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Assessing Recent Land Subsidence in Bandar Lampung City, Indonesia through Time Series InSAR from 2015 to 2023

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ABSTRACT

Bandar Lampung is a densely populated city with a rapidly increasing growth rate each year, faces challenges related to significant demand for water resources that contributes to subsidence. This study detect the recent land subsidence in Bandar Lampung using Sentinel-1 data, panning the period from 2015 to 2023. The Small Baseline Subset (SBAS) interferometric synthetic aperture radar (InSAR) method was employed to analyze the subsidence trends, with corrections for atmospheric effects applied using the Generic Atmospheric Correction Online Service (GACOS) to enhance data accuracy. The analysis revealed an average subsidence rate in the city ranging from approximately -2 mm/year to -6.9 mm/year. The InSAR analysis identified that the eastern regions of Bandar Lampung, particularly subdistricts such as Sukabumi, Sukarame, Tanjung Senang, Kedamaian, and Wayhalim, experienced the most significant rates of subsidence. This pronounced ground sinking is closely associated with intensive industrial activities and excessive groundwater extraction in these areas, which together have accelerated the destabilization of the ground surface. The continuous monitoring of subsidence is crucial for mitigating potential risks, including infrastructure damage and increased flood vulnerability.

ARTICLE INFO

Article History:
Submitted/Received 30 May 2024
First Revised 30 September 2024
Accepted 30 October 2024
First Available online 31 Octtober 2024
Publication Date 31 October 2024

Keywords:
Land Subsidence,
InSAR,
Sentinel 1,
Line of Sight (LOS),
Vertical Displacement

DOI: https://doi.org/10.17509/gea.v24i2.71315
p- ISSN 1412-0313 e- ISSN 2549-7529

1. INTRODUCTION

Land subsidence caused by excessive compaction of aquifer systems and climate change has caused severe damage to agricultural land, excessive air use, industrial activities, and urban infrastructure (Ghorbani et al., 2022; Yang et al., 2021). Land subsidence occurs in big cities in Indonesia, such as Jakarta City (Abidin et al., 2011; Luo et al., 2022), Bandung City (Gumilar et al., 2015), and Semarang City (Lo et al., 2022). Land subsidence is an environmental problem in large cities and needs to be studied to determine the risks by monitoring land subsidence. Precise and accurate monitoring can provide the necessary information to identify potential hazards, measure the level of vulnerability, and plan effective mitigation actions.

Bandar Lampung City is the capital of Lampung Province and has a strategic location. Many transportation activities from the island of Java to other provinces on the island of Sumatra through the city of Bandar Lampung make this city busy with activity. This increases sector activity in various fields and triggers rapid growth of built-up land. The Population growth rate in Bandar Lampung City from 2020 to 2022 is 2.13%, with a total Population of 1,209,937 (Badan Pusat Statistik, 2023). The growth of built-up land occurs due to increasing Population activity to meet their living needs. This is also in line with the increasing population of Bandar Lampung City from year to year. Increased built-up land and population activities will impact natural phenomena, including land subsidence (Orhan, 2021).Bandar Lampung, the capital of Lampung Province, has the potential for significant land subsidence due to population activity and development that continues to grow. Based on the Geological Map, Bandar Lampung, located on the Lampung - Panjang fault, has the potential for large deformation and land subsidence (Moisidi et al., 2020). The occurrence of land subsidence can cause water to pool on land, and if it occurs in coastal areas, it can cause sea water levels to be higher than land levels and increase the potential for ROB flooding. The Disaster Risk Study Document (KRB) for Bandar Lampung City for 2016-2020 shows that Bandar Lampung City has a history of flood disasters up to several meters high in 9 subdistricts, while in the coastal area of Bandar Lampung City experiencing ROB flooding, it is recorded that four subdistricts experienced annual ROB flood. ROB floods in Bandar Lampung City's coastal areas were found in Panjang, East Betung Bay, South Betung Bay, and Panjang subdistricts. Land subsidence is a serious matter if it occurs in coastal areas. Coastal areas are vulnerable to pressure from various environments, including land and sea (Tay et al., 2022; Cigna & Tapete, 2021).

Deformation can be observed using GNSS (Global Navigation Satellite System) by measuring the precise movement of the Earth's surface (Alif et al., 2021; Anggara et al., 2024). Additionally, InSAR (Interferometric Synthetic Aperture Radar) provides spatial deformation data by analyzing radar images taken from satellites for detecting ground displacement over larger areas (Alif et al., 2024). Previous studies have highlighted the risk of land subsidence in Bandar Lampung, with research between 2007 and 2011 detecting rates of up to 30 mm/year using Interferometric Synthetic Aperture Radar (InSAR) (Zaenudin et al., 2018). However, research using longer and more recent data is still rarely carried out in Bandar Lampung City, this research will support and complement previous research using Interferometric Synthetic Aperture Radar (InSAR) data. In several studies, Sentinel 1 can provide spatial deformation such as deformation of volcanoes (Anggara et al., 2023; Natadikara et al., 2023), flood vulnerability (Yusup et al., 2023), earthquakes (Biggs et al., 2007), and land subsidence (Cigna & Tapete, 2021). This research using Sentinel 1 with the Small Baseline Subset (SBAS) InSAR method from 2015 to 2023 to monitoring land subsidence in Bandar Lampung City. Monitoring land subsidence in Bandar Lampung City as an effort to understand the risk of

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p- ISSN 1412-0313 e- ISSN 2549-7529

disasters caused by the phenomenon of land subsidence and its implications for vulnerability and potential hazards.

2. METHODS

The research area covers the entire city of Bandar Lampung, covering a total area of 197.22 km² and consisting of 20 subdistricts, as shown in **Figure 1**. This study processes interferogram data from Sentinel-1 satellite images, using data from 2015 to 2023 for ascending images and from 2017 to 2023 for descending images.

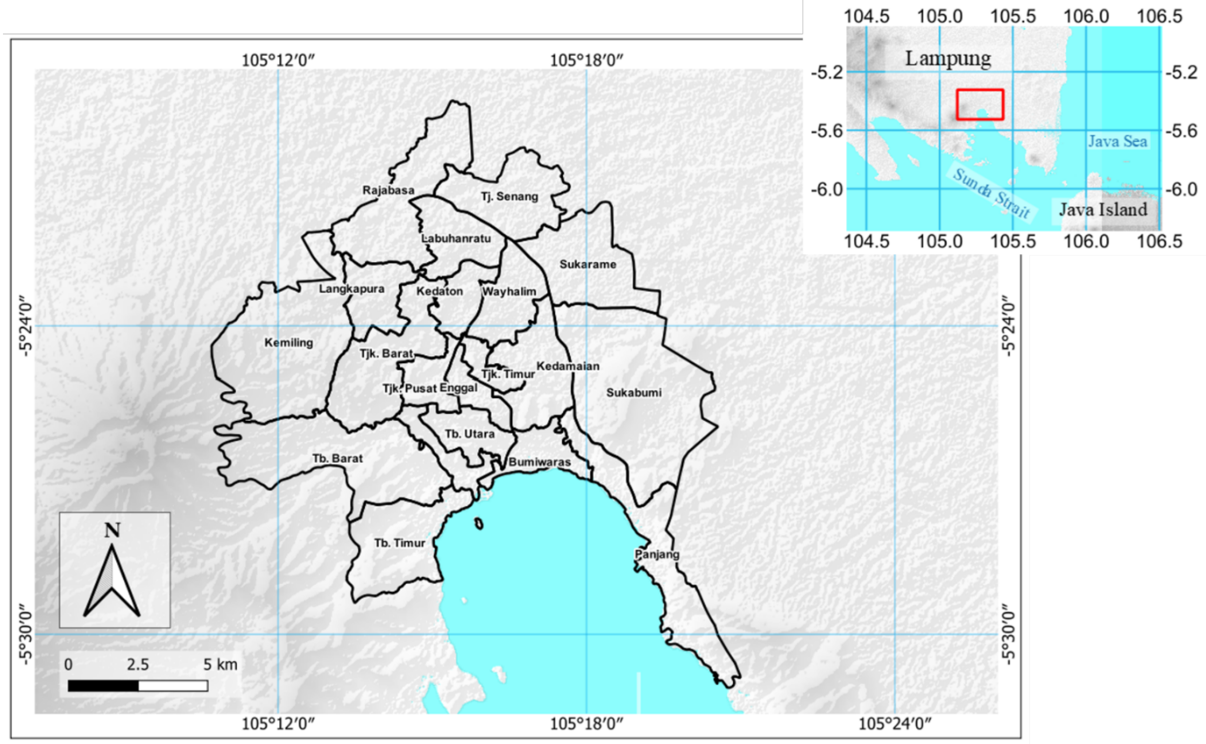

Figure 1. Research Location in Bandar Lampung City, Indonesia. The red rectangle is an inset showing the research location

Interferogram data is downloaded from the COMET-LiCS Sentinel-1 InSAR web portal on the page https://comet.nerc.ac.uk/COMET-LiCS-portal/ with an area of approximately 250 x 250 km with the interferometric wide (IW) swath mode. Interferogram processing using LICSBAS software (Morishita et al., 2020), includes interferogram data used to obtain Line of Sight (LOS) deformation values with 841 Ascending interferogram data and 272 Descending interferogram data. Interferogram data on a footprint frame with an area of 250x250 km is cropped according to the research location to increase data processing time. Sentinel data require a reduction of the tropospheric effect from interferogram data, which has noise due to water vapour, temperature and pressure in the atmosphere (Hayati et al., 2022). Then applied to remove tropospheric noise correction using the Generic Atmospheric Correction Online Service (GACOS) data accessed from http://www.gacos.net/ (Yu et al., 2018). Then, quality checks and loop closures are used to eliminate poor-quality interferogram data based on coherence and unwrapped parameters. The unwrapped process is obtained from quality and loop check results by estimating the unwrapped phase from various time series and converting them into line of sight (LOS) deformation pixels. The LOS deformation results and time series with vertical projection to determine the rate of land subsidence based on off-nadir projections (e.g., Sun et al., 2023). Decomposition applying 2.5 D to obtain the vertical velocity rate value from LOS deformation (Fuhrmann & Garthwaite, 2019).

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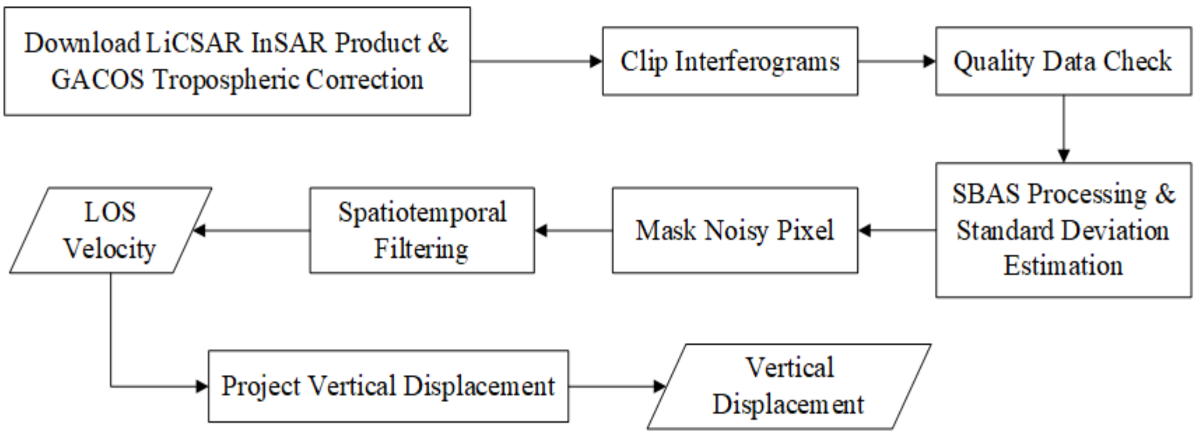

Figure 2. Flowchart Methodology Estimation Subsidence using SBAS Method

3. RESULTS AND DISCUSSION

Line of Sight (LOS) deformation is the angle of view of the satellite in transmitting and receiving signals back. LOS deformation shows the amount of deformation based on the satellite's viewpoint (e.g., Alif et al., 2023). Positive values indicate deformation approaching the satellite direction, and negative values indicate deformation moving away from the satellite direction. The LOS deformation of the ascending image processing rate using atmospheric correction in the Bandar Lampung City area from 2015 - 2023. The LOS deformation rate value in Bandar Lampung City is ~-7.2 mm/year to ~+9.8mm/year, with an average LOS deformation rate of ~+0.4 mm/year. The average LOS deformation value in Bandar Lampung City is ~-1.7 mm/year. The subdistrict with the highest subsidence LOS deformation value is the Sukarame subdistrict, which is ~-2.3 mm/year. Negative LOS deformation values are dominated in the eastern part of Bandar Lampung City, as represented in **Figure 3**.

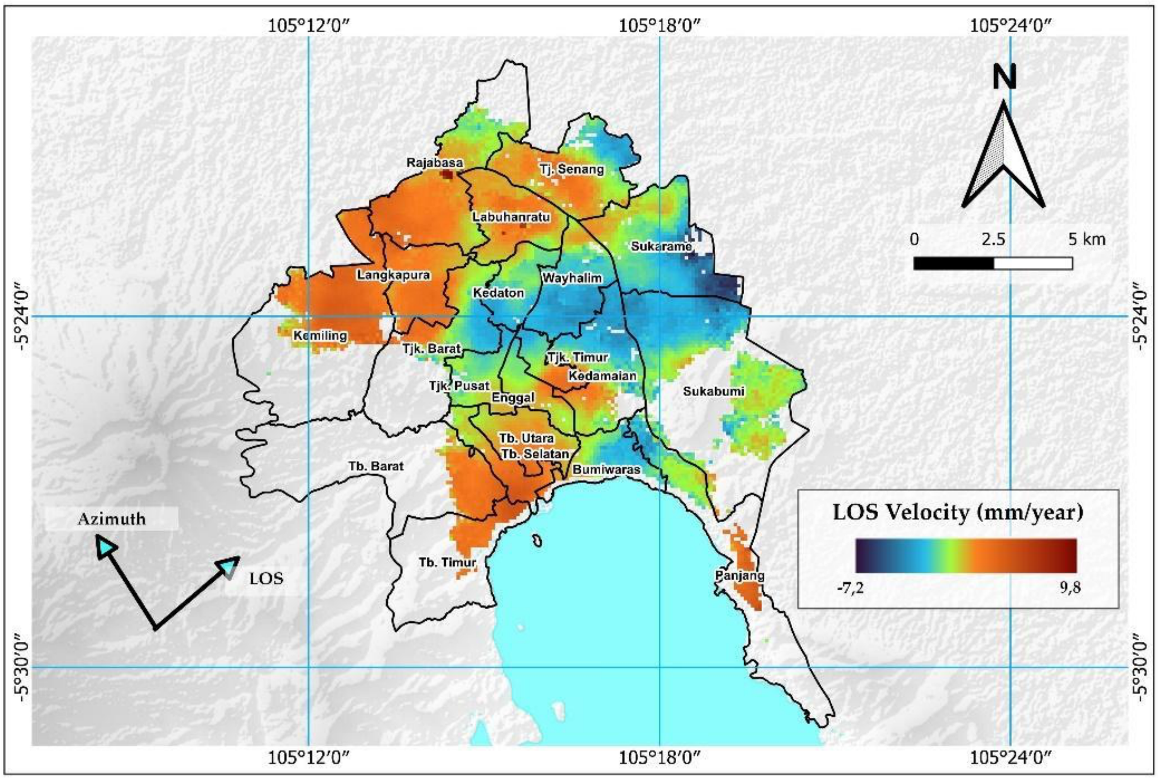

Figure 3. Line of Sight (LOS) Deformation from Satellite Ascending Direction

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The LOS deformation value of descending image processing using atmospheric correction in the Bandar Lampung City area in 2017 - 2023. The LOS deformation value in Bandar Lampung City is -12.3 mm/year to +5.1 mm/year, with an average LOS deformation value of +0.8 mm/year. The average LOS value in Bandar Lampung City is -1.0 mm/year. The subdistrict that experienced the highest subsidence was Panjang, which reached -1.9 mm/year. LOS deformation indicated subsidence is dominated in the eastern part of Bandar Lampung City, represented in **Figure 4**.

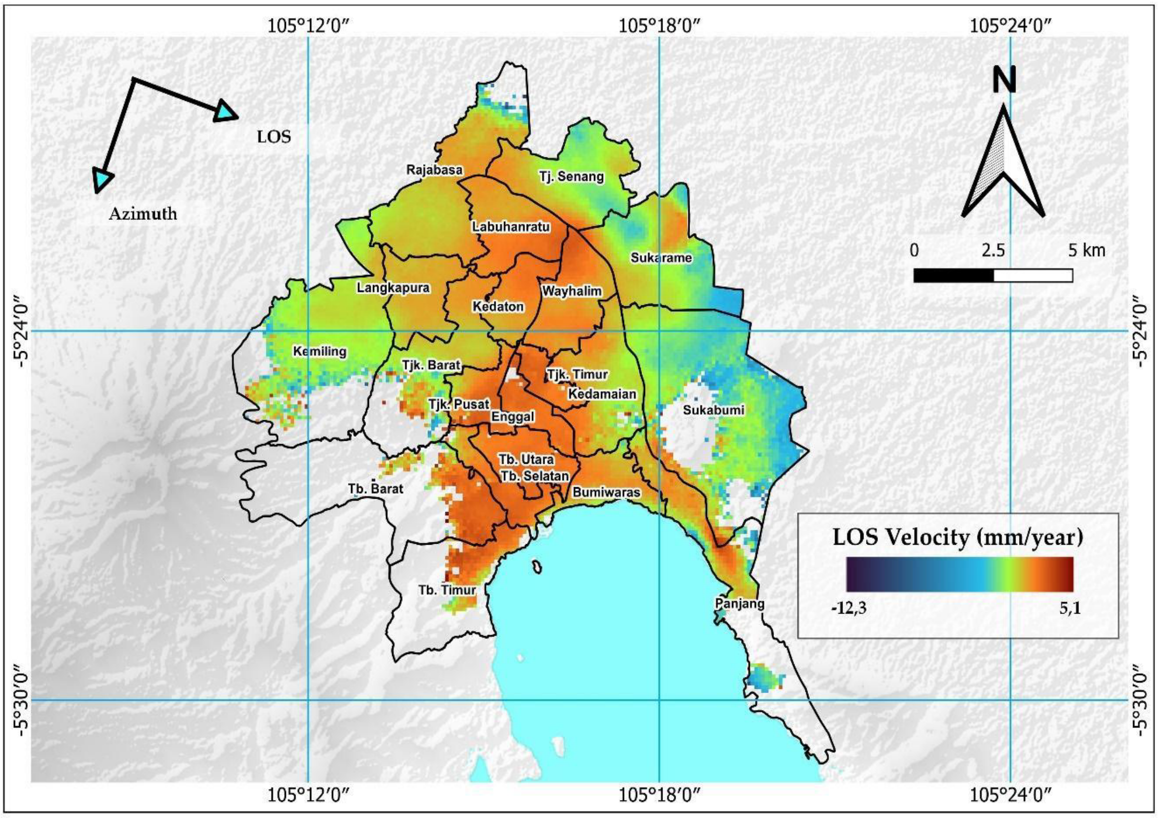

Figure 4. Line of Sight (LOS) Deformation from Satellite Descending Direction

Vertical displacement is the amount of vertical uplift and subsidence of land surface obtained from a combination of ascending and descending images with different trajectory directions and satellite geometries. **Figure 5** shows that positive values indicate uplift, and negative values indicate subsidence. The vertical displacement value using atmospheric correction in the Bandar Lampung City area is presented in Table 3. The vertical displacement value in Bandar Lampung City is ~-5.7 mm/year to ~+6.4 mm/year, with an average vertical displacement value of ~+0.9 mm/year. The average subsidence value in Bandar Lampung City is ~-0.8 mm/year. The results of vertical deformation show that nine subdistricts experiencing subsidence with an area of >10 hectares per subdistrict. The subdistrict with the highest subsidence value is Sukarame, which reaches ~-1.6 mm/year. Subsidence in the data is dominated in the eastern part of Bandar Lampung City.

Table 3. Vertical deformation rate in mm/yr in Bandar Lampung City

No	Subdistrict	Uplift	Subsidence	Mean
1	Bumiwaras	2.8	-1.9	0.5
2	Enggal	3.0	0.5	1.9
3	Kedamaian	3.0	-2.3	0.3
4	Kedaton	2.5	-0.9	0.6

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5	Kemiling	2.8	-0.6	1.8
6	Labuhan Ratu	6.4	1.2	2.2
7	Langkapura	2.9	1.0	2.1
8	Panjang	3.5	-4.9	0.8
9	Rajabasa	6.2	-2.5	1.7
10	Sukabumi	3.8	-4.2	-1.1
11	Sukarame	2.7	-5.7	-0.9
12	Tanjungkarang Barat	2.5	-1.8	0.6
13	Tanjungkarang Pusat	2.5	-0.7	1.2
14	Tanjungkarang Timur	3.2	-0.4	1.8
15	Tanjungsenang	2.3	-2.0	0.6
16	Telukbetung Barat	4.3	0.2	3.1
17	Telukbetung Selatan	4.5	-0.6	2.7
18	Telukbetung Timur	4.5	1.5	3.4
19	Telukbetung Utara	3.7	1.1	2.4
20	Wayhalim	2.9	-1.1	0.2

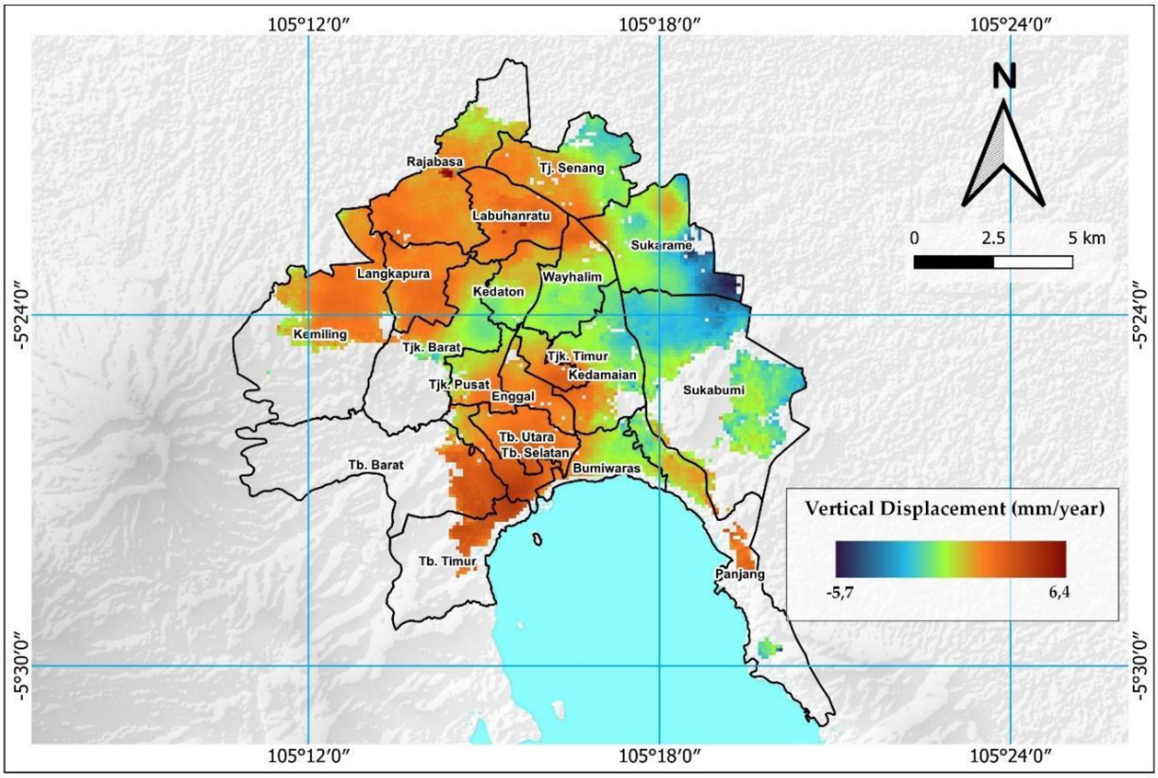

Figure 5. Vertical deformation rate from Sentinel 1 in Bandar Lampung City

The distribution pattern of subsidence in Bandar Lampung City is spatially divided into two: local (<10 km2) and regional (10 – 100 km2). Local subsidence occurred in areas C, D, and E, namely Ketapang Kuala, Garuntang, Sukaraja, and Srengsem subdistricts. Local subsidence also occurs in the southern part of the Kedaton subdistrict and the eastern part of the West Tanjungkarang subdistrict. Regional subsidence predominantly occurs in Sukabumi, Sukarame, Kecepatan, and Wayhalim subdistricts. The area is divided into five areas of interest, and several sample points are shown in **Figure 6**.

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p- ISSN 1412-0313 e- ISSN 2549-7529

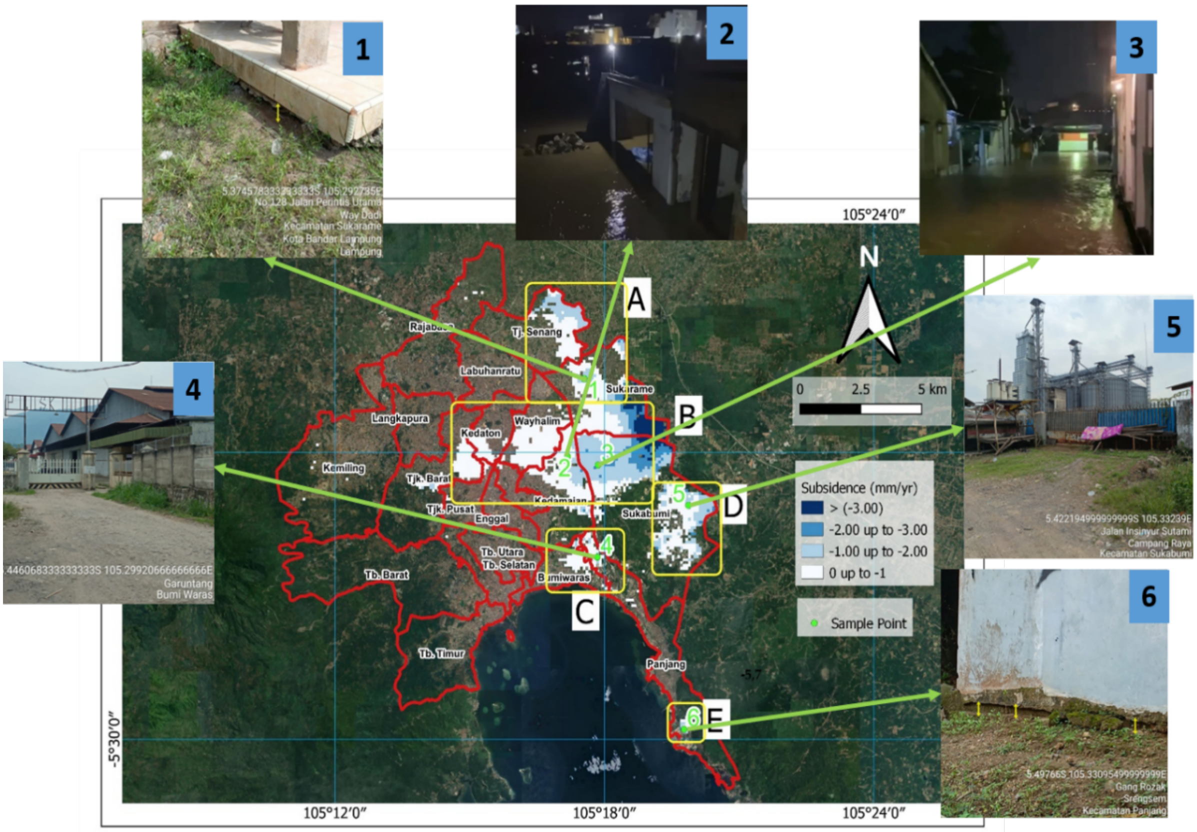

Figure 6. Vertical deformation rate from Sentinel 1 in Bandar Lampung City

Land subsidence in Bandar Lampung City occurs due to tectonic activity and also due to human activities such as industry, loading, mining, groundwater extraction and land conversion at the rate of 5 mm/yr to 30 mm/yr (Zaenudin et al., 2018). The locations in area A are Waydadi, Korpri Raya, and Tanjung Senang subdistrict. This location indicates a local subsidence pattern of -1.4 mm/year based on sample point 1. Waydadi and Waydadi Baru subdistricts are often affected by flooding, which is thought to be one of the impacts of land subsidence in the area. Area B Subsidence occurs in parts of Kedaton and West Tanjungkarang subdistricts with a small value of < -1 mm/year. The pattern of distribution of subsidence with a value of 1-3 mm/year in this area tends to be on the edge of river flows, as is the case in Kedamaian and Sukabumi subdistricts. In area C, subsidence occurred in the Ketapang Kuala, Garuntang, and Sukaraja areas, while area D experienced subsidence in Sukabumi subdistrict, namely the eastern part of Campang Jaya, Waylaga and Waygubak subdistrict. Area C subsidence is -1.4 mm/year based on sample point 4, and area D is -1.1 mm/year based on sample point 5. Field observations show that areas C and D are industrial and densely residential. In residential and industrial areas, it is suspected that there is quite a large amount of groundwater exploitation, and the load on the ground surface is causing subsidence. In area E, subsidence occurred with an area of 0.81 km2 in Srengsem subdistrict, Panjang subdistrict. From sample point 6, the subsidence rate in this area is -1.3 mm/year. This is because the settlement is close to an industrial area. Subsidence occurs, which is an indication of groundwater exploitation that causes subsidence in the area.

4. CONCLUSION

Bandar Lampung experienced an average subsidence rate ranging from approximately -2 mm/year to -6.9 mm/year from 2015 to 2023, as observed using InSAR Sentinel 1 data. The InSAR analysis revealed that the most significant subsidence is predominantly distributed in

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the eastern part of Bandar Lampung City, affecting areas such as Sukabumi, Sukarame, Tanjung Senang, Kedamaian, and Wayhalim subdistricts. This subsidence is primarily due to industrial activity and substantial groundwater extraction, which have contributed to the gradual sinking of the ground surface in these areas.

5. RECOMMENDATIONS

It is recommended that a higher spatial resolution be used in future research related to land subsidence studies. Integration with GNSS and Groundwater Extraction Data will increase the validity of InSAR data and provide a more complete knowledge of the processes that contribute to ground surface deformation.

6. ACKNOWLEDGEMENT

The authors would like to thank Institut Teknologi Sumatera for providing the research grant (No. 1539bz/IT9.2.1/PT.01.03/2024) through "Hibah Penelitian ITERA 2024." We also thank COMET LICS for providing interferogram data Sentinel 1.

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DOI: https://doi.org/10.17509/gea.v24i2.71315
p- ISSN 1412-0313 e- ISSN 2549-7529