



Landslide Movement Detection Using DInSAR and Sentinel-1A Imagery in a Tropical Volcanic Highland

Ikhwannur Adha¹, Dani Mardiaty¹, Sari Bahagiarti Kusumayudha¹, Rama Erdy Dwitama¹,
Kristina Candra Sari¹, Afreeda Salmaputri¹, Nandra Eko Nugroho²

¹ Department of Geological Engineering, UPN "Veteran" Yogyakarta, Indonesia;

² Department of Environmental Engineering, UPN "Veteran" Yogyakarta, Indonesia

Received : September 4, 2026

Revised : September 27, 2026

Accepted : September 28, 2026

Online : October 7, 2026

Abstract

Landslides are major geological hazards in tropical mountainous regions, where steep topography, weathered materials, geological structures, and rainfall promote slope instability. This study evaluates Differential Interferometric Synthetic Aperture Radar (DInSAR) to detect and quantify post-landslide surface deformation in a tropical volcanic highland affected by a catastrophic landslide in December 2014. A single Sentinel-1A interferometric pair acquired on 4 August 2017 and 1 May 2026 from the same ascending relative orbit was processed using a standard DInSAR workflow. Line-of-Sight (LOS) displacement was interpreted with geological and geomorphological data. Results show LOS displacement of -0.69 to -0.40 m accumulated over 8.74 years (3,192 days), equivalent to an interval-average rate of approximately 46–79 mm/year. The displacement is spatially associated with structurally controlled volcanic terrain, weathered lithologies, fault and joint systems, and slopes of 30–40%. This study quantifies post-2014 deformation at Telagalele using DInSAR. However, the estimates derive from a single 8.74-year interferometric pair without independent validation and should therefore be interpreted cautiously. The findings indicate DInSAR's potential for post-landslide deformation assessment in tropical mountainous environments.

Keywords: *DInSAR, Sentinel-1A, Landslide Monitoring, Surface Deformation, Post-Landslide Deformation, Tropical Volcanic Highland*

INTRODUCTION

Landslides are among the most destructive geological hazards, causing substantial loss of life, infrastructure damage, and environmental degradation worldwide. In Indonesia, steep topography, complex geology, weathered materials, seasonal rainfall, and anthropogenic activities influence landslide occurrence (Hutomo & Maryono, 2016). These conditions contribute to frequent slope failures in mountainous Java, where landslides repeatedly threaten communities and infrastructure. Monitoring slope deformation is therefore important for understanding landslide behavior and supporting hazard assessment and disaster risk reduction.

Conventional landslide investigations, including geological mapping, geodetic surveys, and geotechnical instrumentation, provide valuable information but can be limited by spatial coverage, accessibility, and the cost of repeated observations. Differential Interferometric Synthetic Aperture Radar (DInSAR) estimates surface displacement from phase differences between SAR images acquired at different times and can achieve centimeter- to millimeter-level precision under favorable conditions (Massonnet & Feigl, 1998; Bürgmann et al., 2000). Sentinel-1A provides freely accessible C-band imagery with systematic acquisitions, extending the use of DInSAR for deformation monitoring over large or inaccessible areas.

The study area is the Telagalele area, Karangobar District, Banjarnegara Regency, Central Java, a tropical volcanic highland affected by the catastrophic Jemblung landslide in December 2014. The event occurred in Jemblung Hamlet and caused more than 100 fatalities (Hutomo &

Copyright Holder:

© Adha, Mardiaty, Kusumayudha, Dwitama, Sari, Salmaputri & Nugroho. (2026)

Corresponding author's email: ikhwannur.adha@upnyk.ac.id

This Article is Licensed Under:



Maryono, 2016).

More than a decade after the disaster, determining whether residual or reactivated movement persists remains relevant to communities and infrastructure in the affected area. Post-landslide deformation assessment therefore provides information on present-day slope conditions beyond documentation of the 2014 failure.

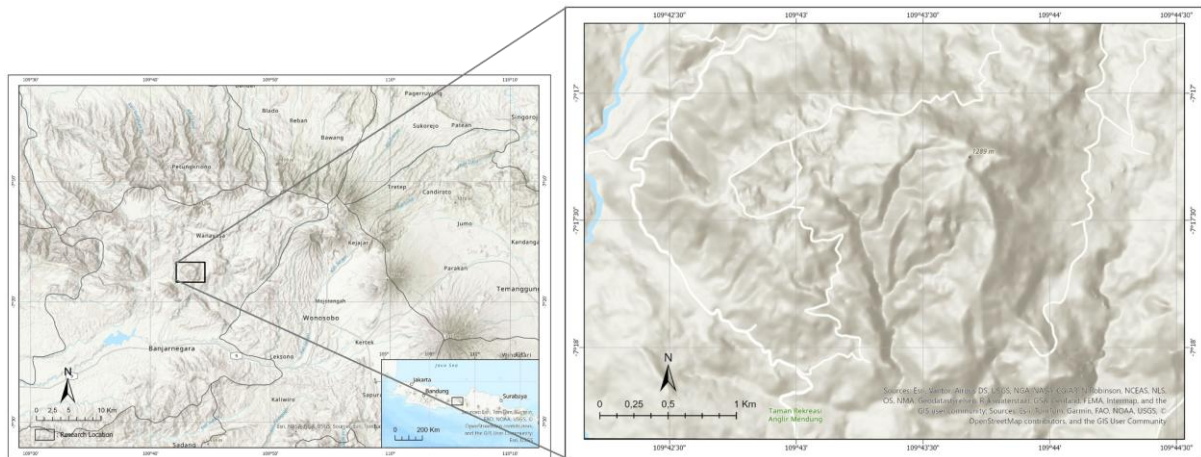


Figure 1. Research Area

Although interferometric techniques are increasingly used for landslide monitoring, quantitative investigation of post-landslide deformation at Telagalele remains limited. Previous work in Karangkobar focused on landslide susceptibility (Hutomo & Maryono, 2016), while Kusumayudha and Purwanto (2021) examined hydrogeological controls on mass transfer around Telagalele without quantitative surface-displacement analysis.

DInSAR studies in neighboring Yogyakarta reported measurable landslide deformation using ALOS PALSAR and Sentinel-1 data (Putri et al., 2013; Bahti & Praptawati, 2021). The present study therefore aims to (1) detect post-landslide surface deformation using DInSAR, (2) quantify the magnitude and spatial distribution of LOS displacement from Sentinel-1A imagery, and (3) evaluate the potential applicability of DInSAR for supporting landslide monitoring and hazard assessment in tropical mountainous environments.

LITERATURE REVIEW

Monitoring landslide deformation supports the assessment of slope instability and landslide risk. Surface deformation may indicate evolving instability in some landslides, although abrupt failures may show little measurable precursory movement (Novellino et al., 2024; Albanwan et al., 2024; Dini et al., 2026).

Satellite remote sensing complements field monitoring by providing repeated observations across large and difficult-to-access areas (Cheng et al., 2025). SAR suits tropical regions because observations can be acquired under cloudy conditions and at night, while Sentinel-1A provides systematic C-band observations for deformation analysis.

DInSAR estimates displacement from the interferometric phase difference between SAR acquisitions. After removing the topographic contribution, the differential phase includes ground deformation along with atmospheric effects, orbital errors, and residual noise (Tomás et al., 2026). Performance varies with land cover, slope geometry, displacement magnitude, and interferometric coherence. At the vegetated Corvara landslide, Darvishi et al. (2018) showed that retrieved deformation is sensitive to coherence thresholds and phase-unwrapping strategies.

In the mountainous Western Ghats, Devaraj et al. (2022) reported spatial and temporal

decorrelation caused by dense vegetation and rugged terrain, while [Chindo et al. \(2023\)](#) identified poor coherence and phase-unwrapping difficulties in a humid tropical environment.

Vegetation changes can reduce interferometric coherence because radar scattering conditions change between acquisitions ([Devaraj et al., 2022](#); [Chindo et al., 2023](#); [Chen et al., 2025](#)). Short temporal baselines are commonly used to limit decorrelation; [Tzouvaras \(2021\)](#) used 12-day Sentinel-1 pairs, while [Ciuffi et al. \(2024\)](#) used 6–24-day interferograms to improve deformation detection. [Chen et al. \(2025\)](#) further demonstrated challenges in low-coherence mountainous areas. These findings are relevant to the present 8.74-year single-pair analysis because a long temporal baseline increases the chance that vegetation, soil moisture, and other surface changes disrupt phase coherence.

In Indonesia, InSAR has been applied to landslide and ground-deformation studies. [Putri et al. \(2013\)](#) used ALOS PALSAR in the Kayangan catchment, Yogyakarta, and compared the results with GPS measurements. [Bahti and Praptawati \(2021\)](#) used PS-InSAR and Sentinel-1 data in Kalibawang, Yogyakarta, to investigate LOS deformation and rainfall relationships.

[Rosyidy et al. \(2021\)](#) applied SBAS-InSAR to landslides in southern Sukabumi, West Java, demonstrating the value of multi-temporal Sentinel-1 observations. [Arham and Wibowo \(2024\)](#) reported DInSAR-derived displacement associated with the 2022 Cianjur earthquake, and [Burrows et al. \(2025\)](#) used Sentinel-1 time series to investigate landslide timing and reactivation in Lombok. These studies show the relevance of Sentinel-1 interferometry in Indonesian mountainous settings and the value of multi-temporal analysis.

At Telagalele, previous studies have focused on landslide susceptibility and hydrogeological processes rather than quantitative post-event deformation. [Hutomo and Maryono \(2016\)](#) modeled landslide susceptibility in Karangobar, while [Kusumayudha and Purwanto \(2021\)](#) investigated hydrogeological controls on mass transfer around Mount Telagalele.

Multi-temporal techniques such as PS-InSAR and SBAS can reconstruct deformation time series ([Ferretti et al., 2001](#); [Berardino et al., 2002](#)), but the present study uses a single Sentinel-1A pair from August 2017 and May 2026. The result therefore represents cumulative LOS displacement between two dates and cannot resolve deformation timing or temporal changes within the interval. The long baseline also increases the possibility of temporal decorrelation in vegetated tropical terrain.

RESEARCH METHOD

This study used a quantitative remote-sensing approach to characterize post-landslide surface deformation with DInSAR. One Sentinel-1A interferometric pair from the same ascending relative orbit was processed to derive LOS displacement. The workflow comprised data acquisition, DInSAR processing, spatial integration, and deformation analysis.

Data Acquisition

The Sentinel-1A Single Look Complex (SLC) pair comprises a master scene acquired on 4 August 2017 and a secondary scene acquired on 1 May 2026, both from ascending relative orbit track 25. The temporal baseline is 3,192 days (8.74 years). Table 1 summarizes the acquisition parameters.

Table 1. Sentinel-1A Acquisition Parameters for the Single Interferometric Pair Used

Parameter	Value
Satellite/sensor	Sentinel-1A, C-band SAR
Acquisition mode	Interferometric Wide Swath (IW)
Product type	Single Look Complex (SLC), 1SDV

Polarization	VV + VH (dual)
Orbit direction	Ascending
Relative orbit/track	Track 25; same relative orbit for both scenes
Master (reference) scene	4 August 2017, 11:06:13 UTC; S1A_IW_SLC__1SDV_20170804T110613_..._017772_01DC6D_5468
Secondary scene	1 May 2026, 11:06:30 UTC; S1A_IW_SLC__1SDV_20260501T110630_..._064322_08194D_A570
Temporal baseline	3,192 days (approximately 8.74 years)
Coherence threshold	0.30; pixels below this threshold were excluded from displacement interpretation

DInSAR Processing

The Sentinel-1A SLC scenes were processed using a standard DInSAR workflow in the ESA Sentinel Application Platform (SNAP), including orbit correction, co-registration, interferogram generation, topographic-phase removal using DEMNAS, Goldstein filtering, phase unwrapping with SNAPHU, terrain correction, and conversion of unwrapped phase to LOS displacement.

Orbit correction reduces phase contributions from satellite-state uncertainty, co-registration aligns the two acquisitions, and Goldstein filtering reduces interferometric phase noise before phase unwrapping (Goldstein & Werner, 1998). The DEMNAS dataset has a spatial resolution of 0.27 arc-seconds (approximately 8–8.25 m) and is referenced to the EGM2008 vertical datum. DEMNAS was used for topographic-phase removal and terrain correction.

The unwrapped interferometric phase was converted to LOS displacement using the standard phase-to-range relationship, $d_{\text{LOS}} = (\lambda/4\pi)\varphi_{\text{unw}}$, where λ is the radar wavelength, and φ_{unw} is the unwrapped differential phase (Hanssen, 2001). Pixels with coherence below 0.30 were excluded from interpretation. No independent atmospheric phase correction was applied; residual atmospheric delay, orbital effects, DEM errors, and phase-unwrapping uncertainty are therefore treated as potential error sources (Hanssen, 2001).

Spatial Integration

The geocoded LOS displacement raster was integrated in a Geographic Information System (GIS) with geological, geomorphological, elevation, and slope datasets. All layers were transformed to a common coordinate reference system before overlay to avoid positional offsets (Burrough & McDonnell, 1998).

The geological reference layer was the Regional Geological Map of the Banjarnegara–Pekalongan Sheet at 1:100,000 scale, published by the Geological Survey Center (Pusat Survei Geologi). Lithological polygons and mapped structural features were compared with the spatial distribution of displacement. Because of the regional map scale, these comparisons reflect spatial associations rather than pixel-scale causal relationships.

The authors produced the geomorphological map from DEMNAS through terrain and landform interpretation. Elevation and slope were derived from DEMNAS using standard digital terrain-analysis procedures (Florinsky, 2016). The slope data were overlaid with the displacement raster to examine the spatial distribution of deformation relative to slope conditions; the geomorphological map shows slopes of 30–40%.

The spatial overlay procedure consisted of projecting datasets to a common coordinate system, clipping them to the study area, applying the 0.30 coherence mask, and comparing valid displacement pixels with lithological units, mapped structures, geomorphological units, elevation, and slope. The relationships were interpreted as spatial associations rather than proof of causation.

Deformation Analysis

The analysis summarized the magnitude and range of LOS displacement within coherent pixels and examined its spatial relationship with lithology, structural features, geomorphological units, and slope. The 46–79 mm/year value is an interval-average magnitude obtained by dividing cumulative displacement by the 8.74-year observation period and does not imply constant velocity. Because only one interferometric pair was used, the method cannot resolve acceleration, deceleration, episodic movement, or the timing of deformation within 2017–2026. Multi-temporal PS-InSAR or SBAS-InSAR is recommended for future time-series analysis (Ferretti et al., 2001; Berardino et al., 2002).

FINDINGS AND DISCUSSION

Geomorphological Setting

The geomorphological map (Figure 2) shows that the Telagalele study area is dominated by structural hills and structural valleys, with slopes of 30–40% and elevations of approximately 600–1280 m above sea level. These landforms provide the geomorphological framework for interpreting post-landslide deformation. Structural hills represent potential source or deformation zones, whereas structural valleys provide pathways for surface-water and sediment transport; these observations describe context rather than establish causation.

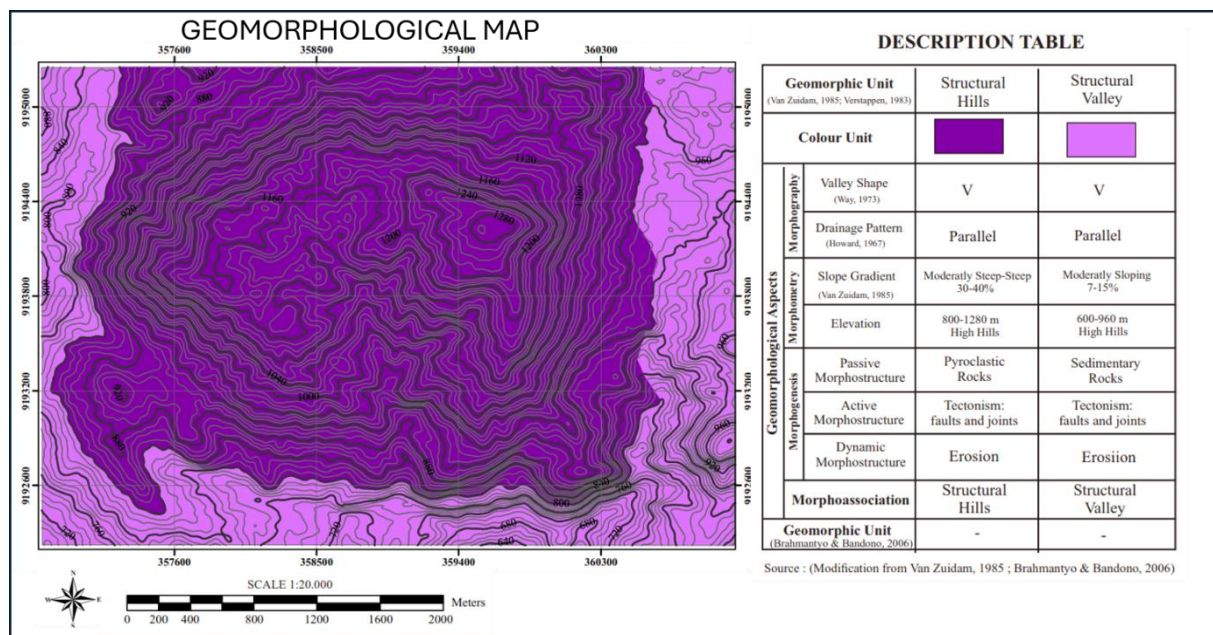


Figure 2. Geomorphological Map of Telagalele.

Geological Setting

The geological map (Figure 3) comprises the Dieng Volcanics (Qdo), Jembangan Volcanics (Qjmf), Halang Formation (Tmph), Rambatan Formation (Tmr), Clay Member of the Ligung Formation (Qtlc), and dioritic intrusive rocks (Tmd), with inferred faults across the area. The displacement pattern is spatially associated with intensely weathered volcanic and volcanoclastic terrain. Such materials provide a plausible geological context for deformation, but the available data do not quantitatively establish lithology or faults as independent controls.

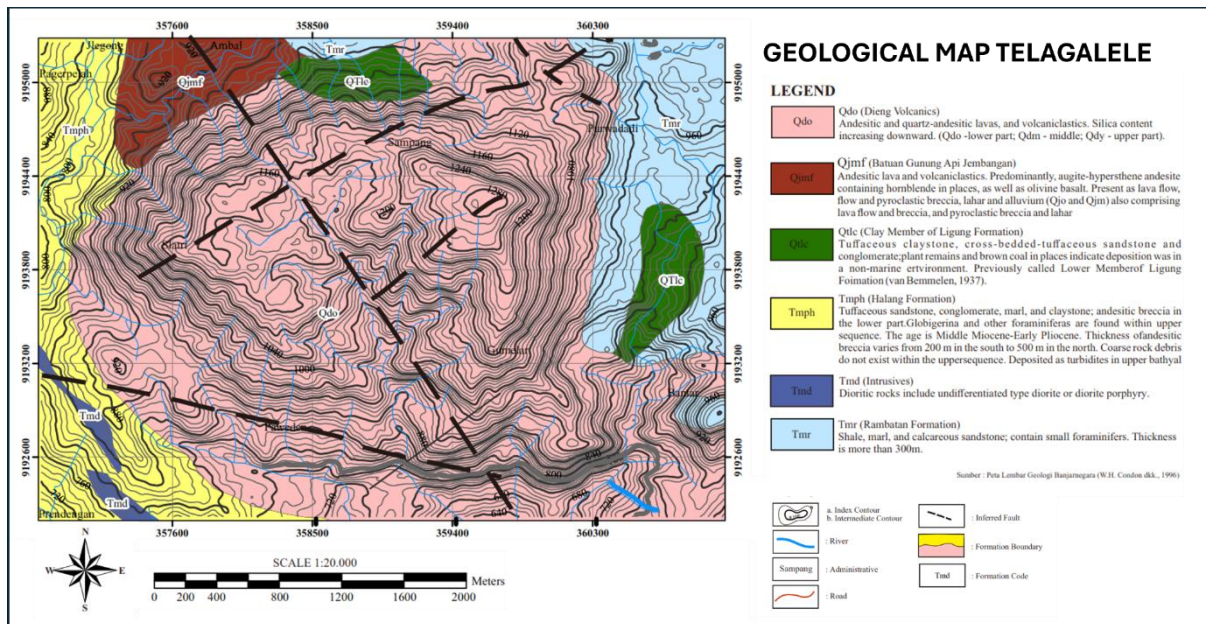


Figure 3. Geological Map of Telagalele.

DInSAR-Derived Displacement

The 2017–2026 interferometric pair (Figure 4) indicates LOS displacement ranging from -0.69 to -0.40 m accumulated over the 8.74-year observation interval (3,192 days). Dividing cumulative displacement by 8.74 years gives an interval-average magnitude of approximately 46–79 mm/year; this does not indicate a constant deformation rate throughout the interval.

Displacement Sign Convention

Under the adopted processing convention, negative LOS displacement represents relative motion away from the radar sensor and positive values represent motion toward the sensor. Because LOS is a one-dimensional measurement, the negative signal cannot by itself distinguish vertical subsidence from downslope movement. The values should therefore be interpreted as relative LOS displacement between the two acquisitions, subject to the limitations of the single-pair analysis.

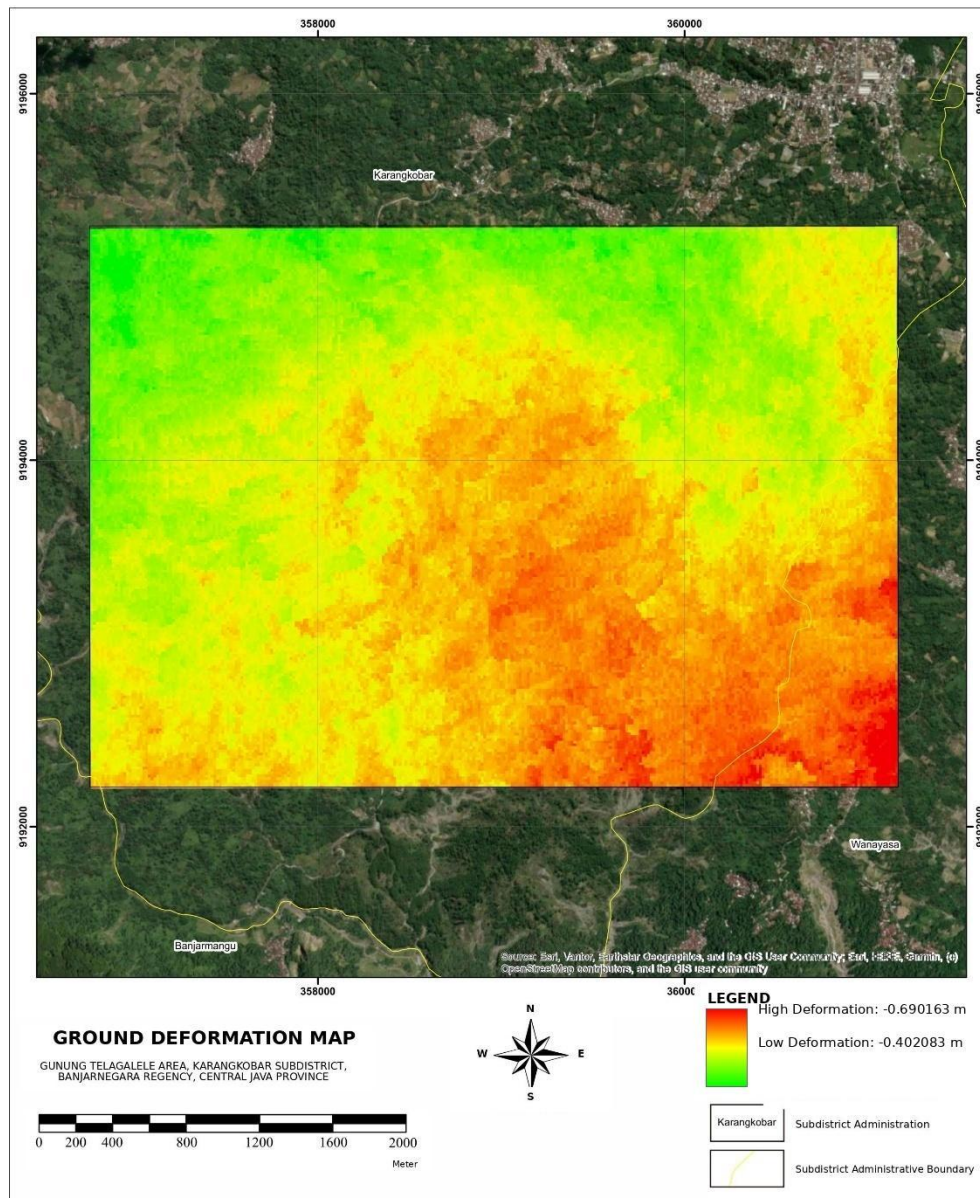


Figure 4. Ground Deformation Map of Telagalele.

Integrated Interpretation

Figures 2–4 indicate that larger negative LOS displacement occurs in parts of the volcanic and volcanoclastic terrain and on moderate-to-steep structural slopes. Some deformation anomalies coincide spatially with mapped faults or structural lineaments, while weathered volcanic materials provide a plausible setting for reduced slope strength. Because the present dataset provides no unit-by-unit statistical summary, these observations are treated as spatial associations rather than demonstrated causal controls.

Comparison with Previous Studies

The cumulative LOS displacement of -0.69 to -0.40 m over the 8.74-year interval corresponds to an interval-average magnitude of 46–79 mm/year. This range is at the lower end of the 52–579 mm/year range reported by Putri et al. (2013) for the Kayangan catchment, Yogyakarta. Treat the comparison cautiously because Putri et al. (2013) used ALOS PALSAR data over a shorter observation period and validated displacement with GPS. In contrast, the present study uses one

Sentinel-1A pair without independent displacement validation. [Bahti and Praptawati \(2021\)](#) reported a maximum LOS rate of -23 mm/year in Kalibawang, Yogyakarta, lower than the interval-average magnitude estimated here. [Darvishi et al. \(2018\)](#) reported rates reaching several meters per year at the vegetated Corvara landslide. Differences reflect variations in landslide activity, land cover, sensor characteristics, temporal baselines, processing, and validation.

Methodological Limitation and Specific Contribution

Interpretation is constrained by the single 8.74-year interferometric pair, potential temporal decorrelation in tropical and vegetated terrain, uncertainty in phase unwrapping, possible residual atmospheric or orbital effects, and the absence of independent ground-based validation. The derived displacement is therefore a cumulative LOS difference between two dates, not a continuous deformation history. This study quantitatively characterizes cumulative post-2014 surface deformation at Telagalele using Sentinel-1A DInSAR and interprets it spatially in relation to local geological and geomorphological conditions.

CONCLUSIONS

This study applied Differential Interferometric Synthetic Aperture Radar (DInSAR) to a single Sentinel-1A Single Look Complex (SLC) interferometric pair acquired on 4 August 2017 and 1 May 2026 along an ascending orbit to characterize post-landslide surface deformation in the Telagalele area, Central Java.

LOS displacement ranged from -0.69 to -0.40 m over the 8.74-year observation interval (3,192 days), corresponding to an interval-average magnitude of approximately 46–79 mm/year. Negative values indicate relative motion away from the satellite under the adopted LOS sign convention. Because only two acquisition dates were analyzed, the values represent cumulative LOS displacement rather than a continuously validated deformation trend.

In relation to the study objectives, the results indicate measurable post-landslide surface deformation and quantify its magnitude and spatial distribution. Relatively greater displacement is spatially associated with structurally controlled volcanic terrain, weathered volcanic and volcanoclastic materials, mapped faults and joints, and moderate-to-steep slopes.

These relationships provide geological and geomorphological context but do not independently establish causal controls. The results therefore indicate the potential applicability of DInSAR for post-landslide deformation assessment in tropical mountainous environments, pending confirmation through multi-temporal interferometric analysis and independent ground-based validation.

From a practical perspective, areas showing relatively greater negative LOS displacement, particularly where structural features coincide with steep and weathered volcanic terrain, may warrant further monitoring by BPBD Banjarnegara and relevant local authorities. The present results should be treated as screening-level evidence rather than a standalone basis for operational hazard decisions.

The interpretation is broadly consistent with the susceptibility context reported by [Hutomo and Maryono \(2016\)](#). It provides complementary spatial evidence to the hydrogeological and mass-transfer processes discussed by [Kusumayudha and Purwanto \(2021\)](#). The present DInSAR analysis does not directly validate the specific mechanisms proposed in those studies, but it extends their focus by documenting measurable post-event surface deformation at Telagalele. This is the study's specific contribution.

Several limitations constrain the interpretation. The single 8.74-year interferometric pair increases susceptibility to temporal decorrelation and phase-unwrapping uncertainty and cannot resolve temporal evolution or episodic deformation. DInSAR measures displacement only along the

satellite LOS, while residual atmospheric effects, orbital or ramp-related artifacts, DEM errors, and unwrapping errors may add uncertainty. Independent ground measurements did not validate the results, and the regional geological map and DEM-derived geomorphological interpretation limit local-scale characterization.

Future research should use a multi-temporal Sentinel-1 time series, preferably with SBAS-InSAR or PS-InSAR, along with higher-resolution topography, rainfall records, GNSS observations, and field-based geotechnical monitoring to resolve temporal behavior and strengthen validation of post-landslide deformation at Telagalele.

REFERENCES

- Albanwan, H., Qin, R., & Liu, J. (2024). Remote sensing-based 3D assessment of landslides: A review of the data, methods, and applications. *Remote Sensing*, 16(3), 455. <https://doi.org/10.3390/rs16030455>
- Arham, B., & Wibowo, A. (2024). Analisis bencana longsor akibat gempa bumi Cianjur 2022 dengan DInSAR. *Journal of Regional and Rural Development Planning (Jurnal Perencanaan Pembangunan Wilayah dan Perdesaan)*, 8(2), 104–115. <https://doi.org/10.29244/jp2wd.2024.8.2.104-115>
- Bahti, F. N., & Praptawati, A. (2021). The disaster mitigation of slow-landslide movement induced by rainfall based on PS-InSAR method. *Indonesian Scholars Scientific Summit Taiwan Proceeding*, 3, 76–83. <https://doi.org/10.52162/3.2021115>
- Berardino, P., Fornaro, G., Lanari, R., & Sansosti, E. (2002). A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms. *IEEE Transactions on Geoscience and Remote Sensing*, 40(11), 2375–2383. <https://doi.org/10.1109/TGRS.2002.803792>
- Bürgmann, R., Rosen, P. A., & Fielding, E. J. (2000). Synthetic aperture radar interferometry to measure Earth's surface topography and its deformation. *Annual Review of Earth and Planetary Sciences*, 28(1), 169–209. <https://doi.org/10.1146/annurev.earth.28.1.169>
- Burrough, P. A., & McDonnell, R. A. (1998). *Principles of geographical information systems* (2nd ed.). Oxford University Press.
- Burrows, K., Milledge, D. G., & Ferrario, M. F. (2025). Detection of landslide timing, reactivation and precursory motion during the 2018, Lombok, Indonesia earthquake sequence with Sentinel-1. *Earth Surface Dynamics*, 13, 1039–1057. <https://doi.org/10.5194/esurf-13-1039-2025>
- Chen, Y., Dai, K., Chang, L., Li, Z., Zhuo, G., Liu, X., & Shao, Y. (2025). Improved landslide monitoring in low-coherence mountainous areas: A coherence-enhanced multitemporal InSAR approach. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 18, 20690–20707. <https://doi.org/10.1109/JSTARS.2025.3596713>
- Cheng, Y., Pang, H., Li, Y., Fan, L., Wei, S., Yuan, Z., & Fang, Y. (2025). Applications and advancements of spaceborne InSAR in landslide monitoring and susceptibility mapping: A systematic review. *Remote Sensing*, 17(6), 999. <https://doi.org/10.3390/rs17060999>
- Chindo, M. M., Hashim, M., & Rasib, A. W. (2023). Challenges of InSAR DEM derivation with Sentinel-1 SAR in densely vegetated humid tropical environment. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLVIII-4/W6-2022, 93–98. <https://doi.org/10.5194/isprs-archives-XLVIII-4-W6-2022-93-2023>
- Ciuffi, P., Bayer, B., Berti, M., Franceschini, S., & Simoni, A. (2024). InSAR stacking to detect active landslides and investigate their relation to rainfalls in the Northern Apennines of Italy. *Geomorphology*, 457, 109242. <https://doi.org/10.1016/j.geomorph.2024.109242>
- Darvishi, M., Schlögel, R., Kofler, C., Cuozzo, G., Rutzinger, M., Zieher, T., Toschi, I., Remondino, F., Mejia-Aguilar, A., Thiebes, B., & Bruzzone, L. (2018). Sentinel-1 and ground-based sensors for

- continuous monitoring of the Corvara Landslide (South Tyrol, Italy). *Remote Sensing*, 10(11), 1781. <https://doi.org/10.3390/rs10111781>
- Devaraj, S., Yarrakula, K., Martha, T. R., Murugesan, G. P., Vaka, D. S., Surampudi, S., Wadhwa, A., Loganathan, P., & Budamala, V. (2022). Time series SAR interferometry approach for landslide identification in mountainous areas of Western Ghats, India. *Journal of Earth System Science*, 131, 133. <https://doi.org/10.1007/s12040-022-01876-3>
- Dini, B., Lacroix, P., & Doin, M.-P. (2026). Beyond and beneath displacement time series: Towards InSAR-based early warnings and deformation analysis of the Achoma landslide, Peru. *Natural Hazards and Earth System Sciences*, 26, 863–879. <https://doi.org/10.5194/nhess-26-863-2026>
- Ferretti, A., Prati, C., & Rocca, F. (2001). Permanent scatterers in SAR interferometry. *IEEE Transactions on Geoscience and Remote Sensing*, 39(1), 8–20. <https://doi.org/10.1109/36.898661>
- Florinsky, I. V. (2016). *Digital terrain analysis in soil science and geology* (2nd ed.). Academic Press.
- Goldstein, R. M., & Werner, C. L. (1998). Radar interferogram filtering for geophysical applications. *Geophysical Research Letters*, 25(21), 4035–4038. <https://doi.org/10.1029/1998GL900033>
- Hanssen, R. F. (2001). *Radar interferometry: Data interpretation and error analysis*. Kluwer Academic Publishers.
- Hutomo, I. A., & Maryono, M. (2016). Model prediksi kawasan rawan bencana tanah longsor di Kecamatan Karangobar. *Jurnal Pembangunan Wilayah dan Kota*, 12(3), 303–314. <https://doi.org/10.14710/pwk.v12i3.12905>
- Kusumayudha, S. B., & Purwanto, H. S. (2021). Hydrogeological drives in mass transfers of Mount Telagalele and surrounding area, Banjarnegara Regency, Central Java, Indonesia. *AIP Conference Proceedings*, 2363, 020007. <https://doi.org/10.1063/5.0061060>
- Massonnet, D., & Feigl, K. L. (1998). Radar interferometry and its application to changes in the Earth's surface. *Reviews of Geophysics*, 36(4), 441–500. <https://doi.org/10.1029/97RG03139>
- Novellino, A., Pennington, C., Leeming, K., Taylor, S., Gonzalez Alvarez, I., McAllister, E., Arnhardt, C., & Winson, A. (2024). Mapping landslides from space: A review. *Landslides*, 21, 1041–1052. <https://doi.org/10.1007/s10346-024-02215-x>
- Putri, R. F., Wibirama, S., Alimuddin, I., Kuze, H., & Sri Sumantyo, J. T. (2013). Monitoring and analysis of landslide hazard using DInSAR technique applied to ALOS PALSAR imagery: A case study in Kayangan catchment area, Yogyakarta, Indonesia. *Journal of Urban and Environmental Engineering*, 7(2), 308–322. <https://doi.org/10.4090/juee.2013.v7n2.308-322>
- Rosyidy, M. K., Dimyati, M., Shidiq, I. P. A., Zulkarnain, F., Rahaningtyas, N. S., Syamsuddin, R. P., & Zein, F. M. (2021). Landslide surface deformation analysis using SBAS-InSAR in the southern part of the Sukabumi area, Indonesia. *Geographia Technica*, 16(Special Issue), 138–152. https://doi.org/10.21163/GT_2021.163.11
- Tomás, R., Navarro-Hernández, M. I., Lopez-Sanchez, J. M., Reyes-Carmona, C., & Liu, X. (2026). Satellite-based differential radar interferometry in landslide research: An overview of applications and challenges. *Remote Sensing*, 18(7), 1081. <https://doi.org/10.3390/rs18071081>
- Tzouvaras, M. (2021). Statistical time-series analysis of interferometric coherence from Sentinel-1 sensors for landslide detection and early warning. *Sensors*, 21(20), 6799. <https://doi.org/10.3390/s21206799>