Advancing Airport Land Subsidence Monitoring Through Time-Series InSAR Technology

Anuphao Aobpaet[a], Intira Thanomsin, Chanikan Yodya[b] and Suchanpong Obnam[c]
Department of Civ 10900, Thailand
fengaha@ku.ac.th, {intita.tha, chanikan.yod, suchanpong.ob}@ku.th

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Abstract: The airport is a pivotal infrastructure project, serving as a hub for parking, transporting, and maintaining aircraft carrying passengers, freight, and cargo. However, the substantial usage of the airport leads to the challenge of land subsidence, necessitating ongoing monitoring and assessment. This study focuses on monitoring land subsidence at Suvarnabhumi Airport, Thailand's premier international airport catering to passengers and aircraft. In a lowland area with soft soil, applying advanced technology becomes imperative for continuous monitoring and analysis of subsidence over time. Employing InSAR Time-Series technology, researchers processed data from Sentinel-1 satellites spanning October B.E. 2017 to December 2023 to analyse the evolving conditions at Suvarnabhumi Airport. Results reveal that the most significant subsidence occurs in the Runway and Taxiway areas, with values ranging between -9.1 and 5.1 millimeters. per year. This subsidence is likely attributed to the constant heavy air traffic on these surfaces. Continuous monitoring and evaluation are crucial to planning effective maintenance. InSAR technology is valuable for monitoring land subsidence or displacement, alleviating data constraints and streamlining operational processes.

1 INTRODUCTION

An airport is a critical infrastructure connecting air and ground transportation systems and facilitating links between national and global economies (Pornpiboon, 1997; Chimtawan, 2005). Runways and taxiways experience continuous use and are subject to heavy loads and temperature fluctuations, leading to wear, deformation, and subsidence, posing risks to safety and infrastructure integrity.

Suvarnabhumi Airport, located in Samut Prakan Province, is in a soft soil zone on the lower Chao Phraya floodplain (Department of Mineral Resources, 2016). The area's geological structure comprises low-density soft sedimentary soils, making them unsuitable for supporting heavy loads. Groundwater extraction has exacerbated subsidence, with approximately 28–100 mm/year rates before airport operations (Srisompong, 2008). Post-construction monitoring indicates continued subsidence at 20–30 mm/year in the apron and runway areas. Ongoing monitoring and evaluation are essential to mitigate potential damage.

Traditional subsidence monitoring methods, such as benchmarks and GNSS-based elevation surveys, provide high accuracy but are limited in spatial coverage and costly for large-scale monitoring (Kheerinarat, 2020; Eiaurattanawadi, 2023). InSAR technology, which uses phase differences in SAR satellite images, offers a cost-effective and efficient alternative for detecting land movement over large areas (Piyamarat, 2022). Time-series InSAR further enhances this by providing average subsidence rates in millimeters per year using widely available satellite imagery without requiring field installations.

This research applies time-series InSAR to analyse Sentinel-1 satellite images (October 2017 to December 2023) to monitor subsidence at Suvarnabhumi Airport, Thailand's largest airport. Subsidence is achieved through maps created in QGIS, which provide insights into subsidence patterns for improved infrastructure management and safety.

[a] https://orcid.org/0000-0001-7638-853X
[b] https://orcid.org/0009-0004-7114-7066
[c] https://orcid.org/0009-0001-0548-5639

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1.1 Scope of the Research

1.1.1 Study Area

Samut Prakan Province is located along the Chao Phraya River, at the river's endpoint just above the Gulf of Thailand, between latitudes 13-14 degrees north and longitudes 100-101 degrees east. The province covers an area of approximately 1,004 square kilometers, or about 627,557 rai, in central Thailand, about 29 kilometers southeast of Bangkok. The general landscape is predominantly lowland plains, with the Chao Phraya River flowing through the center, dividing the province into western and eastern parts (Samut Prakan Province, n.d.; Office of Project Administration, Royal Irrigation Department, 2018; Department of Mineral Resources, 2016).

Suvarnabhumi Airport (IATA: BKK, ICAO: VTBS) is located on Debaratana Road and Burapha Withi Expressway, approximately at kilometer 15, in the subdistricts of Nong Prue and Racha Thewa, Bang Phli District, Samut Prakan Province. It lies about 31 kilometers east of Bangkok and covers an area of approximately 22,000 rai. As Thailand's largest airport and the tenth largest globally, Suvarnabhumi Airport opened for commercial service on September 28, 2006. It serves as Thailand's primary airport, featuring modern design and advanced technology, providing excellent service across all areas (Airports of Thailand Public Company Limited, n.d.). Currently, Suvarnabhumi Airport has two runways, capable of handling 68 flights per hour. A third runway, 4,000 meters in length, is under construction on the airport's west side to accommodate increasing air traffic in the future and to ensure capacity during maintenance closures of Runways 1 and 2. The third runway will increase the airport's capacity to 94 flights per hour. In optimal conditions with entire runway and taxiway operations, it will support an average of 800-1,000 flights per day (Suvarnabhumi Airport Construction Project Management Office, n.d.; AEC Consortium Group, 2020). Thus, the airport is a vital infrastructure component that influences the future of the aviation industry, symbolising economic growth and facilitating international business operations.

1.1.2 Duration of Implementation

This study uses Sentinel-1 satellite images from October 2017 to December 2023 for analysis based on Synthetic Aperture Radar (SAR) technology.

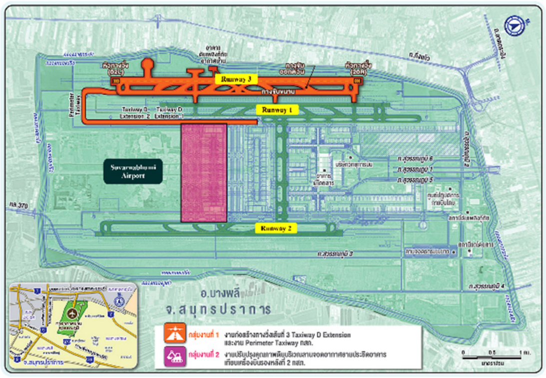

Figure 1: Suvarnabhumi Airport Layout (Suvarnabhumi Airport Construction Project Management Office, n.d.).

2 PRINCIPLES AND THEORY

2.1 Sentinel-1 Satellite Data

The Sentinel-1 satellite, part of the European Space Agency's (ESA) Copernicus program, began operations in 2014 and includes Sentinel-1A and Sentinel-1B satellites (Bunyapoluk, 2022). However, Sentinel-1B cannot transmit data back to Earth due to an issue with its power supply (Eiaurattanawadi, 2023). Sentinel-1 utilises a radar imaging system that uses microwave signals from a satellite-based energy source and transmits them to Earth at an oblique angle (GISTDA, 2021). It operates in the C-band with a frequency of 5.405 GHz, providing images with varying spatial resolutions and swath widths, as detailed in Table 1. For this research, the Interferometric Wide-Swath Mode (IW) is selected, covering a 250-kilometer swath and offering an image resolution of 5 x 20 meters in range and azimuth directions. Additionally, it operates in dual polarisation mode with an incidence angle ranging from 31 to 46 degrees (European Space Agency, n.d.).

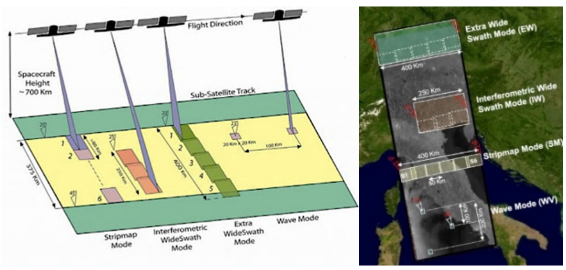

Figure 2: SAR Operating Mode (European Space Agency, n.d.).

Table 1: SAR Operating Mode Under Sentinel-1 Satellite (European Space Agency, n.d.).

Modes	Swath (km)	Spatial resolution (m)
Strip Map (SM)	80	5 x 5
Interferometric Wide Swath (IW)	250	5 x 20
Extra-Wide Swath (EW)	400	20 x 40
Wave (WV)	20 x 20	5 x 5

The Sentinel-1A satellite operates in a near-polar, sun-synchronous orbit at 693 kilometers, with an inclination angle of 98.18 degrees and a 12-day repeat cycle. Equipped with a C-SAR sensor, it provides data under all weather conditions, day and night. The satellite requires precise orbital control to ensure accurate InSAR measurements for land and maritime monitoring, emergency management, and infrastructure analysis.

2.2 Interferometric Synthetic Aperture Radar (InSAR)

InSAR (Interferometric Synthetic Aperture Radar) technology is an advancement of SAR technology, which combines Synthetic Aperture Radar (SAR) images with wave interferometry technology (Aobpaet & Trisirisatayawong, 2012). The working principle of InSAR involves analysing phase differences between two or more SAR images. Synthetic Aperture Radar is a radar system that produces high-resolution images (Piromthong, 2015). When images of the same area taken at different times are compared, the resulting phase differential indicates surface movement (Geoscience Australia, n.d.; Chelbi, Khireddine, & Charles, 2011). The difference due to movement creates discrepancies between the two images. The phase difference allows the study of deformation patterns in various forms of land changes (Chaitawee, 2015). However, while InSAR technology can operate in all weather conditions, both day and night, a significant limitation is the signal distortion caused by the atmosphere, which leads to phase measurement errors (Lu, Kwoun, & Rykhus, 2007).

2.3 Time-Series InSAR

The analysis using Time-series InSAR provides a sufficient density of checkpoints to resolve issues related to sparse checkpoints. It also addresses the limitations of using such points to monitor displacement or subsidence. As a result, this technique offers high accuracy and precision.

Persistent Scatterer Interferometry (PS-InSAR) is a technique that uses phase data from Synthetic Aperture Radar (SAR) images to analyse changes in land displacement over time or across specific periods. It relies on the consistent and permanent backscatter (Permanent Scatterer, PS) of radar signals, which are transmitted to objects and reflected to the satellite antenna. The method generates multiple Differential Interferogram pairs, each referenced to a master image for image matching (Chaitawee, 2015). This study processes time-series radar images using the Persistent Scatterers method, another approach in the Time-series InSAR technique.

2.4 Persistent Scatterers InSAR

Persistent Scatterers InSAR (PSInSAR) is an advanced remote sensing technique developed from InSAR to address issues related to the lack of data correlation and signal distortions caused by the atmosphere (Piromthong, 2015). It utilises the backscatter of microwave signals from prominent and permanent reflectors (Permanent Scatterers, PS), which reflect off objects and return to the signal receiver, resulting in backscattering values for each pixel. The amplitude and phase of each pixel are vector sums of the backscattering from various scatterers. Over time, any changes in these objects, regardless of the cause, lead to changes in the amplitude and phase of the pixel, indicating movement, as shown in Figure 3 (Sricharoenpramong, 2015; Hooper, Segall, & Zebker, 2007). This technique is, therefore, suitable for monitoring subsidence at airports.

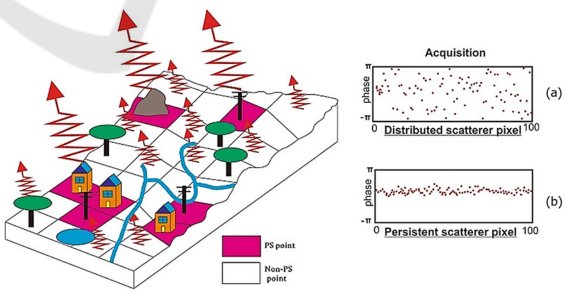

Figure 3: Simulation of Scattering Characteristics a) Distributed Scatterer Pixel (b) Persistent Scatterer Pixel (Yhokha, Goswami, & Chang, 2018).

2.5 Stanford Method for Persistent Scatterers (StaMPS)

StaMPS is a software used for InSAR processing with the Persistent Scatterers (PS) method, developed to work even in areas without human-made structures or regions experiencing unstable deformation (Hooper, Bekaert, & Spaans, 2013). The core of the PS technique involves identifying PS pixels and using only the values from the selected pixels for displacement processing. In the early stages of the PS technique, amplitude values were primarily used for filtering, which limited its use to areas with bright scatterers, such as regions with many structures. Another limitation was that a model of surface displacement had to be known beforehand, or the surface needed to exhibit stable movement to provide reliable results. However, StaMPS uses amplitude and the positional correlation of phase values for PS pixel filtering. This allows StaMPS to identify PS pixels even in areas with few structures. It enables it to work in regions with non-stable displacement without prior knowledge of the surface displacement rate (Chaitawee, 2015).

3 METHODOLOGY

3.1 Preparation of Satellite Image Data

The data used in this study consists of images from the Sentinel-1 satellite in the ascending orbit, which moves from south to north over the Earth's surface, covering the area of Suvarnabhumi Airport, Samut Prakan Province, as shown in Figure 4. The dataset to be used includes 75 Synthetic Aperture Radar (SAR) satellite images recorded from October 25, 2017, to December 29, 2023, covering 7 years. These images are captured in the ascending orbit, with L1 Single Look Complex (SLC) data, operating in VH and VV polarisation modes, and recorded in Interferometric Wide (IW) mode. The coordinate system used is WGS 1984, in Path 172 and Frame 1222, ensuring all images overlap perfectly for subsequent analysis.

Figure 4: Scope of Ascending Orbit Satellite Images Covering the Study Area.

3.2 Data Processing

Interferometric processing (InSAR) relies on the phase difference between two SAR images, referred to as the master image and the slave image, from the same area. Creating the interferogram uses the SNAP software to select the master image from the 75 images available. The image from October 21, 2020 (Subswath: IW2, Polarization VV, Burst 6-8) was chosen as the master image for reference and image matching, as shown in Figure 5. Then, the Co-registration algorithm aligned the sub-images from nearby areas, ensuring their coordinates were consistent (Laohudomchoke, 2023).

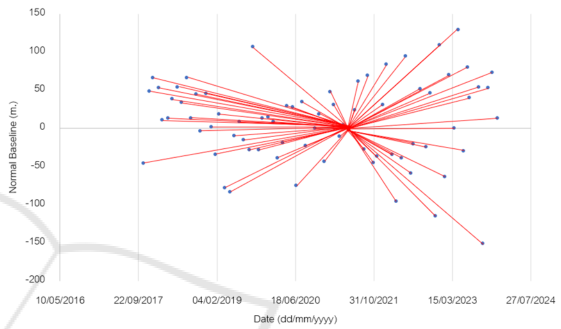

Figure 5: Image Matching of Slave Using the Master Image as a Reference.

The algorithm for processing time-series satellite data works as follows: first, Sentinel-1 satellite images are downloaded. Once completed, the SNAP software is used to read and convert the data by performing image matching between the Master and Slave images to create the interferogram. Then, a PS candidate file is created (using the command mt_prep_snap), and MATLAB is used to process the data with the Persistent Scatterers method in StaMPS to identify PS pixels. Phase unwrapping is performed to obtain complete phase values, and atmospheric noise is corrected using a linear process in TRAIN. Finally, time series plots are generated (Ladawadee, 2022). The workflow for the algorithm to determine subsidence rates can be illustrated in the flowchart shown in Figure 6.

3.3 Displaying Data on the Subsidence Map

Using MATLAB, the application of time-series InSAR for monitoring subsidence at Suvarnabhumi Airport allows for calculating displacement (Deformation) and coordinates (Latitude and longitude). The displacement data can then be

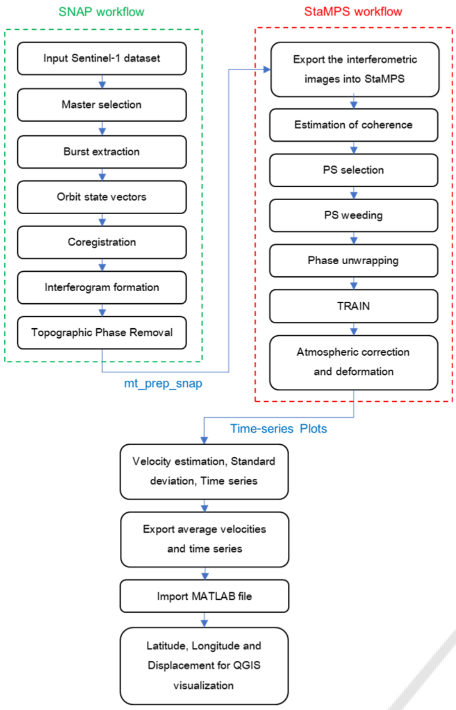

Figure 6: Flowchart of the Algorithm Workflow.

displayed on a map in QGIS, as shown in Figure 9. This is done by creating a data layer and defining coordinates along the axis, followed by classification to display the frequency of the data. The resulting data is shown as points, with varying colors representing the different subsidence values across the study area, as depicted in Figure 7.

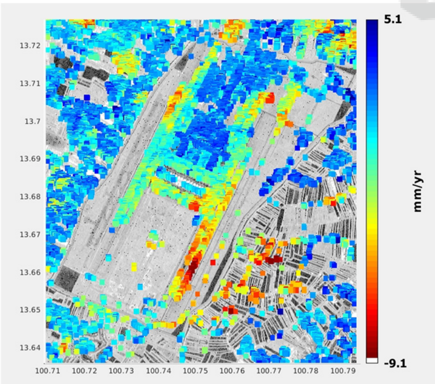

Figure 7: Results of Subsidence Analysis from MATLAB.

3.4 CORS Station

This research used data from one CORS station, BPLE, operated by the Department of Lands. This station is located at the Samut Prakan Land Office, Bang Phli branch, as shown in Figure 8. It provides automatic GNSS satellite signal surveying data under the supervision of the Royal Thai Survey Department. The data was collected from 2021 to 2023 and processed to display horizontal and vertical displacement. The results are presented in positional data (Latitude, Longitude, Height), which can be used as a reference for comparing subsidence trends alongside time-series InSAR analysis using Sentinel-1 satellite images from the same period. The GNSS data were obtained through high-precision single-point positioning, calculated by GPS surveying using the online AUSPOS service, developed by Geoscience Australia, a government agency. This service offers free online GPS data processing. The data processing utilises MicroCosm software, using high-precision satellite orbit and IGS high-precision satellite clock corrections. The processing can only be done with static survey data using dual-frequency receivers in RINEX format (Receiver Independent Exchange Format). The accuracy of the results may depend on the quality of the receiver, the survey duration, and the distance from the reference station (Sukwimonsaree et al., 2011).

Figure 8: Position of BPLE CORS Station.

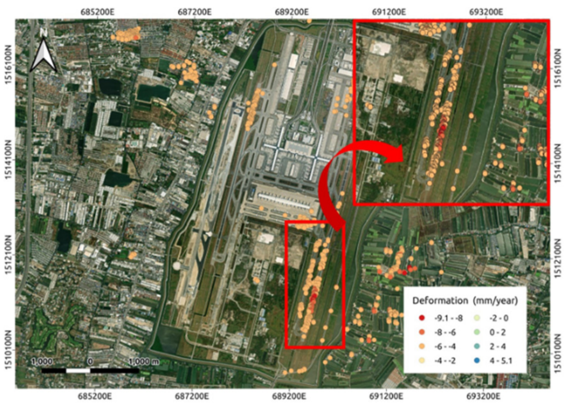

Figure 9: A subsidence rate map of Suvarnabhumi Airport, focusing on the runways and taxiways that require special attention, derived from time-series InSAR processing.

4 RESULTS

4.1 Checking the Subsidence Value

The study on the application of time-series InSAR for monitoring subsidence at Suvarnabhumi Airport, using 75 Sentinel-1 satellite images from October 2017 to December 2023, detected 44,343 PS pixels indicating subsidence and uplift across the airport area. The analysis of subsidence values in the ascending satellite orbit revealed land subsidence ranging from -9.1 mm/year (subsidence) to 5.1 mm/year (uplift), as shown in Figure 9. These subsidence values are within the normal range for airport design in typical lowland areas, allowing subsidence of up to 300 to 450 mm over 10 years without causing operational or safety issues (Srisompong, 2008).

As shown in Figure 13, the runway and taxiway areas have a clear difference in subsidence compared to other areas. For example, areas marked with orange to red indicate subsidence ranging from -9.1 to -4 mm per year, showing more significant subsidence than other locations. These areas should, therefore, be closely monitored and inspected. However, time-series InSAR provides preliminary information about subsidence.

4.2 Verification of Time-Series InSAR Technique

The processing using the Persistent Scatterer Interferometry (PSI) time-series technique to monitor subsidence at Suvarnabhumi Airport, specifically in the runway and taxiway areas (Runway 2), referenced at coordinates Lat 13.6637, Lon 100.7536, was conducted within a 100-meter radius. As shown in Figure 10, the airport's cumulative subsidence trend is increasing. The graph in Figure 11 illustrates daily cumulative subsidence values in millimeters. The detailed time-series measurements of PS deformation reveal a clear subsidence pattern.

4.3 Comparison of Subsidence Trends

The results obtained from processing RINEX data from 2021 to 2023 for station BPLE, reported as positional data including Latitude (X), Longitude (Y), and Height (Z), reveal movement in three directions: X, Y, and Z.

This research focuses on vertical displacement (Z) or land subsidence. From data processing, the height of station BPLE on January 25, 2021 (initial date), was -18.319 meters, and on December 29, 2023

Figure 10: The points within the 100-meter inspection radius on Runway 2, located at coordinates Lat 13.6637, Lon 100.7536, are measured in the Line of Sight (LOS).

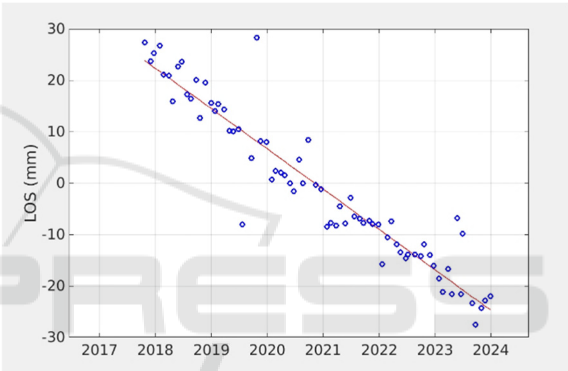

Figure 11: The cumulative subsidence trend from 2017 to 2023 within a 100-meter radius on Runway 2, located at coordinates Lat 13.6637, Lon 100.7536.

(final date), it was -18.390 meters. A height difference of 0.071 meters, equivalent to 71 millimeters, was observed from 2021 to 2023. Over the three years of processing, this indicates a land subsidence rate of 71 millimeters or 23.7 millimeters per year. As shown in Figure 12, when compared to the subsidence rates obtained using the InSAR technique at Suvarnabhumi Airport, which range from -9.1 to -5.1 millimeters per year, the results demonstrate an increasing trend in land subsidence that is consistent with the overall pattern.

The subsidence rate trends derived from InSAR time-series processing and the permanent GNSS station BPLE, under the Department of Lands, from 2021 to 2023, exhibit a consistent pattern. The subsidence rate increases over time. The subsidence in the Suvarnabhumi Airport area is lower due to soil improvements and specialised construction techniques designed to support massive loads. In contrast, station BPLE, located approximately 10

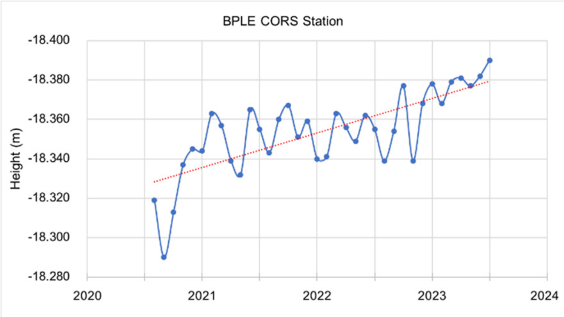

Figure 12: The height statistics and subsidence trends of station BPLE.

kilometers from the airport, shows a higher subsidence rate despite being in a nearby area.

5 CONCLUSIONS

Time-series InSAR technology is an effective method for monitoring airport subsidence. This study analysed Sentinel-1 satellite data using the Persistent Scatterer (PS) technique from October 2017 to December 2023, utilising 75 ascending orbit SLC images. The analysis identified 44,343 monitoring points with subsidence rates ranging from -9.1 to 5.1 mm/year, where negative values indicate subsidence and positive values indicate uplift. Runway and taxiway areas exhibited significant cumulative subsidence due to continuous air traffic use.

GNSS data from the BPLE station (10 km from Suvarnabhumi Airport) recorded a subsidence rate of 23.7 mm/year (2021–2023), aligning with InSAR-derived trends. Differences in subsidence values reflect varying construction techniques and land use. Still, both highlight Samut Prakan's susceptibility to subsidence due to its soft soil and impacts from urbanisation and groundwater extraction.

The findings underscore the importance of continuous subsidence monitoring to mitigate risks. InSAR technology proves valuable in engineering surveys, offering preliminary insights into ground stability, reducing fieldwork, and optimising time and costs. Thus, it is a practical tool for infrastructure management and hazard prevention.

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