ELKOMIKA: Jurnal Teknik Energi Elektrik, Teknik Telekomunikasi, & Teknik Elektronika

ISSN(p): 2338-8323 | ISSN(e): 2459-9638 | Vol. 12 | No. 4 | Halaman 1116 - 1126
DOI : http://dx.doi.org/10.26760/elkomika.v12i4.1116 Oktober 2024

Utilization of PS-InSAR for Analyzing Land Subsidence in the Bandung Basin, Indonesia using Sentinel-1A Data

DEWI KANIA SARI[1], HENRI KUNCORO[1], RIAN NURTYAWAN[2]

[1]Institut Teknologi Nasional Bandung, Indonesia
[2]Universitas Pakuan, Bogor, Indonesia
Email: dewiks@itenas.ac.id

Received 30 Agustus 2024 **|** *Revised* 25 Oktober 2024 **|** *Accepted* 30 Oktober 2024

ABSTRAK

Cekungan Bandung, yang berlokasi di Provinsi Jawa Barat, Indonesia, rentan terhadap penurunan muka tanah. Penelitian ini menganalisis laju penurunan muka tanah di Cekungan Bandung selama tahun 2019 menggunakan metode PS-InSAR yang diterapkan pada citra satelit Sentinel-1A. Sebanyak delapan citra Sentinel-1A, yang diperoleh antara Januari hingga Desember 2019, diproses menggunakan perangkat lunak SNAP dan STAMPS. Hasil analisis menunjukkan bahwa laju deformasi permukaan tanah di Cekungan Bandung berkisar dari -133 hingga 98 mm/tahun, dengan penurunan paling signifikan terjadi di Kota Bandung dan Kabupaten Bandung. Perbandingan hasil PS-InSAR dengan data survei GPS dari sembilan titik pemantauan menunjukkan korelasi yang kuat (R=0,75), mengonfirmasi keandalan metode PS-InSAR untuk pemantauan penurunan tanah. Temuan ini menegaskan pentingnya pemantauan berkelanjutan dan pengelolaan sumber daya secara bijak guna mengurangi dampak penurunan muka tanah di Cekungan Bandung.

***Kata kunci**: penurunan muka tanah, PS-InSAR, Cekungan Bandung, Sentinel-1A*

ABSTRACT

The Bandung Basin, situated in West Java Province, Indonesia, is highly vulnerable to land subsidence. This study assesses the rate of land subsidence in this area throughout 2019 using the PS-InSAR method applied to Sentinel-1A satellite imagery. We processed eight Sentinel-1A images, acquired between January and December 2019, by using SNAP and STAMPS software. The findings reveal that deformation rates in the Bandung Basin vary between -133 and 98 mm per year, with the most severe subsidence observed in Bandung City and Bandung Regency. A comparison between PS-InSAR measurements and GPS survey data from nine monitoring points revealed a strong correlation (R=0.75), confirming the reliability of the PS-InSAR method for land subsidence monitoring. These findings underscore the importance of continuous monitoring and sustainable resource management to mitigate land subsidence in the area.

***Keywords**: land subsidence, PS-InSAR, Bandung Basin, Sentinel-1A*

1. INTRODUCTION

The Bandung Basin Urban Area is a National Strategic Area (NSA) from the point of view of economic interests stipulated based on Presidential Regulation Number 45 of 2018 concerning Spatial Plans for the Bandung Basin Urban Area (**Presidential Regulation of the Republic of Indonesia No. 45, 2018**). The aim of spatial planning is to create world-class urban areas as cultural centers, tourism centers, as well as centers for national creative services and economic activities, based on higher education and high-tech industries that are competitive and environmentally friendly. The Bandung Basin Urban Area consists of the Core Area, namely Bandung City and Cimahi City and the Surrounding Areas namely Bandung Regency, West Bandung Regency, and 5 Districts in Sumedang Regency. The Bandung Basin, located in West Java Province, Indonesia, is an extensive intramontane basin enclosed by volcanic plateaus. This region is a rapidly urbanizing area that has experienced significant population growth over the past few decades. The Bandung Basin is quite vulnerable to land subsidence, caused partly by an increase in population, industrial activities, and groundwater extraction in this area. Another factor believed to contribute to land subsidence in the Bandung Basin is the movement of geological or tectonic structures **(Gumilar et al., 2012)**.

Land subsidence is a type of ground deformation that frequently occurs worldwide, especially in urban and coastal regions. This phenomenon results from natural processes, human activities, or a combination of both. The negative effects of land subsidence may include infrastructure damage in the affected area caused by excessive withdrawal of water for industrial purposes and soil-forming structures in the area. Therefore a method is needed to measure and map land subsidence, especially in urban areas with highly dynamic human activities such as the Bandung Basin.

The subsidence phenomenon in the Bandung Basin has been investigated through geodetic methods, namely Global Positioning System (GPS) surveys **(Abidin et al., 2006)** and InSAR remote sensing techniques **(Abidin et al., 2008; Sudiana et al., 2017)**. GPS or GNSS networks serve as reliable inputs for disaster monitoring systems, offering precise and point-specific data. However, their deployment and configuration are constrained by topographical challenges. Furthermore, monitoring a large area requires significant costs and extended time. To address these limitations, a complementary approach is necessary. Remote sensing technology, such as InSAR, offers an alternative solution due to its ability to measure deformation across extensive regions efficiently. This method utilizes radar sensors, typically mounted on aircraft or satellites, to map the Earth's surface from a specific altitude. Persistent Scatterer-InSAR (PS-InSAR) is an approach developed to address decorrelation issues present in earlier techniques (**Ansar et al., 2021; Khan et al., 2022**). PS-InSAR, which is an extension of the (DInSAR) method, exploits phase information in a collection of SAR images obtained at the same area and at different times, to obtain measurements and monitor deformation in an area. The PS-InSAR technique, which has been developed in recent years, addresses temporal and geometric decorrelation by detecting pixels where the primary backscattering signal originates from a single persistent scatterer (PS) across multiple interferograms **(Hooper & Zebker, 2007)**. These pixels exhibit high coherence, stable amplitude, and strong scattering properties over time **(Crosetto et al., 2016)**.

The PS-InSAR method has become a highly effective tool for monitoring land subsidence in various cities worldwide, such as Shanghai **(Zhang et al., 2023)**, Jakarta **(Handika et al., 2024)**, Lahore **(Hussain et al., 2022),** and Changcun **(Wang et al., 2021)**. The key advantages of PS-InSAR include high spatial and temporal resolution, measurement accuracy at the sub-millimeter level, and the ability to cover large areas with cost efficiency **(Zhang et**

al., 2023). Additionally, PS-InSAR enables continuous ground deformation monitoring without requiring physical sensor installations in the field, making it a non-destructive and cost-effective method **(Hussain et al., 2022)**. This capability is crucial for identifying high-risk subsidence areas, particularly in urban regions with dense infrastructure. However, the effectiveness of PS-InSAR can be influenced by factors such as atmospheric disturbances and the availability of stable scatterers, which is why it is often combined with other methods, such as SBAS-InSAR **(Zhang et al., 2022)** or GPS data **(Hu et al., 2016)**, to enhance data accuracy and validity.

According to the findings of a GPS survey carried out by **(Gumilar et al., 2015)**, It was observed that between 2000 and 2012, several areas in the Bandung Basin experienced subsidence, with an average rate of approximately 8 cm per year, reaching up to 16.9 cm per year in specific locations and time periods. Comparable findings were derived from InSAR data, indicating that between 1999 and 2010, the maximum subsidence rate in the Bandung Basin reached 2 meters, primarily occurring in industrial zones **(Gumilar et al., 2015)**. Meanwhile, **(Sudiana et al., 2017)** applied the PS-InSAR method to observe subsidence in the Bandung Basin using ten ALOS/PALSAR images, from 10 June 2007 to 13 December 2008. The results of their study show that during this period, the rate of deformation of the ground surface in nearly all metropolitan areas in Bandung, West Java, Indonesia increased. The most significant land subsidence rates were detected in Cimahi and Bojong Districts, each reaching 13.5 cm per year.

The rate of land subsidence in the Bandung Basin requires ongoing monitoring using better and more up-to-date methods and data. The application of the PS-InSAR method for monitoring land subsidence in the Bandung Basin remains limited and needs a more precise validation process. This study analyzed land subsidence in the Bandung Basin in 2019 by applying the PS-InSAR method to Sentinel-1A data. The results were compared with GPS survey measurements.

2. DATA AND METHODS

2.1 Study Area

Geographically, the Bandung Basin area is located between 6°48'28.47"–6°59'15" South Latitude and 107°30'.45"–107°44'56.19" East Longitude. The Bandung Basin or also known as Greater Bandung is one of the metropolitan areas that has 5 (five) administrative areas including the Bandung Regency, covering an area of 176,812 hectares, West Bandung Regency, spanning 130,557.40 hectares, part of Sumedang Regency (Tanjungsari, Cimanggung, Jatinangor, Sukasari, and Pamulihan Districts) with a total area of 15,486 hectares, as well as the City of Cimahi with an area of 4,023 hectares and the City of Bandung with an area of 16,729.65 hectares as the core cities. The Bandung Basin is a landform characterized by its basin-shaped topography (Fig. 1) with an area of approximately 343,087 hectares. The lowest part of the Bandung Basin has an area of approximately 75,000 hectares and an elevation of approximately 650–700 m above sea level **(Sistem Informasi Pemanfaatan Ruang (Sifataru), 2019)**.

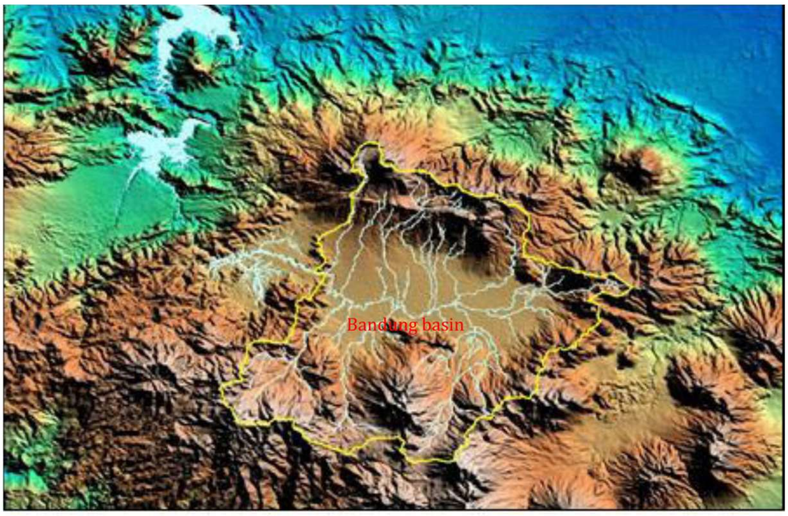

Figure 1. Topography of the Bandung Basin Area (Gumilar et al., 2015)

2.2 Data

The data used in this research consists of:

- Sentinel-1A satellite data, consisted of 8 data collected between January to December, 2019 (Table 1). The data were downloaded freely from the Copernicus website (https://scihub.copernicus.eu/). The imaging mode employed is Interferometric Wide Swath (IW) with a level-1 Single Look Complex (SLC) product type and Vertical-Vertical (VV) polarization.
- 1Arc-Second SRTM DEM data, meaning that the DEM provides information on the height of the earth's surface with a resolution of 1 arc-second, approximately 30 meters **(U.S. Geological Survey (USGS), 2020).** This data is downloaded automatically to the SNAP software, and is used to eliminate topographical effects and differential interferometry.
- Land subsidence rate data for the Bandung Basin derived from GPS observations provided by the Geodesy Research Group at Institut Teknologi Bandung (ITB). There are nine GPS points (Fig. 2) with observation periods ranging from 2014 to 2019; however, observations were not conducted at all points every year.

Table 1. List of Sentinel-1A Images

No	ID Scene	Date of Image	Level	Orbit Direction
1	S1A_IW_SLC__1SDV_20190107T111440_20190107T111510_025370_02CF15_572D	January 7, 2019	1.0 SLC	Ascending
2	S1A_IW_SLC__1SDV_20190212T111439_20190212T111509_025895_02E20B_CCF7	February 12, 2019	1.0 SLC	Ascending
3	S1A_IW_SLC__1SDV_20190401T111439_20190401T111509_026595_02FB7A_773C	April 1, 2019	1.0 SLC	Ascending
4	S1A_IW_SLC__1SDV_20190612T111442_20190612T111512_027645_031ED2_8493	June 12, 2019	1.0 SLC	Ascending
5	S1A_IW_SLC__1SDV_20190811T111446_20190811T111516_028520_03397F_0A2B	August 11, 2019	1.0 SLC	Ascending
6	S1A_IW_SLC__1SDV_20190904T111447_20190904T111517_028870_0345A8_3437	September 4, 2019	1.0 SLC	Ascending
7	S1A_IW_SLC__1SDV_20191103T111448_20191103T111518_029745_0363DF_FD36	November 3, 2019	1.0 SLC	Ascending
8	S1A_IW_SLC__1SDV_20191209T111448_20191209T111517_030270_037614_BF79	December 9, 2019	1.0 SLC	Ascending

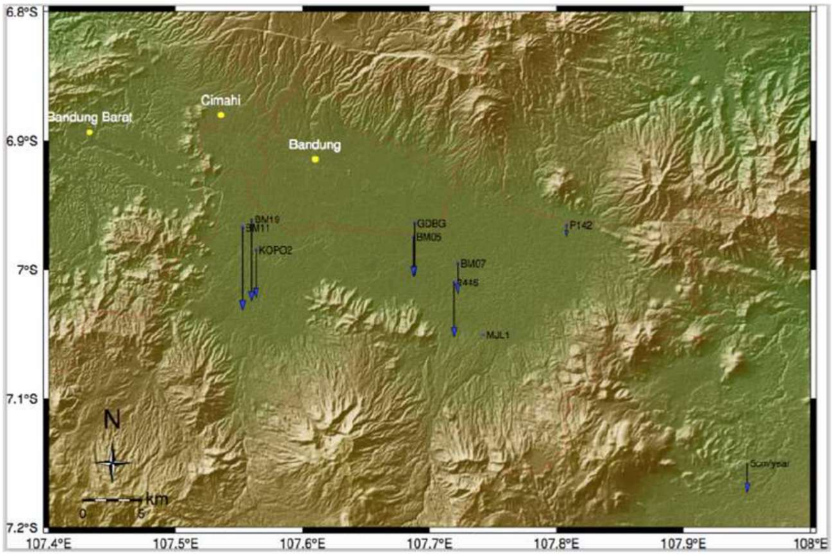

Figure 2. Arrangement of GPS Stations in Bandung Basin for Land Subsidence Monitoring

2.3 Methods

PS-InSAR processing was carried out using SNAP and STAMPS softwares. Figure 3 shows the flowchart representing the SNAP and StaMPS processing steps **(Ahmad et al., 2022)**. PS-InSAR processing is grouped into three stages, namely pre-StaMPS processing, StaMPS processing, and post-StaMPS processing. The pre-StaMPS processing stage includes the collection and selection of SAR image data and several processes carried out in SNAP software such as main distance estimation, Back Geocoding, Interferogram Formation, TOPSAR Deburst, Topographic Phase Removal, and Gamma Export processes. The StaMPS processing stage consists of pre-processing, seven core stages, and the PS points and distribution plotting stage which is carried out using the Matlab software which runs on the Ubuntu Linux OS. The post-StaMPS processing stage was the exporting stage of PS-InSAR processed points. The PS-InSAR points were then interpolated using the IDW interpolation method to obtain deformation data in raster format. The rate of land subsidence resulting from PS-InSAR processing was then compared to that obtained from GPS observations.

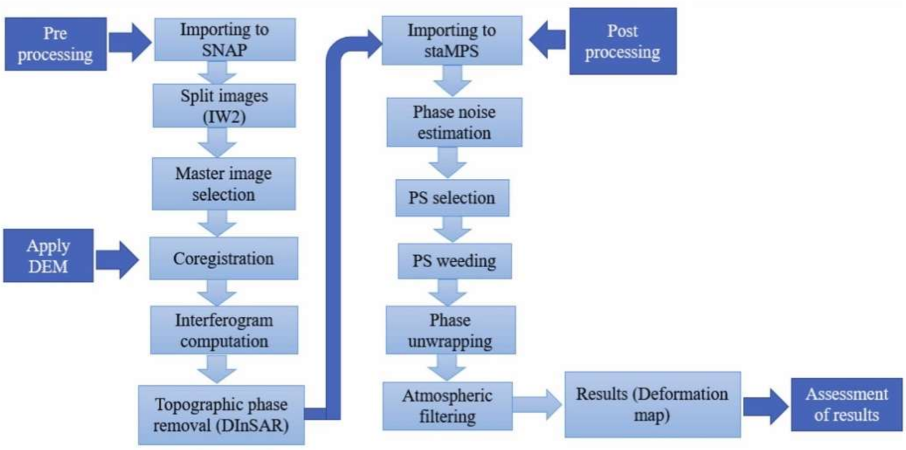

Figure 3. PS-InSAR Processing Steps (Ahmad et al., 2022)

3. RESULTS AND ANALYSIS

3.1 Land Subsidence of Bandung Basin Observed from PS-InSAR

Figure 4 presents the surface deformation velocity of the Bandung Basin during 2019, derived from the PS-InSAR method applied in this study using eight Sentinel-1A images. The deformation velocity in the study area ranges from -133 to 98 mm/year, where positive values on the map indicate uplift. Although land subsidence rates vary, the Bandung Basin has experienced subsidence annually. The most significant subsidence rates are primarily observed in Bandung Regency and Bandung City. Figure 5 illustrates the deformation in the Bandung Basin, highlighting the subdistrict boundaries in the area.

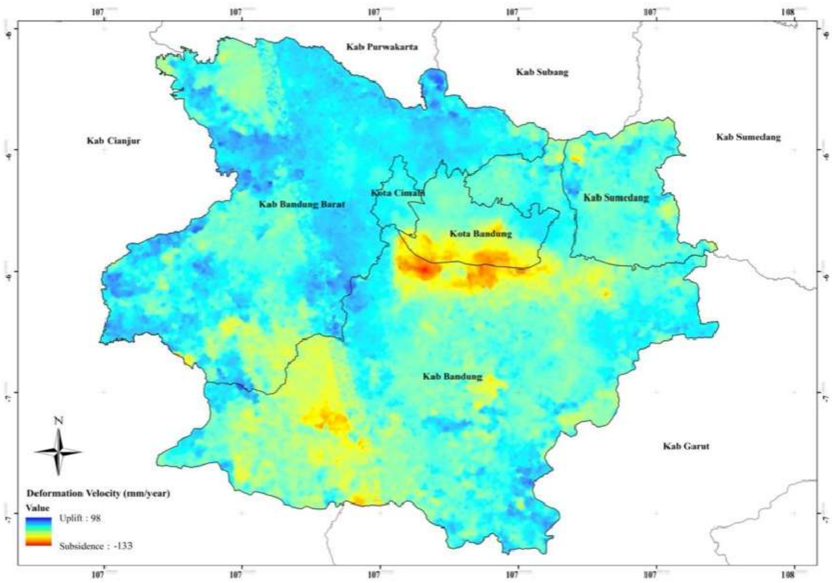

Figure 4. Deformation Map of the Bandung Basin Area in 2019 from PS-InSAR processing

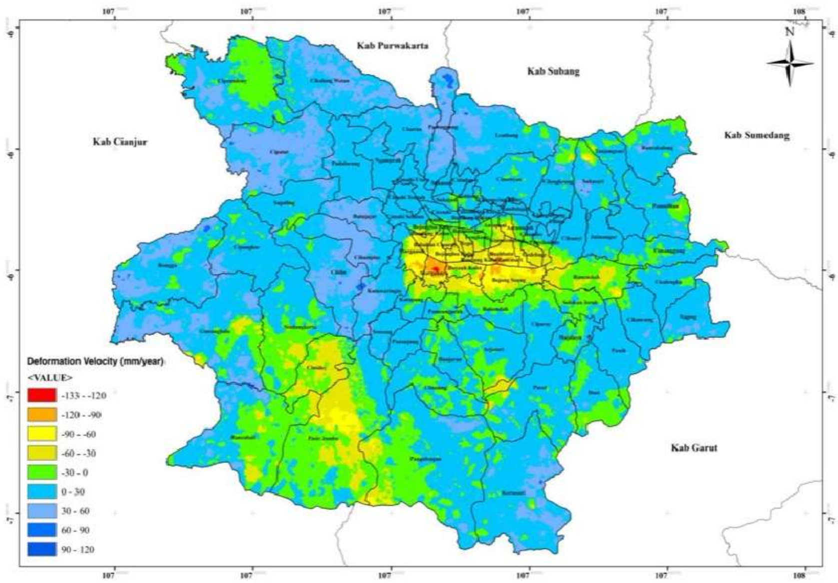

Figure 5. Deformation Map of the Bandung Basin in 2019 Showing District Boundaries

Table 2 details the subdistricts in each city/regency that experienced the most land subsidence, i.e., velocities greater than 9 cm/year. The result of this study is somewhat different from the study by **(Sudiana et al., 2017)**, where the most severe land subsidence was recorded in Cimahi and Bojongsoang Subdistricts at a rate of 13.5 cm per year. This is possibly due to the data used by **(Sudiana et al., 2017)** were obtained from ALOS PALSAR between June 10, 2007, and December 13, 2008. Likewise, a study by **(Prasetyo et al., 2014)** using ALOS PALSAR data (from July 2007 to February 2011) found that the Astana Anyar, Babakan Ciparay, Bandung Kulon, and Regol Subdistricts experienced the highest subsidence rates in Bandung City, ranging from 28.7 mm/year to 58 mm/year. Meanwhile, a GPS survey conducted by **(Gumilar et al., 2015)** revealed that several areas within the Bandung Basin underwent subsidence between 2000 and 2012, with an average rate of 8 cm per year and a peak rate of 16.9 cm per year in certain locations and time frames.

An extensive study on land subsidence in Gedebage Subdistrict was conducted by **(Gumilar et al., 2021)** using GNSS and InSAR data. They processed Sentinel image pairs for three consecutive periods (2016–2017, 2017–2018, and 2018–2019), generating separate land subsidence maps for each period in the Bandung Basin. Their findings indicate that the most affected areas are Kopo (located in Bandung Kaler Subdistrict), Dayeuhkolot Subdistrict, and Gedebage Subdistrict, with respective average subsidence rates of 9.2 cm per year, 10.06 cm per year, and 13.51 cm per year.

In Gedebage Subdistrict, their study observed subsidence rates ranging from 4 to 15 cm/year between 2016 and 2019, with variations across different areas. Meanwhile, the present study shows that most areas of Gedebage Subdistrict experience subsidence at rates of 3 to 6 cm/year. A small portion in the north has rates ranging from 0 to 3 cm/year, while in the south, a very small area exhibits a rate of 6 to 9 cm/year. In this study, although Kopo is among the areas experiencing significant subsidence, it does not have the highest rate, with a maximum of 6 cm/year.

Table 2. Subdistrict Areas Experiencing the Highest Land Subsidence in 2019

City/Regency	Subdistrict
Bandung City	Buahbatu, Bandung Kidul, Rancasari, Bojongloa Kidul
Bandung Regency	Bojong Soang, Dayeuh Kolot, Margahayu, Margaasih

3.2 Comparison of Land Subsidence from PS-InSAR and GPS Survey Results

To evaluate the viability of land subsidence measurements obtained using the PS-InSAR method, a comparison was conducted with GPS observation results. However, this comparison is not entirely ideal, as the available GPS data covers a different observation period than the PS-InSAR data. Therefore, this analysis is more focused on assessing plausibility. Table 3 and Fig. 6 present the comparison results, while Fig. 5 illustrates the regression line.

In this paper, subsidence rates are expressed as positive values, as subsidence inherently refers to ground sinking. However, in tables and graphs, they are represented as negative values to visually emphasize ground lowering relative to GPS data. This difference in format does not affect the interpretation of the data.

Table 3. Comparison of Bandung Basin Land Subsidence from GPS and PS-InSAR

STA	Observation Years	Land Subsidence	
		GPS (cm/yr)	PS-InSAR (cm/yr)
KOPO2	2014, 2015, 2016, 2019	-8.0	-4.7
BM19	2016, 2019	-13.6	-7.0
BM11	2014, 2015, 2016, 2019	-13.4	-9.0
P142	2014, 2015, 2016, 2019	-2.0	-0.3
MJL1	2014, 2015, 2016	-0.1	0.2
GDBG	2014, 2015, 2016, 2019	-8.7	-6.2
2445	2014, 2015, 2016	-9.1	-1.2
BM07	2014, 2015, 2016, 2019	-5.1	-3.6
BM05	2014, 2015, 2016	-6.6	-8.3

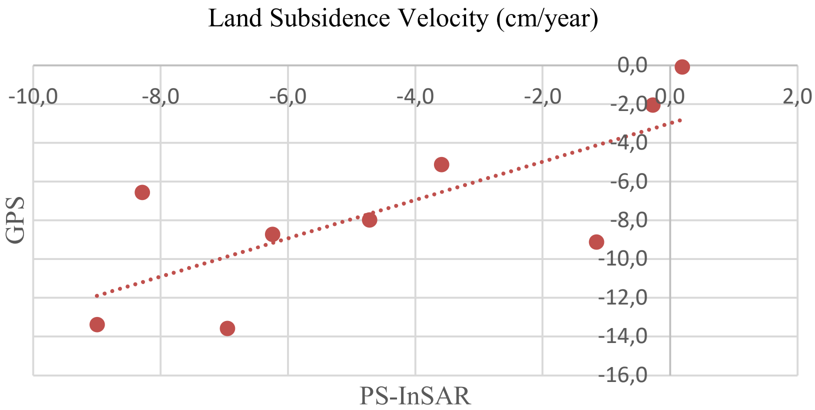

Figure 5. Regression Analysis of Land Subsidence Between PS-InSAR and GPS Survey Results

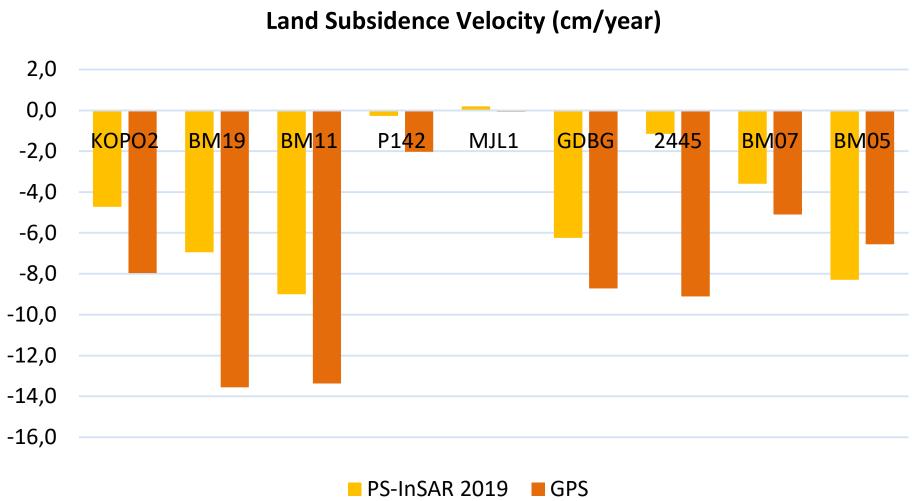

Figure 6. Graphic of Land Subsidence on Monitoring Points from PS-InSAR and GPS Survey

The comparison results indicate that although land subsidence at each GPS monitoring point varies in velocity, both methods confirm that subsidence has occurred in various areas of the Bandung Basin. Regression analysis also demonstrates a strong correlation (**R = 0.75**) between the GPS and PS-InSAR observation results (Fig. 5). This suggests that the PS-InSAR method holds significant potential for monitoring land subsidence, including in the Bandung Basin, which is one of Indonesia's national strategic areas. Further research is needed to assess the reliability of PS-InSAR observations over a longer period and to validate them using high-precision GPS measurements. Additionally, exploring other remote sensing methods that are considered reliable for measuring land subsidence is recommended.

4. CONCLUSIONS

This study analyzed land subsidence in the Bandung Basin through the application of the PS-InSAR method and compared the results with previous studies and GPS survey data. The findings confirm that subsidence continues to affect various areas, with the highest rates observed in Bandung City and Bandung Regency. Compared to earlier studies, differences in the identified locations and subsidence rates highlight the influence of different observation periods and data sources. The comparison between PS-InSAR and GPS data indicates a strong correlation (R = 0.75), demonstrating the potential of PS-InSAR for monitoring land subsidence. However, differences in observation periods limit the direct comparability of results, making this analysis more of a plausibility assessment. Future research should focus on long-term monitoring using PS-InSAR, validation with high-precision GPS surveys, and the exploration of other remote sensing techniques to enhance the accuracy of subsidence measurements in the Bandung Basin.

ACKNOWLEDGMENTS

This research was funded by the Institut Teknologi Nasional (Itenas) Research Grant. The authors would like to thank Copernicus, the European Union's Earth Observation Programme, for supplying the Sentinel-1A data. Gratitude is also extended to the Geodesy Research Group at Institut Teknologi Bandung (ITB) for providing the GPS survey data on land subsidence in the Bandung Basin. Additionally, the authors express their gratitude to PT. Pratama Persada Airborne for supporting this research with computing facilities.

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