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RESEARCH ARTICLE

Analysis Of Presumed Land Subsidence In The Cities Of Lampung Province Using InSAR And GNSS Data

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Abstract

Land subsidence is a naturally occurring phenomenon that has become a growing concern in various regions, including Lampung Province. In this study, we investigate land subsidence in various cities within Lampung Province, Indonesia, utilizing Sentinel-1A using Sentinel-1A satellite image data from the period 2014 to 2022. The cities of Lampung Province analyzed in this study were Liwa, Kota Agung, Kalianda, Sukadana, Bandar Lampung and Krui. The method used is Interferometric Synthetic Aperture Radar (InSAR) with the Small Baseline Area Subset (SBAS) technique. Furthermore, to validate and improve the accuracy of land subsidence measurements, the Global Navigation Satellite System (GNSS) velocities were utilized. The land subsidence result obtained in this study is presumed land subsidence. The cities that experienced land subsidence was Kalianda, Sukadana, Bandar Lampung and Krui ranging from ~3 mm/yr to ~15 mm/yr. Meanwhile, the areas that experienced an uplift were the Liwa and Kota Agung cities.

Keywords: Cities, GNSS, Land Subsidence, Sentinel-1A, SBAS.

1. Introduction

Land subsidence is a natural phenomenon that occurs due to cavities beneath the soil surface, which if accumulated over a long period of time can result in land subsidence up to several meters (e.g., Hakim et al., 2020; Bott et al., 2021; Cigna and Tapete, 2021). Land Subsidence can occur naturally or suddenly. Land subsidence generally occurs in many regions of the world, especially in large cities located along the coast or alluvial land, such as Ardabil Plain, Iran (Ghorbani et al., 2022), Bangkok-Thailand (Endo, 2011), Morelia, Mexico (Cigna and Tapete., 2022), Tianjing-China (Hu, et al., 2009), and also Jakarta-Indonesia (Abidin, et al., 2011; Ardha et al., 2021; Luo et al., 2022).

There are several factors that cause land subsidence, which are caused by natural and human factors such as tectonic processes, soil conditions, geological structure, land suitability for development, excessive groundwater extraction, and loads from many buildings. The negative impacts of this event are damage to infrastructure which could hamper the development of cities and cause great losses to local communities (Yulyta et al., 2015). In addition, there would be the potential for flooding when the rainy season.

Lampung Province is one of the areas on the island of Sumatra which is quite vulnerable to the impact of the land subsidence. This province is quite densely populated with a land area of around 35,288.35 km². Geographically, the area along the coast is in the west and the hilly area is in the south of Lampung Province. Lampung Province is also an area that has quite complex geographical conditions and is located in the southernmost of Sumatra Island (Perkim Province of Lampung, 2020). Based on data from the Information System and Regional Basic Data Management of the National Development Planning Agency (SIMREG-BAPPENAS) the economic growth rate for Lampung Province in 2022 is 4.28%, which value has increased compared to previous years (SIMREG, 2022). The rapid rate of economic growth in this Province has resulted in increased infrastructure development, the need for water resources and an increase in population (Sosilawati, 2017). The growth area would indicate the possibility of land subsidence in these areas.

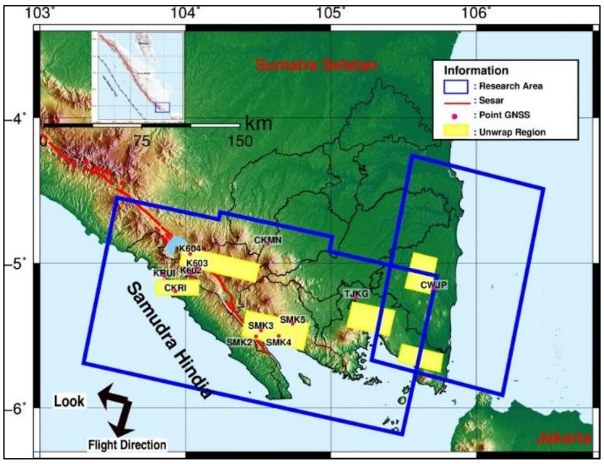

Fig 1. Research area

Data and information related to land subsidence are very useful for various aspects of development such as spatial planning, planning for the development of facilities and infrastructure, community protection and others. Therefore, it is necessary to identity the possibility of land subsidence in the cities (Hestiningsih, 2021). This research will utilize is Global Navigation Satellite System (GNSS) and InSAR (Gumilar et al., 2023) to identify land subsidence in the cities of Lampung Province.

2. Data and Method

The data used in this study are Sentinel-1A imagery data, GNSS velocity, and Digital Elevation Model (DEM) data. The GNSS velocities were obtained from the previous studies in the study area (Alif et al., 2020; Alif et al., 2022). Then, DEM Shuttle Radar Terrain Mission **(**SRTM) with an accuracy of 30 meters is used for image data correction (Farr et al., 2007). The Sentinel-1A imagery data used in this study has specifications as follows: descending Single Look Complex (SLC) type with Wide Interferometry (IW) Swath recording mode and VV+VH polarization measured from 2014 to 2022.

The image data used are divided into two different regions (Table 1 and Table 2), namely Region A consisting large part of Lampung Province which includes 4 cities (Krui, Liwa, Kota Agung, and Bandar Lampung), and Region B consisting smaller part of Lampung Province which includes 2 cities (Kalianda, Sukadana). In addition, the GNSS velocities used to correct the InSAR results are the velocities located close to the respective cities. The details of the GNSS velocities used in this study are presented in Table 3. The research area, including the unwrapped region of InSAR and sites of GNSS velocities, is presented in Figure 1.

Table 1. Details of SentineL-1A image data for the major sections of lampung province

Image Number	Year	Month	Date	Start of Measurement	End of Measurement	Image Pair	Region
A1	2014	10	13	22:41:09	22:41:41	2,3,4,5	A
A2	2015	03	06	22:41:07	22:41:38	1,3,4,5,6	A
A3	2015	09	14	22:41:20	22:41:47	2,4,5,6,7	A
A4	2016	01	12	22:41:13	22:41:39	3,5,6,7,8	A
A5	2016	07	22	22:41:19	22:41:45	4,6,7,8,9	A
A6	2017	01	30	22:41:19	22:41:45	5,7,8,9,10	A
A7	2017	07	17	10:41:30	22:41:56	6,8,9,10,11	A
A8	2018	01	25	22:41:31	22:41:57	7,9,10,11,12	A
A9	2018	07	12	22:41:36	22:42:02	8,10,11,12,13	A
A10	2019	02	25	22:41:37	22:42:03	9,11,12,13,14	A
A11	2019	08	12	22:41:44	22:42:10	10,12,13,14,15	A
A12	2020	03	15	22:41:43	22:42:09	11,13,14,15,16	A
A13	2020	09	11	22:41:52	22:42:18	12,14,15,16,17	A
A14	2021	02	26	22:41:49	22:42:15	13,15,16,17	A
A15	2021	08	13	22:41:56	22:42:23	14,16,17	A
A16	2022	01	16	22:41:56	22:42:22	15,17	A
A17	2022	05	04	22:41:56	22:42:22	13,14,15,16	A

Table 2. Details of Sentinel-1A image data for a small part of Lampung Province

Image Number	Year	Month	Date	Start of Measurement	End of Measurement	Image Pair	Region
B1	2017	06	30	22:33:09	22:33:37	2,3,4,5	B
B2	2017	12	27	22:33:12	22:33:40	1,3,4,5,6	B
B3	2018	06	25	22:33:09	22:33:43	2,4,5,6,7	B
B4	2018	12	22	22:33:19	22:33:47	3,5,6,7,8	B
B5	2019	06	20	22:33:21	22:33:49	4,6,7,8,9	B
B6	2019	12	29	22:33:25	22:33:53	5,7,8,9,10	B
B7	2020	02	27	22:33:23	22:33:51	6,8,9,10,11	B
B8	2020	08	25	22:33:32	22:33:59	7,9,10,11,12	B
B9	2021	02	21	22:33:29	22:33:57	8,10,11,12	B
B10	2021	08	20	22:33:37	22:34:05	9,11,12	B
B11	2022	02	28	22:33:34	22:34:02	10,12	B

Table 3. Details of GNSS velocity data

Point	Station Name	Longitude	Latitude	Location	Vertical Velocities (mm/year)
1	SMK2	104.4854	-5.5064	Tanggamus	64.07
2	SMK3	104.5195	-5.4648	Wonosobo	65.95
3	SMK4	104.6416	-5.5032	Kota Agung	281.52
4	SMK5	104.7375	-5.4175	Gisting	81.01
5	K602	104.0377	-5.0757	Kuripan	19.64
6	K603	104.0812	-5.0355	Pagelaran	-1.69
7	K604	104.0329	-4.9372	Buay Nyerupa	-0.57
8	CKMN	103.5668	-4.8653	Bukit Kemuning	-1.77
9	CKRI	103.9308	-5.1961	Krui	-7.16
10	KRUI	103.8547	-5.0901	Krui	-0.0005
11	TJKG	105.1746	-5.2395	Bandar Lampung	-3.23
12	CWJP	105.7061	-5.1741	Way Jepara	-7.91

The method used in processing this research data is InSAR technology or Interferometric Synthetic Aperture Radar. InSAR combines two SAR (Synthetic Aperture Radar) images recorded at different recording times and angles to produce an interferogram image (Anggara et al., 2023; Alif et al., 2023). These interferogram images can be used to monitor deformation on the ground surface with sub-centimeter accuracy (Yalvac, 2020). The deformation value is calculated using the Small Baseline Area Subset (SBAS) method. SBAS is a method or technique developed to evaluate deformation changes on the earth's surface by utilizing multiple small baseline subsets combined to obtain unwrapped differential interferograms (Hayati et al., 2022). The SBAS technique produces information regarding the average velocity of deformation in the Line Of Sight (LOS) direction. Figure 2 shows the research methodology.

The initial stage carried out in this research is Pre-Processing, processes with the aim is to create raw image data consisting of master and slave images. Then, the co-registration is conducted with the aims to combine images to determine which images are suitable for the interferogram process. The next process is the interferogram to obtain different phase and amplitude values on each image pair. In this process, DEM-SRTM data input is carried out which is used to eliminate the topographic effect. The unwrapping process is conducted to determine the value of the absolute interferometric phase from the relative phase because it is directly related to deformation. The conversion of surface deformation values is conducted from phase units to metric units (mm). Then, SBAS is conducted to obtain information about the average velocity of deformation in the direction of LOS. The vertical velocity is then calculated from LOS velocity using the look angle of Sentinel 1-A (38°). Then, these vertical velocities are corrected by GNSS vertical velocities.

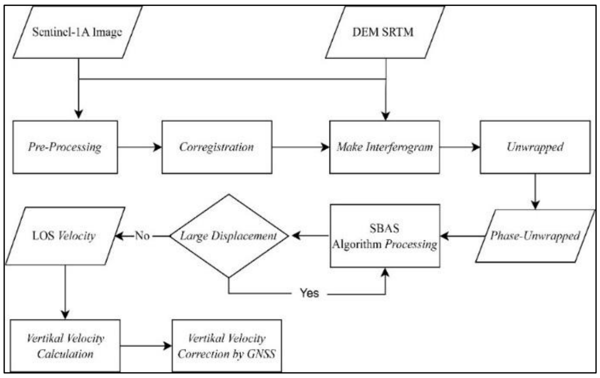

Fig 2. Research flowchart

3. Results and Discussion

The process of identification and processing in this research was carried out in the area of cities of Lampung Province which included Liwa, Kota Agung, Sukadana, Kalianda, Bandar Lampung and Krui. Based on the results of processing using the SBAS-InSAR technique, the *mean velocity* LOS is obtained in mm/year in each region, which are shown in Figure 3.

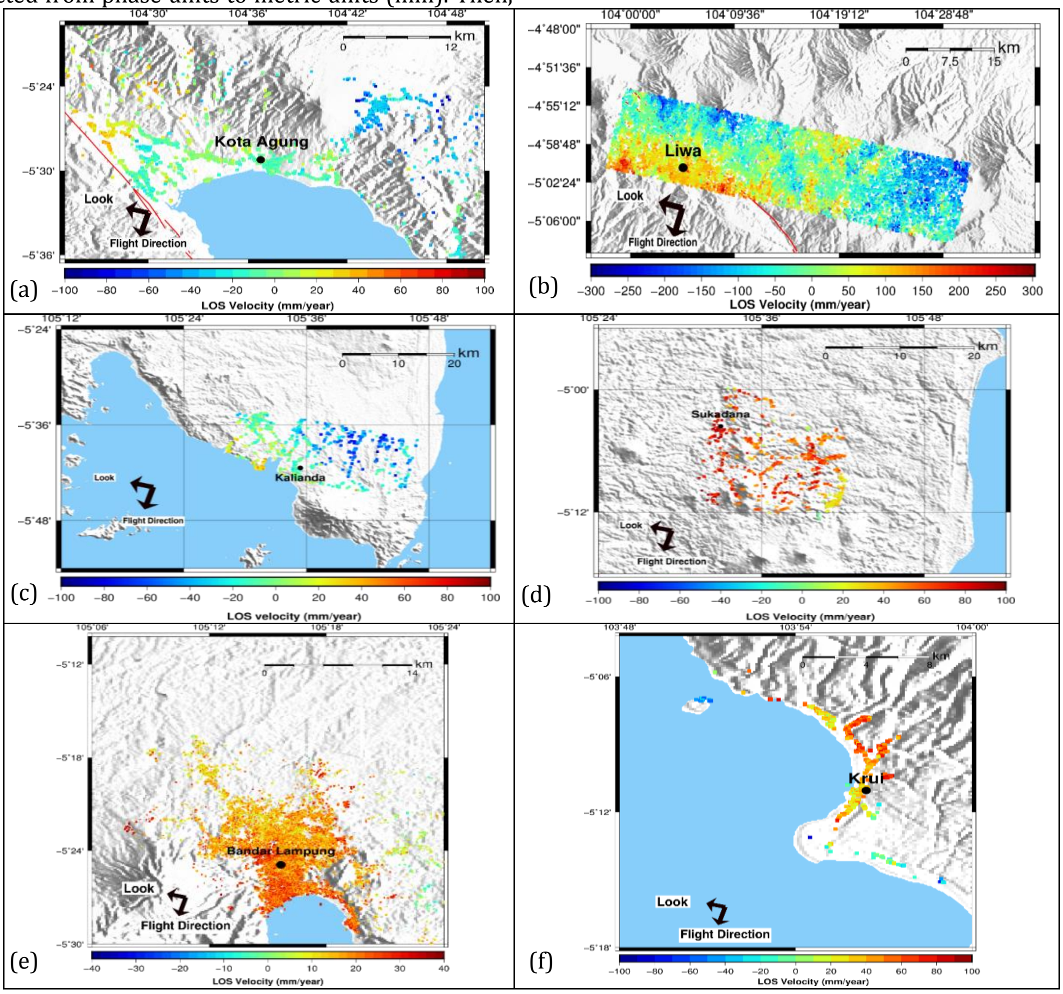

Fig 3. The LOS velocities of (a) Liwa, (b) Kota Agung, (c) Sukadana, (d), Kalianda, (e) Bandar Lampung, and (f) Krui

The LOS velocities in the cities of Lampung Province are as follows, Liwa of -286.50 mm/year to 283.85 mm/year, Kota Agung of -122.65 mm/year to 43.86 mm/year, Kalianda of -100 mm/year to 40 mm/year, Sukadana of 20 mm/year to 100 mm/year, Bandar Lampung of -1 mm/year to 40 mm/year, and Krui of -50 mm/year to 60 mm/year. The LOS velocities value is still quite large. This study also obtains the value of the results of the *vertical velocity calculation processing* in each city, which is presented in Figure 4.

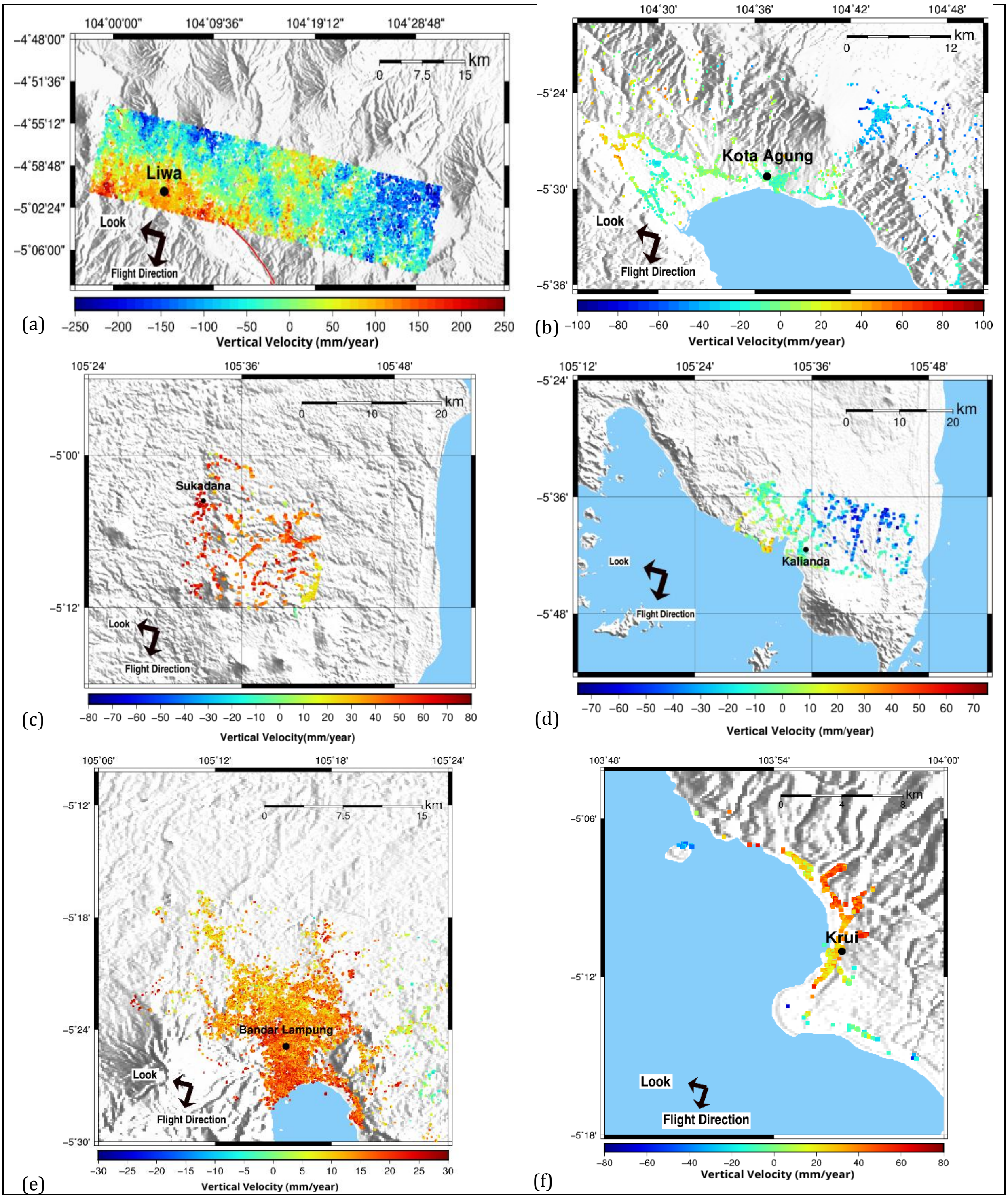

Fig 4. Vertical velocities of (a) Liwa, (b) Kota Agung, (c) Sukadana, (d), Kalianda, (e) Bandar Lampung, dan (f) Krui

The vertical velocities in the cities of Lampung Province are as follows, Liwa of -250 mm/year to 250 mm/year, Kota Agung of -122.65 mm/year to 43.86 mm/year, Kalianda of -100 mm/year to 40 mm/year, Sukadana of 20 mm/year to 100 mm/year, Bandar Lampung of -1 mm/year to 40 mm/year, and Krui of -80 mm/year to 80 mm/year. The vertical velocities in the image obtained in research using the SBAS-InSAR method is still not very clear because some of the distortions that occur in the form of temporal decorrelation and geometric decorrelation have not been completely eliminated. Therefore, the results of processing using the SBAS-InSAR technique are then corrected with the GNSS velocity data presented in Table 4.

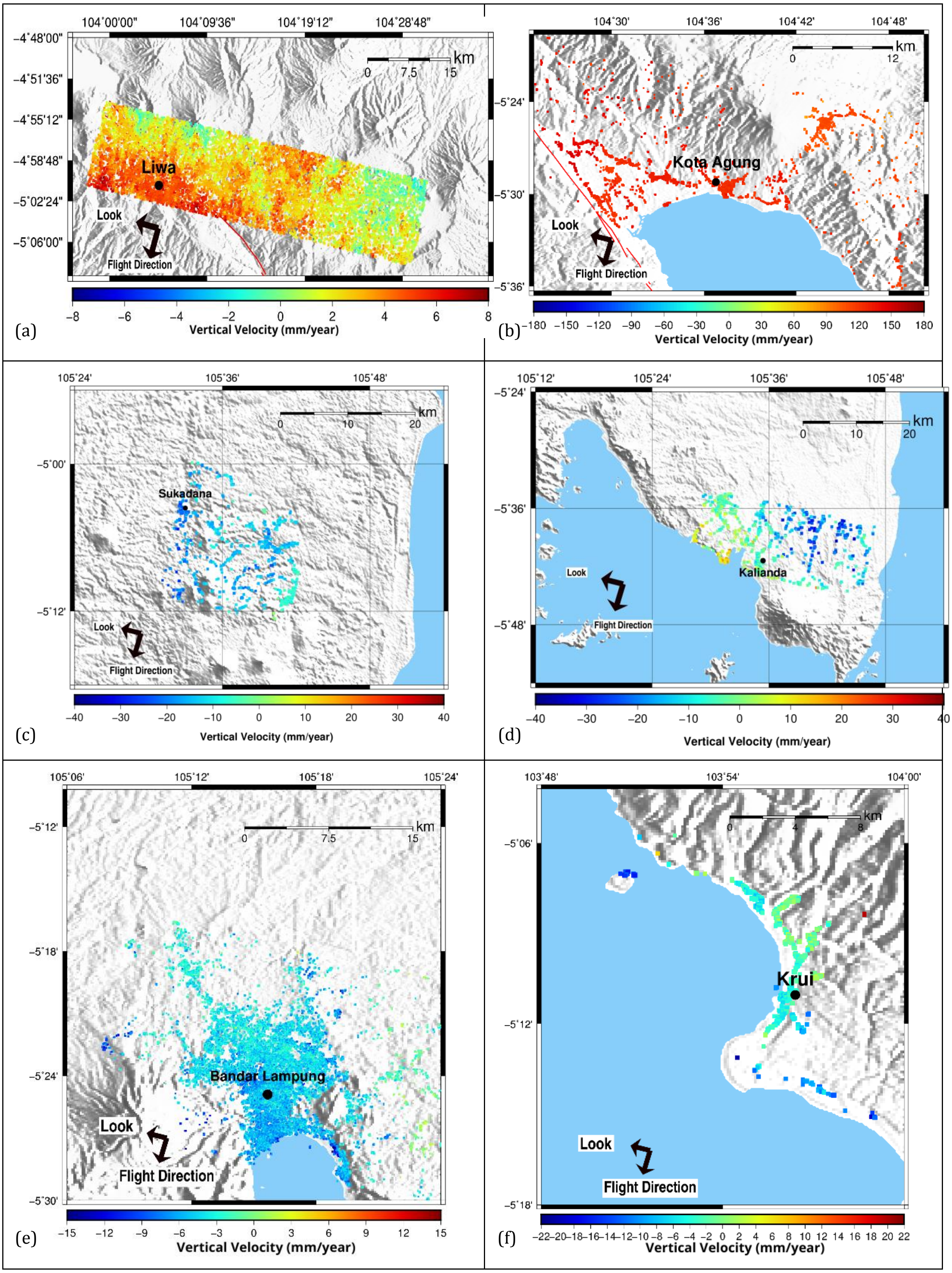

Fig 5. The GNSS-corrected vertical velocities of (a) Liwa, (b) Kota Agung, (c) Sukadana, (d), Kalianda, (e) Bandar Lampung, and (f) Krui

The GNSS-corrected vertical velocities in the cities of Lampung Province are as follows, Liwa of -2 mm/year to 8 mm/year, Kota Agung of 120 mm/year to 180 mm/year, Kalianda of -40 mm/year to 20 mm/year, Sukadana of -30 mm/year to 0 mm/year, Bandar Lampung of -9 mm/year to 0 mm/year, and Krui of -22 mm/year to 22 mm/year. A positive value of the vertical velocities indicates an uplift. Meanwhile, a negative value of the vertical velocities indicates subsidence. **Table 4** is the land subsidence value of each city in Lampung Province.

Table 4. Land subsidence rate from GNSS-corrected velocities in the cities of Lampung Province

No	Kota	The original vertical velocities (mm/year)	The GNSS-corrected vertical velocities (mm/year)
1	Liwa	-9.98	2.70
2	Kota Agung	-8.07	124.18
3	Sukadana	46.10	-14.34
4	Kalianda	-15.86	-7.91
5	Bandar Lampung	14.41	-4.70
6	Krui	28.88	-3.73

The land subsidence or negative vertical velocities are occurred in Sukadana, Kalianda, Bandar Lampung, and Krui. The minor uplift on the Liwa is probably related to the Sumatran Fault Zone due to the distance from the city to the fault. The high uplift rate in the Kota Agung is due to unreliable GNSS velocities. These GNSS velocities calculated from GNSS campaign (periodic) data or is not continuous. These land subsidence rate on the other 5 cities is reliable due to reliable GNSS vertical velocities used as correction. These land subsidence rates are relatively lower than the land subsidence rate in the other cities in Indonesia. Several regions in Indonesia experience high subsidence such as Surabaya with a value of ~3.2 cm/yr (Hayati et al., 2022), subsidence in Semarang with rate 6 to 7 cm/yr (Abidin et al., 2013), and subsidence in Jakarta with a value 1 to 15 cm/yr (Abidin et al., 2011). Groundwater extraction is believed to be one of the causes of land subsidence (Gumilar et al., 2022) and other contributing factors such as natural compaction, building loads and tectonic activity (Abidin et al., 2013).

4. Conclusions

Land subsidence occurred in the Kalianda, Sukadana, Bandar Lampung, and Krui. Liwa and Kota Agung cities experienced an uplift. The result in all cities, except Krui, is reliable due to reliable GNSS vertical velocities used as correction. However, the magnitude of the Land subsidence that occurred in cities in Lampung Province is relatively small when compared to cities in Indonesia and in the world. More integrated GNSS and InSAR studies are strongly recommended to be conducted for more precise land subsidence studies in the cities of Lampung Province.

References

Abidin, H. Z., (2011). Land subsidence of Jakarta (Indonesia) and its relation with urban development. *Natural Hazards,* p. 1753–1771.

Abidin, H. Z., Andreas, H., Gumilar, I., Sidiq, T. P., & Fukuda, Y. (2013). Land subsidence in coastal city of Semarang (Indonesia): characteristics, impacts and causes. Geomatics, Natural Hazards and Risk, 4(3), 226-240.

Alif, S. M., Fattah, E. I. & Kholil, M., (2020). Geodetic slip rate and locking depth of east Semangko Fault derived from GPS measurement. *Geodesi dan Geodinamika,* pp. 222-228.

Alif, S. M., (2022). Slip Rate of Kumering Fault in Lampung Province Calculated from GPS Data from 2007 to 2021. *Jurnal Geosains dan Teknologi,* 5(2), pp. 83-90.

Alif, S. M., Anggara, O., & Ristiana, V. (2023). Coherence Analysis of Sentinel-1A Images in Various Land Covers. *Jurnal Geografi Gea*, 23(2), 135-143.

Anggara, O., Welly, T. K., Fauzi, A. I., Alif, S. M., Perdana, R. S., Oktarina, S. W., Nuha, M. N., & Rosadi, U. (2023). Monitoring ground deformation of Sinabung volcano eruption 2018-2019 using DInSAR technique and GPS data. In AIP Conference Proceedings (Vol. 2654, No. 1). AIP Publishing.

Ardha, M., Argo, G. S., Julzarika, A., Yulianto, F., Yudhatama, D., & Rofifatuz, Z. D. (2021). Utilization of Sentinel-1 satellite imagery data to support land subsidence analysis in DKI Jakarta, Indonesia. Journal of Degraded and Mining Lands Management, 8(2), 2587-2593.

Bott, L. M., Schöne, T., Illigner, J., Haghighi, M. H., Gisevius, K., & Braun, B. (2021). Land subsidence in Jakarta and Semarang Bay–The relationship between physical processes, risk perception, and household adaptation. Ocean & Coastal Management, 211, 105775.

Cigna, F., & Tapete, D. (2021). Present-day land subsidence rates, surface faulting hazard and risk in Mexico City with 2014–2020 Sentinel-1 IW InSAR. Remote Sensing of Environment, 253, 112161.

Cigna, F., & Tapete, D. (2022). Urban growth and land subsidence: Multi-decadal investigation using human settlement data and satellite InSAR in Morelia, Mexico. Science of The Total Environment, 811, 152211.

Endo, T., (2011). Sinking Cities and Governmental Action: Institutional Responses to Land Subsidence in Osaka and Bangkok. *Groundwater and Subsurface Environments.*

Farr, Tom G., "The Shuttle Radar Topography Mission." *AGU Advances*, vol. 45, no. 2, 2007.

Ghorbani, Z., Khosravi, A., Maghsoudi, Y., Mojtahedi, F. F., Javadnia, E., & Nazari, A. (2022). Use of InSAR data for measuring land subsidence induced by groundwater withdrawal and climate change in Ardabil Plain, Iran. Scientific Reports, 12(1), 13998.

Gumilar, I., Sidiq, T. P., Virtriana, R., Pambudi, G., Bramanto, B., & Abidin, H. Z. (2023). Geodetic observations confirming land subsidence of Bandung Basin, Indonesia, and subsequent building damage. Acta Geodaetica et Geophysica, 1-16.

Hakim, W. L., Achmad, A. R., & Lee, C. W. (2020). Land subsidence susceptibility mapping in jakarta using functional and meta-ensemble machine learning algorithm based on time-series InSAR data. Remote Sensing, 12(21), 3627.

Hayati, N., Widodo, A., Kurniawan, A., Sanjiwani, I. D. M. A., Darminto, M. R., Yudha, I. S., & Sumantyo, J. T. S. (2022). Small baselines techniques of time series InSAR to monitor and predict land subsidence causing flood vulnerability in Sidoarjo, Indonesia. Geomatics, Natural Hazards and Risk, 13(1), 2124-2150.

Hestiningsih, (2021). Pemetaan Zona Penurunan Tanah (Land Subsidence) dengan Menggunakan Metode Penginderaan Jauh. pp. 1-105.

Hu, B., (2009). Risk assessment of land subsidence at Tianjin coastal area in China. *Environmental Earth Sciences,* pp. 269-276.

Luo, Q., Li, J., & Zhang, Y. (2022). Monitoring Subsidence over the Planned Jakarta–Bandung (Indonesia) High-Speed Railway Using Sentinel-1 Multi-Temporal InSAR Data. Remote Sensing, 14(17), 4138.

Perkim Provinsi Lampung, (2020). *Permukiman, Perumahan dan Kawasan.* [Online] Available at: https://perkim.id/profil-pkp/profil-provinsi/profil-perumahan-dan-kawasan-permukiman-provinsi-lampung/ [Accessed 19 April 2023].

SIMREG, B., (2022). *SIMREG Sistem Informasi dan Manajemen Data Dasar Regional.* [Online] Available at: https://simreg.bappenas.go.id/ [Accessed 14 Desember 2022].

Sosilawati, (2017). *Sinkronisasi Program dan Pembiayaan Pembangunan Jangka Pendek 2018-2020 Keterpaduan Pengembangan Kawasan dengan Infrastruktur PUPR Pulau Sumatera.* Jakarta: Pusat Pemrograman dan Evaluasi Keterpaduan Infrastruktur PUPR.

Yalvac, S. (2020). Validating InSAR-SBAS results by means of different GNSS analysis techniques in medium- and high-grade deformation areas. Environmental monitoring and assessment, 192(2), 120.

Yulyta, S. A., (2018). Aplikasi Metode SBAS-DInSAR Menggunakan Data Sentinel-1A Untuk Pengamatan Penurunan Muka Tanah Di Kota Surabaya. pp. 1-97.

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