http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 10 No 1 2024

RESEARCH ARTICLE

Deformation Of Lava Tounge at Semeru Volcano using Sentinel-1 DInSAR

Yuliana Iik Iswanti Chandra [1,2], Sukir Maryanto[1,2*], Adi Susilo[1], Faridha Aprilia[1], Mayang Bunga Puspita[1]

[1] *Department Of Physics, Faculty Of Mathematics an Natural Science, Brawijaya University, Jawa Timur 65145, Indonesia.*
[2] *Brawijaya Volcano and Geothermal Research Center, Brawijaya University, Jawa Timur 65145, Indonesia.*

* Corresponding author : sukir@ub.ac.id
Tel.:+6281358727902; fax: +628136281358727902
Received: Dec 2, 2024; Accepted: Mar 11, 2025.
DOI: 10.25299/jgeet.2025.10.1.21444

Abstract

Indonesia is vulnerable to various natural disasters, especially volcanic eruptions. Mount Semeru, located between Malang and Lumajang, is an active volcano with a history of significant eruptions. The eruption on December 4, 2021, caused many casualties and infrastructure damage. This research utilizes Sentinel-1 (SLC) satellite imagery to analyze deformation changes caused by the eruption, with a particular focus on DInSAR analysis to depict changes in the crater's shape. Before the eruption, no significant volcanic activity was detected, resulting in no clear deformation changes, with a deflation range between -0.096 cm and -0.145 cm. However, during the eruption, the outflow of lava forming lava tongues led to the formation of lava deposits that affected surface deformation. During the eruption phase, the deformation changes indicate an inflation phase, with values ranging from 0.064 cm to 0.094 cm, reflecting surface movement due to the accumulation of volcanic material. After the eruption, the deformation changes became more pronounced due to the perfectly and stably formed lava deposits, with an inflation value range between 0.037 cm and 0.079 cm, resulting in significant surface shifts. Phase reading disturbances were also detected at several locations due to lahar flows that occurred during and after the eruption. The results of this study provide beneficial information for the relevant parties in formulating disaster mitigation strategies related to Mount Semeru's activities, as well as in understanding the dynamics of surface deformation influenced by eruptions, lava flows, and the formation of lava tongues.

Keywords: Semeru Volcano, DInSAR Deformation, Lava Tongue, Sentinel-1

1. Introduction

Indonesia situated in a tropical region with it's geographical, geological, hydrological, and demographic traits contribute to a significantly high level of disaster risk (Agustiningsih et al., 2022; Andryana et al., 2011; BNPB, 2016). Mount Semeru is a volcanic formation located within the Bromo Tengger Semeru National Park (TNBTS). Positioned to the south of Mount Bromo and the Tengger mountain range, the Tengger-Semeru complex was geologically developed from Mount Jambangan, followed by Tengger, Ayeg-ayeg, and Mount Semeru, which features an active crater known as Jonggring Seloko. When viewed from the south, Mount Semeru displays the shape of a perfect cone, although its summit is complex due to the movement of the crater from the northwest to the southeast (Arbad et al., 2019; TNBTS, 2023).

Mount Semeru has erupted on December 4th for two consecutive years in 2021-2022, leading to lava flows, material ejections, and ash fall that impacted Lumajang Regency, especially in the Pronojiwo and Sumberwuluh sub-districts (Purba et al., 2022). The 2021 eruption resulted in property damage and fatalities; at least 51 lives were lost, 169 individuals were injured, and 22 others went missing, while 1,047 homes and 49 public facilities experienced significant damage. The villages that were most severely impacted include Sumberwuluh and Sumbermujur in the Candipuro District, along with Supiturang Village in the Pronojiwo District of Lumajang Regency (PVMBG, 2021; Suci Ulamatullah, 2022; Wibowo, 2023). According to (Andi, 2021), The repercussions stacking from the eruption of Mount Semeru are not new and should have been anticipated early on to lessen their negative impacts.

Fig.1 Sentinel-1 satellite (ESA, 2022)

1.1 Sentinel Imagery

Sentinel imagery refers to a satellite developed to provide information for the Copernicus program, aimed at observing, managing, and comprehending environmental changes and climate impact in everyday life. The outputs from the Sentinel satellites can be used to track economic, social, and environmental factors (ESA, 2022). Sentinel-1 is a satellite that utilizes Synthetic Aperture Radar (SAR) technology, featuring an active sensor that enables imaging regardless of the time of day or night, as well as the ability to see through clouds and remain unaffected by weather conditions. The satellite is outfitted with a C-band sensor and comprises two satellites, Sentinel-1A and Sentinel-1B, which orbit simultaneously at an angle of 180°. Each of the satellites has a repeat cycle of 12 days, making Sentinel-1 valuable for tracking land deformation, ocean winds, ice bergs, and more (Ariyantoni and Rokhmana, 2020; ESA, 2022; Hajduch et al., 2023; Utami et al., 2023).

1.2 Differential Interferometry Synthetic Aperture Radar (DInSAR)

Differential Interferometry Synthetic Aperture Radar (DInSAR) is a radar-based method that utilizes phase information from at least two SAR images captured over the same area at different times to assess deformation in a particular region (Febriyanti & Anjasmara, 2017). This involves acquiring two paired SAR images, either through differential SAR by combining complex sentinel image data at identical spatial locations or terrain height InSAR by obtaining images from slightly different locations in the same direction, using multiple conjugate multiplications to produce displacement measurements of the land surface or digital elevation model (Alif et al., 2024; Cumming and Wong, 2004; Fadhlurrohman et al., 2020). DInSAR serves as a remote sensing methodology that observes changes and movements of land surfaces by measuring phase variations (interferogram). It represents an evolution of the InSAR technique (Seftianingtyas, 2024). There are distinctions between InSAR and DInSAR, one notable difference being the end products of the two processes. While InSAR typically yields a Digital Elevation Model (DEM), DInSAR ultimately produces a displacement map or deformation map (Natadikara et al., 2023; Prasojo et al., 2024; Sihombing et al., 2024).

Differential Interferometry Synthetic Aperture Radar (DInSAR) aims to observe ground movement or deformation using the repeat pass interferometry technique (Teguh Purnama Sidiq, 2017). To achieve the deformation effect, it is necessary to employ the differential interferometry technique, which involves comparing two interferograms and removing the effects of topography, noise, and atmospheric conditions. Various techniques utilized in the development of differential interferometry are outlined (Hanssen, 2001).

This study is crucial to undertake, as the outcomes of the DInSAR deformation change analysis will deliver insights into the alterations in the crater's shape resulting from the Semeru volcano eruptions in 2021. This information is essential for stakeholders to consider in their disaster mitigation strategies related to the Semeru volcano eruptions.

2. Research Area

The research conducted by the author only covers Mount Semeru, with the geographical location of the Semeru volcano being 80º 06’ 30” S and 112º 55’ E, situated in the regions of Lumajang Regency and Malang Regency, East Java Province (TNBTS, 2023).

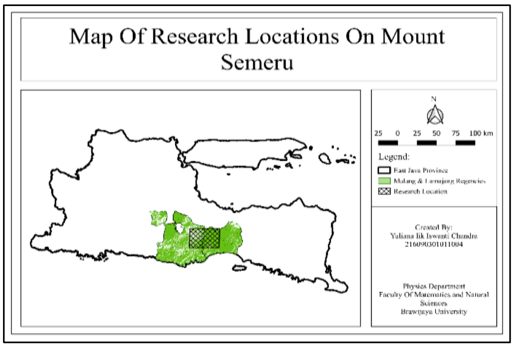

Fig.2 Research location

3. Methodology

This study employs quantitative data by leveraging Sentinel-1 satellite imagery single look complex (SLC) sourced from the website (https://search.asf.alaska.edu/), processed through SNAP, with the final outcomes visualized using Google Earth. The scope of the study focuses on Mount Semeru, ranging from the peak to the base, to examine the DInSAR deformation changes that took place before, during, and after the eruptions in 2021. All processing steps in this research were conducted by following research flow as illustrated in Figure 3.

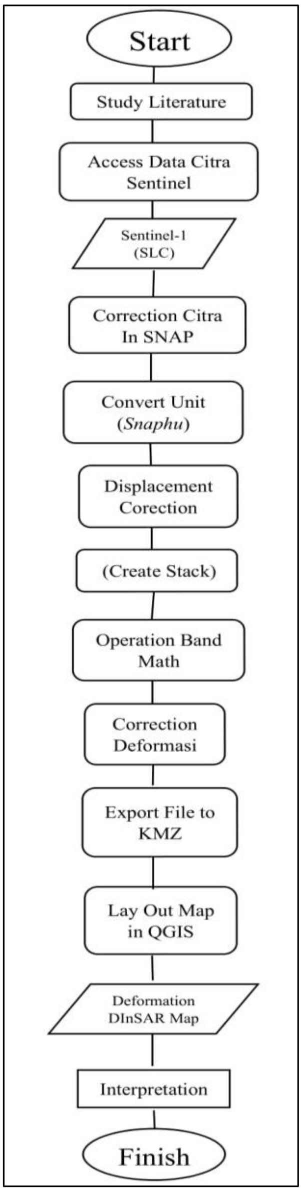

Fig.3 Research Flow Chart

First is to download sentinel-1 SLC imagery, beam mode Interferometric Wide (IW), polarization VV+VH, direction “Ascending”, and subtype SA. The dataused in this research is classified into three periods: before the eruption event (November 13 -25), during the eruption (November 25 - December 7), and after the eruption (December 7 – 19). The data processing was conducted in snap Toolbox software and the saved file in KMZ format then used to create a DInSAR deformation map by QGIS software.

DInSAR Deformation two pass Method in SNAP Toolbox software requires processes below:

a) Preparing two images from the Sentinel-1 satellite in the form file type single look complex (SLC) images.

b) SAR Processing Through Interferometry

This stage essentially forms an interferogram from two SLC data taken in the same area but at different times, and this parameter is used to determine the correlation value between the two data sets.

c) Interferogram

This correction is made because the image is still affected by the curvature of the Earth, satellite orbit effects, topographic effects, noise effects, and deformation effects.

d) Differential InSAR processing

This process is carried out to separate the deformation effects on the interferogram image from other effects (earth curvature effect, satellite orbit effect, topography effect, noise effect, and deformation effect) during post-processing. The process carried out at this stage is:

- Geocoding Process

This process is carried out so that the interferogram image is georeferenced, where the position of each pixel corresponds to a location on the Earth's surface, thereby showing its deformation pattern on the Earth's surface.

- Analysis and map creation

The deformation pattern obtained can be seen from the color combination produced when the Differential Interferometry SAR image undergoes the color composite process, which involves assigning colors based on the signal pattern obtained by the sensor, and then saved in KMZ format to create a DInSAR deformation map.

4. Result and Discussions

The two-pass approach of DInSAR is utilized to assess shape variations on Mount Semeru before, during, and after the eruption, generating both DEM data and DInSAR deformation change data. The DEM data reveals elevation changes for ongoing monitoring, while DInSAR data offers insights into vertical and horizontal ground surface displacements with remarkable precision (up to centimeters).

It is essential to have data with a temporal proximity to the coverage prior to the eruption the tracking of Mount Semeru employs the DInSAR technique from this data, we were able to produce a Digital Elevation Model (DEM) along with a displacement DInSAR deformation map. Processing DInSAR deformation resulted in a DEM before the 2021 eruption mount Semeru as illustrated in Figure 4.

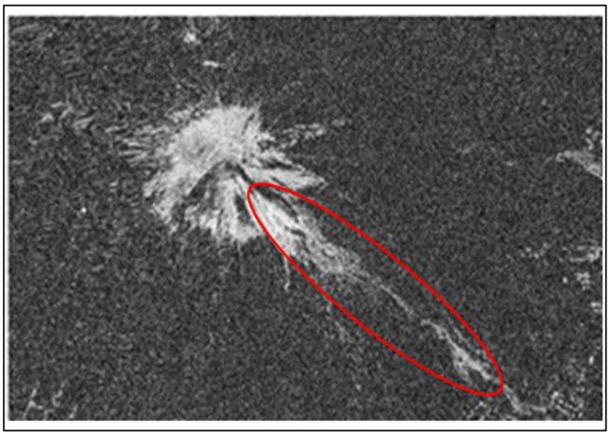

Fig 4. DEM Image Before Mount Semeru Eruption

Figure 4. shows the digital elevation model (DEM) before the eruption, and The red circle highlights the deformation changes since the Semeru eruption last year.

The processing of the DInSAR deformation results in a map of the changes in the DInSAR deformation before the eruption of the mount Semeru eruption in 2021 is illustrated in figure 5. Figure 5 shows the DInSAR land deformation map. The color ranges from red to yellow, and the values changes from -0.145 cm to -0.096 cm. the value (-) does not indicate any deformation changes, so it can be said that the deformation value is experiencing deflation because no changes are occurring. The red circle of the DInSAR land deformation map shows residual changes caused by the mount Semeru eruption in previous years.

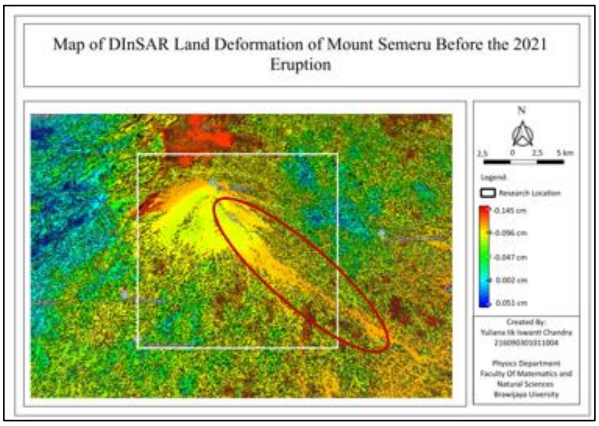

Fig 5. DInSAR land deformation change map before eruption mount Semeru

As can be seen in Figure 5, a layer called lava deposits or tongues lava formed in the deformation of the crust caused by eruptions in previous years. Where the lava flow from the Semeru crater moves to the lowlands or valleys. Cold and solidified lava causes changes in shape due to uneven cooling.

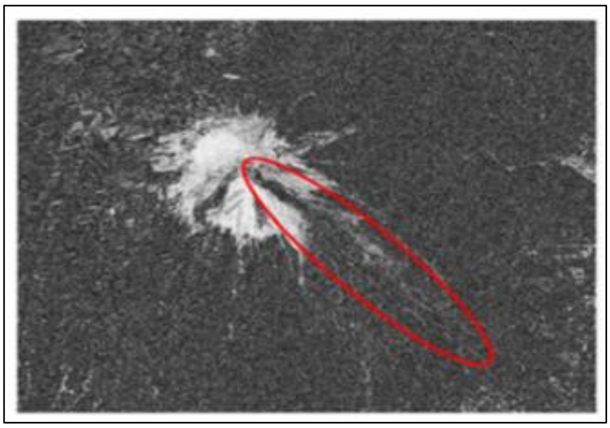

Fig 6. DEM Image During Mount Semeru Eruption

Processing DInSAR deformation resulted in a DEM during the 2021 eruption mount Semeru as illustrated in Figure 6. Figure 6 shows a digital elevation model (DEM) during the eruption. The red circle marks the lava flow's location. DInSAR deformation changes are difficult to discern due to the lava flow during the 2021 Semeru eruption.

The processing of the DInSAR deformation results in a map of the changes in the DInSAR deformation during the eruption of the mount Semeru eruption in 2021, as can be seen in Figure 7. , A color range from light blue to dark blue marks a change of value from 0.064 cm to 0.094 cm. The red circle on the DInSAR land deformation map indicates that the changes in the DInSAR deformation values are incomprehensible due to the location of the lava flows during the eruption of Mount Semeru in this area.

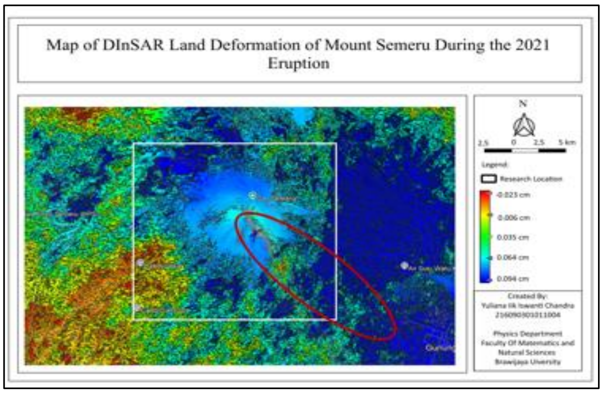

Fig 7. DInSAR land deformation changes map during eruption mount Semeru

Figure 7 illustrates the DInSAR deformation observed during the mount Semeru eruption in 2021, where a layer referred to as a lava deposit or lava tongue was created due to the crustal deformation from the eruption. The lava flow from the Semeru crater travels down to the lowlands or valleys, resulting in the formation of a lava tongue. The DInSAR images in figure 7 Highlight unreadable deformation changes, marked by the red circle, which are attributed to the lava flow during the Semeru eruption. The ongoing flow of hot lava does not result in measurable DInSAR deformation.

Processing DInSAR deformation resulted in a DEM after the 2021 eruption mount Semeru is illustrated in Figure 8. Figure 8 shows a digital elevation model (DEM) after the eruption, with red circles showing the location of the location of the volcanic mudflow eruption, rendering DInSAR deformation changes The red circle marks the lava flow's location. DInSAR deformation changes are difficult to discern due to the lava flow during the 2021 Semeru eruption.

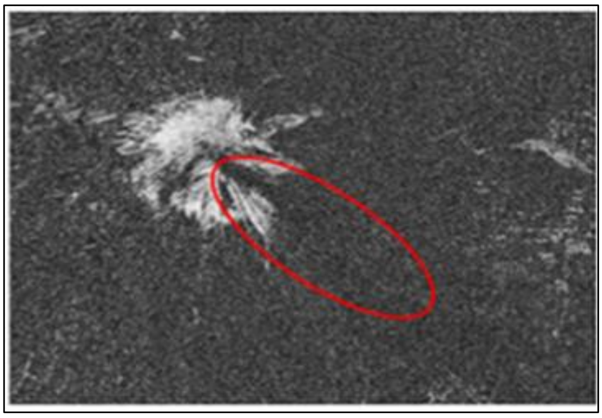

Fig 8. DEM Image After Mount Semeru Eruption

The processing of the DInSAR deformation results in a map of the changes in the DInSAR deformation after the eruption of the mount Semeru eruption in 2021, is illustrated in Figure 9. Figure 9 shows the DInSAR land deformation map after the eruption displayed. A color range from 0.037 cm to 0.079 cm and a hue shift from light blue to dark blue. Due to the presence of volcanic mudflow leftovers from the 2021 eruption of the Semeru volcano, the red circle on the DInSAR deformation map indicates that the DInSAR deformation change data is illegible.

Figure 9 displays the DInSAR deformation recorded following the 2021 eruption of mount Semeru, where a geological layer referred to as lava deposits or lava tongues emerged due to crustal deformation from the earlier eruption. The lava ejected from the Semeru crater descends into the lowlands or valleys, leading to the lowlands or valleys, leading to the development of lava tongues. The DInSAR image in figure 9. Emphasizes, indicated by a red circle, which are linked to traces of lava flow from the Semeru eruption. Hot lava flows do not yield observable DInSAR deformation.

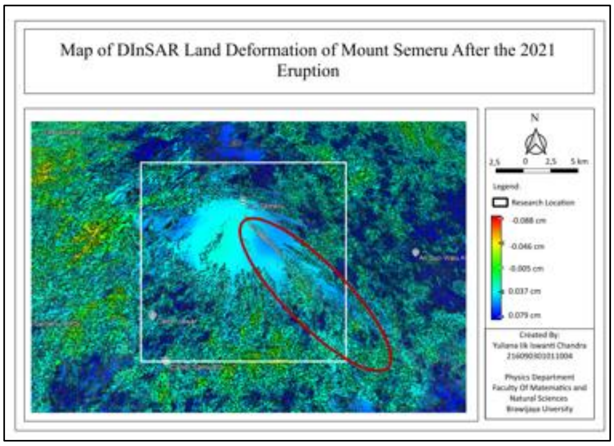

Fig 9. DInSAR land deformation change map after eruption mount Semeru

The locations of the volcanic mudflow from the Semeru volcano are shown by the red circles in Figure 4, 5, 6, 7, 8, and 9. The DInSAR deformation value (+) denotes a change in DInSAR deformation, while the DInSAR deformation value (-) shows no change. Images 5, 7, and 9 of the DInSAR deformation changes maps show it. The map's scale bar shows the colors of Mount Semeru, which represent the presence of lack of DInSAR deformation changes that took place before, during, and following the 2021 eruption. Due to the lack of precise color accuracy, the mixed colors surrounding Mount Semeru fail to reveal the magnitude of the changes that have occurred.

The DInSAR deformation map changes observed in 2021 showed inflation starting from the eruption phase and continuing afterwards. In contrast, prior to the eruption, the scale map values illustrated deflation, ranging from -0.096 cm to -0.145 cm, as depicted in figure 5. During the eruption, however, there was a shift towards inflation, as shown in figure 7, where the scale map values modification from light blue to dark blue, ranging from 0.064 cm to 0.094 cm. Following the eruption, figure 9. Demonstrated clear inflation in the deformation change values, which ranged from 0.037 cm to 0.079 cm, also modification from light blue to dark blue. The unclear deformation color changes resulted from diverse alterations, leading to inconclusive results. Pixels highlights the challenges associated with interpreting DInSAR deformation changes, as the small phase values obtained during filtering and unwrapping were eliminated. Furthermore, ongoing volcanic activities like eruptions or forest fires complicate the processing efforts. The variations in the surface deformation of mount Semeru are illustrated in table 1. Which highlights the distinctions observed before, during and after the eruption of mount Semeru in 2021.

Table 1. Table of DInSAR deformation changes before, during and after the eruption of Semeru mountain in 2021

	Deformation changes (cm)		
color	before	during	after
red	-0.145	-0.023	-0.088
yellow	-0.096	0.006	-0.046
green	-0.047	0.035	-0.005
Light blue	0.002	0.064	0.037
Dark blue	0.051	0.094	0.079

The color scale depicted in the DInSAR deformation map represents the magnitude of change. Table 1 displays the corresponding values on the color scale for each map captured before, during and after the 2021 eruption of mount Semeru.

5. Conclusion

The conclusion of this research on DInSAR deformation changes before, during, and after the 2021 Semeru volcano eruption shows that before the eruption, the deformation changes indicated, the deformation changes indicated a value of (-), meaning there was no detectable deformation. Whereas during the eruption, it showed values from 0.064 cm to 0.094 cm, so it can be concluded that during the eruption, the deformation change experienced an inflation of 0.03 cm. and after the eruption, the value of the deformation change showed from 0.037 cm to 0.079 cm, resulting in a deformation change inflation of 0.042 cm.

The presence of a blank phase on Mount Semeru and the red circle is concluded due to the difficulty in reading the phase values caused by disturbances during image capture. The conclusion of disturbances can be drawn during and after the eruption due to the volcanic mudflow that flows out during the eruption and the remaining volcanic mudflow after the eruption, which prevents the reading of the phase values.

Acknowledgements

Authors would like to thank the data provider from the European Space Agency (ESA) for their valuable input in this study, along with the Brawijaya Volcano & Geothermal Research Center. This study is funded by the Faculty of Mathematics and Natural Sciences at Brawijaya University through the Professor Research Grant Program, referenced by contract number 02172.5/UN10.F0901/B/KS/2024.

References

Agustiningsih, A., Mahmudi, K., Wardoyo, A., Wardani, R., Barif, Z., 2022. Education of Mitigation for Mount Semeru Eruption to Elementary School Students. *J. Basicedu* 6, 9958–9966. https://doi.org/10.31004/basicedu.v6i6.4180 (in Indonesia).

Alif, S.M., Anggara, O., Perdana, R.S., Hasannah, U., Azizah, F.N., 2024. Analysis of Presumed Land Subsidence in the Cities of Lampung Province Using InSAR and GNSS Data. *J. Geol. Eng. Environ. Technol.* 9, 281–287. https://doi.org/10.25299/jgeet.2024.9.3.14096.

Andi, 2021. *Semeru Volcano Eruption* [WWW Document]. URL https://www.kompas.com/tren/read/2021/12/10/205000065/erupsi-gunung-semeru-mengapa-banyak-warga-selfie-di-lokasi-bencana-?page=all (in Indonesia).

Andryana, K., Maryanto, S., Susilo, A., Triastuti, H., 2011. *Mechanism Focus of Volcanic Type A Earthquake at Mount Semeru, East Java - Indonesia*. *Natural-B*, 1, 139–145. https://doi.org/10.21776/ub.natural-b.2011.001.02.7

Arbad, A.P., Takeuchi, W., Yosuke, Y., Jamilah, M., Ardy, A., 2019. Time-Series SAR Interferometry Analysis of Surface Deformation at Mt. Bromo, Indonesia**.** *Semin. Nas. Geomatika* 3, 771. https://doi.org/10.24895/SNG.2018.3-0.956.

Ariyantoni, J., Rokhmana, C.A., 2020. Evaluation of SAR Image Polarization (Synthetic Aperture Radar) for Land Cover Object Classification**.** *Elipsoida J. Geod. dan Geomatika* 3, 22–29. https://doi.org/10.14710/elipsoida.2020.7761 (in Indonesia).

BNPB, 2016. *Disaster Risk of Indonesia*. *Int. J. Disaster Risk Sci.*, 22 (in Indonesia).

Cumming, I.G., Wong, F., 2004. *Digital Processing of Synthetic Aperture Radar Data: Algorithms and Implementation*. Artech House, London.

ESA, 2022. *Sentinel Satellites* [WWW Document]. URL https://www.esa.int/.

Fadhlurrohman, B., Prasetyo, Y., Bashit, N., 2020. *Study of Land Subsidence in the Kendal Industrial Area Using Permanent Scatterer Interferometric Synthetic Aperture Radar (PS InSAR) Method with Sentinel 1-A Imagery from 2014-2019*. *J. Geod. Undip*, 9. https://doi.org/10.14710/jgundip.2020.27177 (in Indonesia).

Febriyanti, R.F., Anjasmara, I.M., 2017. *Deformation Analysis of Mount Raung Using Differential Interferometry Synthetic Aperture Radar (DInSAR) Technology*. *J. Tek. ITS*, 6. https://doi.org/10.12962/j23373539.v6i2.25018 (in Indonesia).

Hajduch, G., Bourbigot, M., Johnsen, H., Piantanida, R., 2023. *Sentinel-1*.

Hanssen, R.F., 2001. *Radar Interferometry, Remote Sensing and Digital Image Processing*. *Journal of Computer and Communications*, Dordrecht. https://doi.org/10.1007/0-306-47633-9.

Natadikara, R., Nurtyawan, R., Fauzi, A.I., 2023. *Deformation Analysis of Mount Anak Krakatau Using Differential Interferometry Synthetic Aperture Radar (DInSAR)*, in: *Machine Learning and Information Processing: Proceedings of ICMLIP 2023*. AIP Conference Proceedings. https://doi.org/http://dx.doi.org/10.1063/5.0181540 (in Indonesia).

Prasojo, O.A., Aufar, A., Syahputra, R., 2024**.** Cost-Efficient Digital Elevation Model (DEM) Acquisition on Flume Tank Morphodynamic Observation**.** *J. Geol. Eng. Environ. Technol.* 9, 4–8. https://doi.org/10.25299/jgeet.2024.9.04.2311

Purba, A., Sumantri, S.H., Kurniadi, A., Putra, D.R.K., 2022. *Analysis of the Community Capacity Affected by the Eruption of Mount Semeru*. *PENDIPA J. Sci. Educ.*, 6, 599–608. https://doi.org/10.33369/pendipa.6.2.599-608 (in Indonesia).

PVMBG, 2021. *Indonesian Volcanoes* [WWW Document]. PVMBG. URL https://vsi.esdm.go.id/data-dasar# (in Indonesia).

Seftianingtyas, E., 2024. *Analysis of Land Deformation Due to the April 10, 2021 Earthquake Based on InSAR and Magnetic Methods (Case Study: Tamanayu Village, Pronojiwo, Lumajang)*. Universitas Brawijaya (in Indonesia).

Sihombing, S., Sunardi, B., Darmawan, H., 2024. Engineering , Environment , and Technology Tsunami Modeling Using DEMNAS and DEM Data from UAV Surveys for Planning Evacuation Routes on Samas Coast , Bantul Regency 9. *J. Geol. Eng. Environ. Technol.* 9. https://doi.org/10.25299/jgeet.2024.9.2.14777

Suci Ulamatullah, T., 2022. Social Economic Issues of the Mount Semeru Eruption Disaster in Lumajang Regency as a Source for Social Science Learning. *J. Basicedu* 3, 829–836 (in Indonesia).

Teguh Purnama Sidiq, 2017. *Utilization of InSAR Method for Monitoring Volcanic Deformation and Land Subsidence*. Thesis. Department of Geodesy and Geomatics Engineering, ITB, Bandung (in Indonesia).

TNBTS, 2023. *Bromo Tengger Semeru National Park* [WWW Document]. *Taman Nasional Bromo Tengger Semeru*. URL https://bromotenggersemeru.org/page-static/wilayah-kerja (accessed 9.25.23) (in Indonesia).

Utami, W., Sugiyanto, C., Rahardjo, N., Juliyani, A., Richasari, D.S., Nurhadi, N., 2023. Spatial Analysis of the Semeru Eruption Disaster Area. Int. J. Geoinformatics 19, 54–66. https://doi.org/10.52939/ijg.v19i8.2783

Wibowo, A., 2023. *Analysis of the Risk Level of Pyroclastic Density Flow of Semeru Volcano Eruption in Candipuro, Lumajang, East Java*. Thesis. Faculty of Geography, Universitas Muhammadiyah Surakarta (in Indonesia).