Result of exploration Well, Proceeding of 9th International symposium on Mineral Exploration (ISME IX), Bandung, Indonesia, 19 – 21 September 2006.
[11] Chen C W and Zebker H A 2002 Phase unwrapping for large SAR interferograms: Statistical segmentation and generalized network models IEEE Transactions on Geoscience and Remote Sensing 40 pp 1709-1719 (2002).
[12] Yu C, Li Z, Penna N T 2018 Interferometric synthetic aperture radar atmospheric correction using a GPS-based iterative tropospheric decomposition model Remote Sensing of Environment 204 pp 109-121 (2018)