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Mapping Potential Land Movement of Pura Sakenan Bali

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Abstract: Sakenan Temple is one of the most sacred and historic temples in Bali. Located on Serangan Island. In addition, Sakenan Temple is an area located in the tectonic pile zone that causes earthquakes. The purpose of this study was to examine possible land movement near Sakenan Temple in Bali in attempts to lessen local calamities. The sentinel 1-A picture data from August 2022–2024 is used in this research methodology. processed on SNAP software with the DinSAR approach to extract variables related to land movement. According to the findings, there was land movement in August 2022–2023 from -0.109 to 0.145 cm/year and in August 2023–2024 from -0.245 to 0.207 cm/year. Negative numbers indicate land subsidence, while positive values indicate uplift. There is an increase in land movement, with an average of -0.158 cm/year for land subsidence and 0.176 cm/year for uplift between August 2022 and August 2023 and -109 cm/year between August 2023 and August 2024. The value of land movement increased, increasing by -0.178 cm/year. The average is -0.156.

Keywords: DinSAR; Land Movement; Land Subsidence; Sentinel-1A; Uplift.

Introduction

Sakenan Temple is one of the most important temples in the south of Bali, located on the beach in the northwest of Serangan Island, Bali. Sakenan Temple was Dang Kahyangan Temple, so it was frequently visited by tourists (Darmawan & Sastrawan, 2020). Located at a relatively low elevation and on the tectonic plate boundary (Indo-Australian Plate) as a trigger for various disasters such as earthquakes, tsunamis, and various subsequent disasters such as ground movements (Sutarja, 2015).

Disaster mitigation has been implemented on the architecture and environment of Serangan Island after reclamation. The results of the analysis found that the most densely populated area on Serangan Island is the residential area on the northwest side, which is the safest area but still at risk of earthquakes accompanied by tsunamis and other disasters (Darmawan & Sastrawan, 2020).

The potential danger of tsunami and earthquakes is not the only concern. Another potential disaster that needs attention is land movement. Earthquakes can cause land movement, such as uplift and subsidence. So, based on this, we need to know the value of the uplift and land subsidence that occur (Hussain et al., 2022). Because of its ability to cause extensive damage and serious threats such as loss of life and infrastructure damage, it demands precise mitigation measures.

Therefore, to mitigate disasters at Sakenan Temple, the Civil Engineering Department of Qamarul Huda Badaruddin Bagu University and the Geophysical Engineering Department of Brawijaya University conducted "Mapping Potential Land Movement of Pura Sakenan Bali." In general, there are five stages of land movement disaster mitigation, namely: mapping, investigation, examination, monitoring, and outreach (Rahman, 2015). The mapping stage is crucial for identifying areas with potential land movements (Fatiatun et al., 2019).

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Land movement mapping that is often used by processing radar image data using the DinSAR method (Nugraha et al., 2022). DinSAR, or Differential Interferometry Synthetic Aperture Radar, is one method of radar imaging that uses the difference between two or more phases of SAR imagery with an acquisition period of years and different processes to obtain displacement movements from the earth's surface (Tzouvaras et al., 2020). The DinSAR method can detect changes in surface topography morphology with a high level of accuracy, utilizing interferogram pairs from SAR images. Apart from that, scale freezing can be more precise, ranging from centimeters to hundreds of kilometers in area (Yastika & Shimizu, 2016).

DInSAR Method at PT Iroha Sidat Indonesia, Bomo, Banyuwangi, using Sentinel 1A image processing results per year shows the vertical deformation around the pond area of PT ISI. The results showed a variation in vertical deformation each year, where subsidence and uplift occurred. The land subsidence value between 2014 and 2019 is around (-0.001) - (-0.031) meters/year, while the uplift value is around 0.016 meters/year (Nugraha et al., 2022).

So, this research was carried out by processing satellite data of the Sentinel-1A image type. Then processed using the SNAP software and then mapped using Google Earth Pro and ArcMap software. Because Sentinel-1A image data has several advantages, including: acquiring imagery in all weather conditions (Simarmata et al., 2023), producing a long-term consistent data archive (Yastika & Shimizu, 2016), and being used to track land subsidence and structural damage (Fárová et al., 2019). Because at Sakenan Temple never been studied about ground movements using satellite image data. Furthermore, this research is very important because of the phenomenon of shifting land positions in the Sakenan temple. To avoid further undesirable events, research on land movement using Sentinel 1A imagery is needed. Because Sentinel 1A image data will provide information regarding real time land movement data that occurs from satellite image data processed using the SNAP application. So, the results of this research will be used for early efforts to mitigate disasters that may occur at Pura Sakenan at any time. It will also be used as a reference by the BPBD of Bali Province. Because, as we know, Pura Sakenan is one of the holiest and most historic temples in the province of Bali.

Method

Research Location & Tool and Data

The research was conducted on Serangan Island, South Denpasar, Denpasar City, Bali, Indonesia, at coordinates 8° 43′ 30.46″ S and 115° 13′ 45.84″ E. The study utilized various tools to support the analysis of Differential Interferometric Synthetic Aperture Radar (DInSAR) data. A Lenovo Yoga laptop served as the main processing device, with SNAP 8.0 software used for DInSAR processing and SNAPHU 1.4.2 for the unwrapping phase. ArcMap 10.8 software facilitated layout creation and data analysis, while Microsoft Office 365 supported documentation and presentation preparation. The data included shapefile information of Serangan Island and Sentinel-1A radar imagery from August 2022 to 2024, enabling a temporal and spatial analysis of surface changes in the region. These tools and datasets were integral to the study, providing a comprehensive understanding of geospatial phenomena in the area.

Figure 1. Map of Sakenan Temple

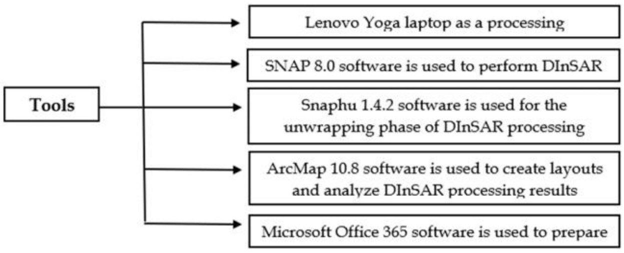

Figure 2. Tools

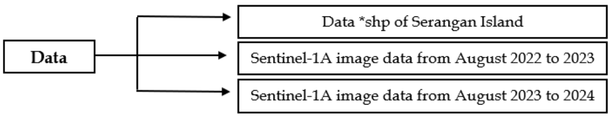

Figure 3. Data

Geology of Bali Island

The surface area of the Island of Bali is composed of various types of volcanic rocks. In the Serangan area, South Bali is composed of alluvium deposit formations (Qal) (Figure 4) as the youngest deposits consisting of clay, sand, silt, and gravel (Suyarto, 2012). From the rock informations on Figure 4, geological disasters often occur, namely earthquakes, tsunamis, abrasion, floods, and land movements.

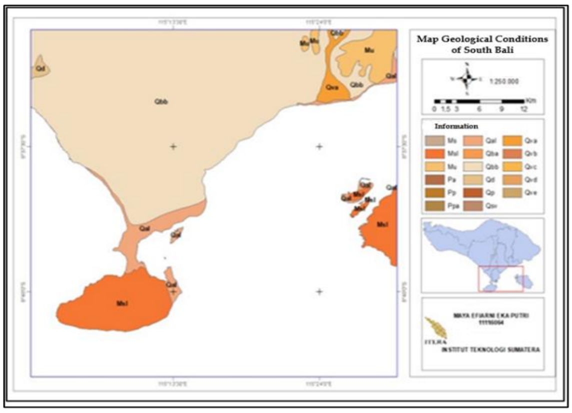

Figure 4. Geological Map of South Bali (Putri et al., 2021)

DinSAR Method

Movement or change in the position of a point is called deformation (Haqqi, 2015). Deformation is the movement of a material, both absolutely and relatively (Ramadhanty et al., 2022) on a certain frame of reference due to forces acting on the material (Castañeda et al., 2011). This deformation or shape change information can be processed to provide a good picture in understanding natural phenomena involving the movement of earth's surface material. Ground movements are usually triggered by excessive groundwater extraction and earthquakes (Whittaker, 1989).

Land movement resulting from earthquakes include uplift and land subsidence. Uplift is a process of land rise caused by external factors in the form of frequent earthquakes. While internal factors carried out by humans include the extraction of ground water. Land subsidence can happen over a large region or be localized to a small area, often caused by underground voids. Over time, land subsidence can lead to a decrease in elevation of several meters. There are multiple factors that contribute to land subsidence which include external and internal factors (Ulfah & Susilo, 2024).

Land movement values can be obtained by processing imagery data from Sentinel-1A. The Sentinel-1 consists of two orbiting satellites that operate day and night using SAR C-band imagery, which allows for data collection unaffected by weather conditions (de Carvalho Alves & Sanches, 2023). This satellite is the first of five missions developed by ESA for the Copernicus initiative (Ulfah et al., 2021). And data products that can be processed with DInSAR method.

Differential Interferometric Synthetic Aperture Radar (DInSAR) is a radar imaging method used to measure land movement (Ng et al., 2012). Works by comparing the phase difference of two or more SAR images acquired at different times (Jaya et al., 2021). The purpose of DInSAR is to isolate the phase changes due to deformation from other contributin. This can be achieved by using a reference topographic surface or by analyzing three or more radar images. Phase information obtained from the interferogram includes elements of topography, orbit shift, surface deformation, and atmospheric effects (Jaya et al. 2021) from 2 SAR observations at different times (Castañeda et al., 2011).

Differential Interferometry SAR (DInSAR) is a technique used to measure the interferometric phase related to displacement. To obtain accurate displacement information, interferometric phase contribution related to topography must be removed using DEM (Digital Elevation Model) (Dang et al., 2021). Calculated interferograms with the DInSAR technique may contain unwanted phase terms due to inaccuracies in topography and orbit parameters (Çakir et al., 2003). The interferometric phase variation can be expressed on Equation 1.

$$\Delta\varphi = \Delta\varphi displ + \Delta\varphi topo + \Delta\varphi orb + \Delta\varphi atm + \Delta\varphi scatt + \Delta\varphi noise \quad (1)$$

Information:

φ : phase
φdispl : phase shift
φtopo : topographic phase
φorb : orbital phase
φatm : atmospheric phase
φscatt : scattering phase
φnoise : noise phase

The displacement measurement at DInSAR stage provides the displacement in the Line of Sight (LOS) direction (Ng et al., 2012). If land subsidence only occurs at vertical direction and angle of incidence approximately same as the off-nadir angle of sensor, then land movement (displacement) in the vertical direction (d_v) can be derived as (Fajrin et al., 2021), on Equation 2.

$$d_v = d_{LOS}.Cos\ \theta \quad (2)$$

Information:

d_v : vertical direction shift
d_{LOS}l : LOS shift
θ : incidence angle

Data Processing and Mapping

The author analyzes the potential of land movement at Sakanan Temple because no research has ever been conducted on this topic. The data was used from August 2022 to August 2023 and from August 2023 to August 2024 to determine the situation over the last two years. The advantages of Sentinel-1A are its ability to capture images in all weather conditions, producing a consistent and long-term data archive that can be used to monitor land uplift, subsidence, and structural damage (Cian et al., 2019).

Next, data processing is carried out on the SNAP application. First processing was carried out with TOPS (Terrain Observation with Progressive Scans) Deburst pair image to generate an interferogram. The criteria for the Sentinel-1A image used are Single-Look Complex (SLC), IW mode, and VV polarization. The second step is coregistration to ensure that the target (ground target) is at the same pixel in range and azimuth on master and slave images (Ulfah et al., 2021).

Image co-registration process to align SAR images so that it can calculate the difference between overlapping image pixel pairs. In the core registration process, the back geocoding and Enhanced Spectral Diversity (ESD) methods are used, which have previously been implemented with accurate orbit data to create an interferogram and after reducing the flat earth phase. The next step is to calculate the interferogram. Then the Deburst process to eliminate gaps between paths. While multilook is used to reduce spots (noise) and improve image interpretation, To reduce noise using Goldstein filtering (Goldstein & Werner, 1998).

Furthermore, the unwrapping phase is carried out to eliminate ambiguous phases into absolute phases; the output in this phase must be exported to the Snaphu device, and the product will be imported back into the SNAP device to convert the phase into displacement. The last step is to perform terrain correction for the land displacement map using the geocoding operator by implementing the Range Dopplar Terrain Correction orthorectification method. The main steps in this study are implemented in the SNAP software environment. Schematically, the DInSAR process in the SNAP software is presented in Figure 5.

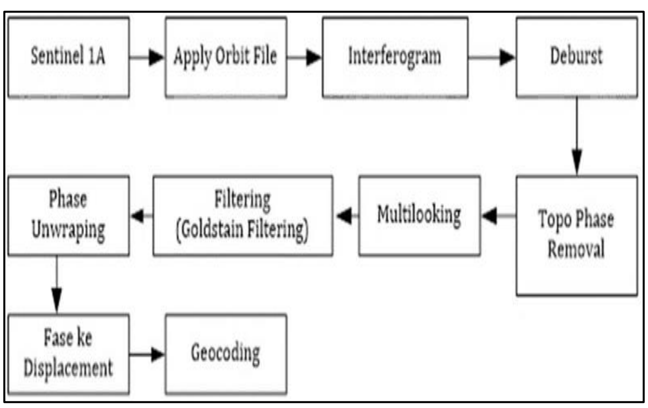

Figure 5. Processing of Sentinel 1-A Image Data with DinSAR Method

The reason why we use DinSAR method, because this method is most suitable for determining land displacement by comparing land displacement that occurs from 2 phases of SAR radar images taken in the same area on different dates (Casagli et al., 2016) dan (Jaya et al., 2021).

After processing the image data from Sentinel 1-A using the DinSAR method, the next step involves using Google Earth Pro and ArcMap 10.8 for mapping. The data generated from the SNAP software is imported into Google Earth to analyze the land movement values obtained and then exported in .kml format. After that, the data is mapped again using ArcMap 10.8, and analysis is conducted to assess the potential for land movement at Sakenan Temple.

Result and Discussion

Sentinel 1-A image data processing for the period August 2022 - 2024 has been carried out on the SNAP software to obtain the results of the land movement values of Pura Sakenan Bali. After being processed on the SNAP software for the accuracy of the location of the research point, readings were carried out on the Google Earth Pro software. The results obtained are shown in Figure 6 for August 2022 - 2023. And from Figure 7 for August 2023 - 2024.

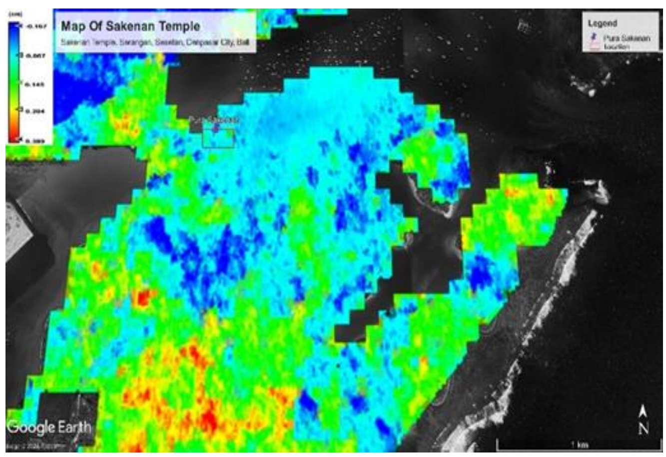

Figure 6. Google Maps of Land Movement Sakenan Temple August 2022 - 2023

From Figure 5 based on data from August 2022 - 2023, the results obtained that at the location of the Sakenan temple building area for the land movement value is -0.109 to 0.145 cm/year. Meanwhile, from Figure 6 based on data from August 2023 - 2024, the results of the land movement value are -0.245 to 0.207 cm/year.

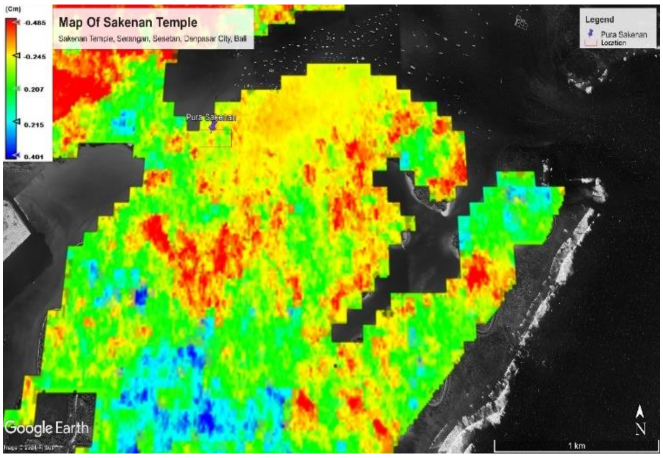

Figure 7. Google Maps of Land Movement Sakenan Temple August 2023 - 2024

Furthermore, for the analysis stage of various points around the Sakenan temple, mapping was carried out using ArcMap software as shown in Figure 8 for August 2022 - 2023. Meanwhile, Figure 9 is for August 2023 – 2024.

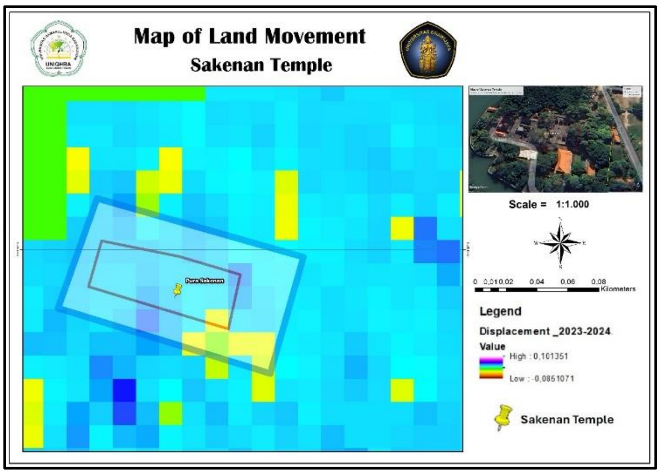

Figure 8. Map of Land Movement Sakenan Temple August 2022 – 2023

The land movement around Sakenan temple was mapped from August 2022 to 2023 (Figure 8). The results showed different land movement values. Area around center of the temple building had a movement of -0.067 cm/year which is marked in light blue color, the southeast end had -0.109 cm/year in dark blue color, and the northeast side had 0.107 cm/year in yellow color. Another mapping from August 2023 to 2024 (Figure 9) revealed different values. Area around center of the temple building had a movement of -0.245 cm/year which is marked in yellow, the southeast end had -0.217 cm/year in light green color, and the northeast side remained at 0.207 cm/year in green color.

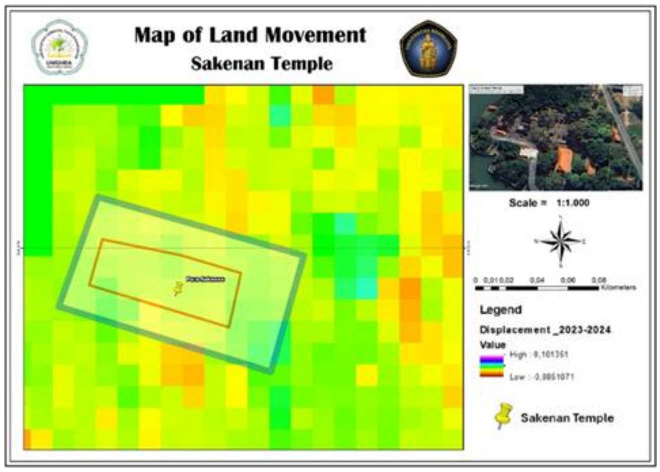

Figure 9. Map of Land Movement Sakenan Temple August 2023 - 2024

Based on the results, we observed that there are 2 types of land movement at Sakanan Temple, namely uplift and land subsidence. This movement is equally dangerous because it can raise and lower the position of the Sakanan temple building. So, from the results of observations in the field, there is a phenomenon of changes position or shifts position of several parts of the building, especially around center and northeast direction of the Sakanan temple. This is very dangerous and requires further research regarding the subsurface structure and the compact safety quality of the soil and rocks at Sakanan temple.

From the findings of these field observations, research results showed that uplift and land subsidence occurred, especially in the middle of the building and to the northeast of Sakanan Temple. Which is in accordance with direct observations in the field. We observe that the obtained land movement values vary from positive to negative. A positive value sign uplift, while a negative value sign land subsidence. Uplift was observed on the northeast side of the Sakenan temple building point. In terms of lithology, areas experiencing subsidence are likely to have surrounding areas experiencing uplift. Thus, this research area shows both uplift and subsidence. Further research on soil stability is needed to ensure safety in this area.

Conclusion

Based on result and discussion, concluded that from data processing and data analysis, the results obtained in the research area showed that there was land movement from -0.109 to 0.145 cm/year in August 2022-2023 and -0.245 to 0.207 cm/year in August 2023-2024. Positive mean uplift, and negative means land subsidence. There is an increase in land movement, with uplift averaging 0.176 cm/year and land subsidence averaging -0.158 cm/year. of -109 cm/year from August

2022 - 2023 and -0.245 cm/year in the August 2023 - 2024 range. There was an increase in the value of land movement, namely -0.178 cm/year. Average value with -0.156 cm/year. And still categorized as slowed land movement. However, even though it is categorized as slow, the local government and BPBD need to conduct a more in-depth study to analyze the disaster hazards that can arise at any time.

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Author Contributions
Syarifatul Ulfah conceptualized the research idea, methodological, data analysis, funding acquisition, writing-original draft, software, management and coordination for the research activity planning and execution. Adi Susilo directed, helped the process of processing and analyzing data, provided ideas and suggestions in writing research. And, as a Corresponding Author.

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Conflicts of Interest
The author declares no conflict of interest. The data published in this article, both in data collection, method, analysis, data interpretation, in writing manuscripts or in the decision to publish research results, there is no conflict of interest with any party.

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