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A METHOD FOR IDENTIFYING AND MONITORING LANDSLIDES USING SENTINEL-1 IMAGERY AND PERMANENT SCATTERER ANALYSIS

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Abstract

The development of Interferometric Synthetic Aperture Radar (InSAR) technology has revolutionized the field of geosciences, providing unprecedented capabilities for earth observation. This is particularly critical in the context of landslides - a phenomenon that is induced as a result of natural or anthropogenic factors, which can potentially cause devastating consequences. Thus, the development of advanced remote sensing techniques to facilitate the timely detection and monitoring of landslides is of paramount importance. This study aims to explore the efficacy of InSAR technology, employing specifically the Sentinel-1 SAR Single Look Complex (SLC) data, in precise monitoring of land displacement with a special focus on landslide detection. This work introduces a method that amalgamates Permanent Scatterer (PS) analysis with Sentinel-1 SAR SLC data, aiming to achieve considerably higher accuracy in measurements. The comprehensive methodological framework includes data acquisition, preprocessing, interferogram generation, coherence analysis, PS analysis, and displacement measurement. This holistic approach is specifically tailored to focus on potential landslide locations by using PS analysis that greatly boosts the effectiveness of the integration of InSAR technology. Once the PS analysis has been completed, the method provides identification and delineation of offset points. The identified displacement points undergo a meticulous examination through a specialized algorithm, which is explicitly designed to evaluate the coherence and stability of these points. Upon the completion of this algorithmic processing, the outcome is the derivation of points that have been rigorously filtered. Each of these points is then imported into a Geographic Information System (GIS) framework where distributions are systematically generated. Then, the method performs a detailed analysis of the time series data associated. A color palette is applied based on the displacement magnitudes where its intensity of red reveals the levels in displacement, which allows for a more detailed and visually accessible interpretation of the spatial distribution of landslides through time. Consequently, this work offers a cardinal contribution toward ensuring significant enhancements to the remote sensing application developments in the realm of geosciences, specifying a robust methodological framework that enables early detection, quantification, and monitoring of land surface deformation due to seismic activities. Most significantly, they enable the identification of localities at risk that are still stable, facilitating early warning and avoidance of untoward outcomes commensurate with a triggered landslide.

Keywords
(Sentinel-1, SLC, Permanent Scatterer InSAR (PSI), StaMPS, Landslides, SAR)

Acronyms/Abbreviations

Synthetic Aperture Radar (SAR), Geographic Information System (GIS), Stanford Method for Persistent Scatterers (StaMPS), Sentinel Application Platform (SNAP), Ground Range Detected (GRD), Permanent Scatterers (PS), Single Look Complex (SLC)

1. Introduction

Landslides are a prevalent natural hazard that can result in severe socioeconomic and environmental impacts, especially in mountainous areas and near water reservoirs. The ability to detect and monitor landslides in their early stages is crucial for risk mitigation and disaster prevention. Synthetic Aperture Radar (SAR) techniques, particularly Interferometric SAR (InSAR), have emerged as an effective approach for detecting ground movements associated with landslides.

This paper explores the use of Sentinel-1 SAR Single Look Complex (SLC) data combined with the Permanent Scatterer InSAR (PSI) method for monitoring potential landslide activity. We focus on the Langar water reservoir area, which is situated in a mountainous region of Uzbekistan. The PSI technique, implemented using SNAP and StaMPS software, provides high-precision measurements of surface deformation in both ascending and descending orbits.

Fig. 1. Langar water reservoir.

The Langar water reservoir area represents a high-priority region for landslide monitoring due to its topography and seasonal variations in water levels. Despite these risk factors, the results of this study, covering four years of data from 2020 to 2024, indicate no significant landslide activity in the region. This outcome demonstrates the utility of the methodology for regular, long-term monitoring and underscores the importance of proactive geohazard assessment.

2. Material and methods

2.1 Study Area: Langar Water Reservoir

The Langar water reservoir is situated in a mountainous area of Uzbekistan. Seasonal variations in water levels, combined with snowmelt, make the area susceptible to potential ground movement. The study area covers approximately 50 km² around the reservoir, with elevations ranging from 800 to 2500 meters.

2.2 Data Selection: Sentinel-1 SLC Imagery

Sentinel-1 is a European Space Agency mission that provides continuous SAR data for Earth observation. For this study, Sentinel-1 SLC data in both ascending and descending modes was used to ensure comprehensive spatial coverage. SLC imagery, as opposed to Ground Range Detected (GRD) products, preserves the phase information necessary for interferometric analysis.

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Sentinel-1 images were acquired from January 2020 to June 2024, with two images per month for both ascending and descending orbits. This high temporal resolution allowed for detailed monitoring of surface movements.

2.3 Preprocessing: SNAP

Preprocessing of Sentinel-1 SLC data was carried out using ESA's Sentinel Application Platform (SNAP). The preprocessing steps included:

Orbital Correction: Ensures precise alignment of images by applying precise orbit ephemeris data.

Radiometric Calibration: Converts pixel values into radar backscatter coefficients.

Multilooking: Reduces speckle noise and prepares the images for interferometric processing.

Co-registration: Aligns pairs of SAR images to a common reference geometry, necessary for interferometric analysis.

Interferogram Generation: Generates the differential interferograms for each image pair by calculating the phase difference between them.

2.4 Permanent Scatterer InSAR Analysis: StaMPS

The PSI technique relies on identifying stable scatterers in the scene, often man-made structures or rock formations, that maintain a consistent radar signature over time. The StaMPS (Stanford Method for Persistent Scatterers) software was used for the PSI analysis. The steps include:

Coherence and Amplitude Stability: Coherence is used to identify candidate Permanent Scatterers based on their stability in radar phase across the time series. Scatterers exhibiting consistent phase over the entire observation period were selected.

Interferometric Time-Series Analysis: StaMPS calculates the displacement time series for each PS. The displacement is calculated relative to a reference point assumed to be stable.

Atmospheric Phase Screen Removal: A key challenge in PSI is separating displacement signals from atmospheric artifacts. StaMPS applies algorithms to estimate and remove atmospheric distortions, allowing for more accurate displacement measurements.

Cumulative Displacement Calculation: The final step involves calculating the cumulative displacement for each PS over the study period, providing a detailed view of ground movements in both ascending and descending orbits.

3. Theory and calculation

Remote sensing techniques for landslide monitoring have evolved significantly over the past few decades. Initially dominated by optical satellite imagery and airborne LiDAR, the advent of SAR-based techniques has transformed the landscape of landslide monitoring. SAR systems such as Sentinel-1 provide the ability to monitor surface displacements regardless of weather conditions, day or night, making them ideal for continuous observation of landslide-prone regions (Rosen et al., 2000).

InSAR and its more advanced variant, PSI, have been widely used to monitor landslides, particularly slow-moving ones. PSI is particularly advantageous in detecting millimeter-level surface displacements by identifying stable reflectors (Permanent Scatterers, or PS) in time-series SAR data (Ferretti et al., 2001). Several studies have demonstrated the effectiveness of PSI in landslide monitoring. For example, Colesanti et al. (2003) successfully used PSI to detect landslide movements in Ancona, Italy, while Berardino et al. (2002) applied PSI techniques to monitor ground deformations in the Campi Flegrei region.

Other studies have applied PSI for monitoring landslide activity near water reservoirs. A notable example is the work of Dai et al. (2016) around the Three Gorges Dam, which identified reservoir-induced landslide risks. Similarly, Schlögel et al. (2020) employed PSI to assess landslide susceptibility in Alpine regions. The Langar reservoir, though not previously studied for such hazards, presents an ideal case for evaluating PSI methods in a similar context.

4. Results

The PSI analysis identified 333 permanent scatterers distributed throughout the study area. These scatterers were used to generate a time-series analysis of surface displacement over the four-year period. The cumulative displacement values ranged between -44.96 mm (downward) and +37 mm (upward) (Figures 1 and 2).

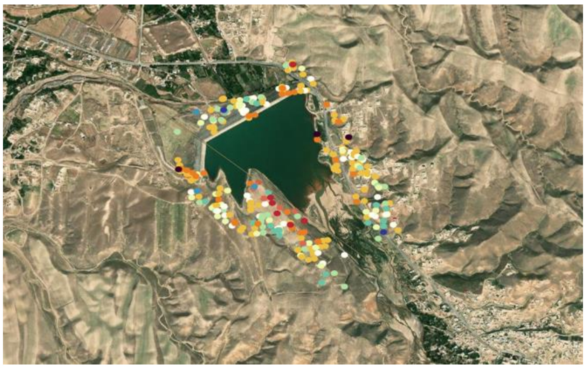

Fig. 2. Surface displacement of Langar water reservoir.

No significant patterns of ground movement indicative of landslide activity were observed. Displacement values were largely within the expected range of normal ground subsidence and heave due to seasonal changes in water levels. The few PS points that exhibited displacement beyond 30 mm did not show progression over time, suggesting they are isolated phenomena unrelated to larger-scale instability.

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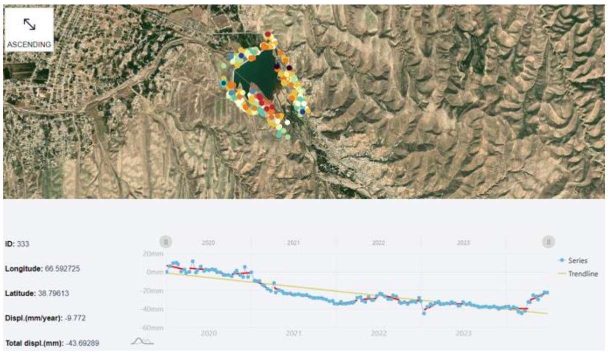

Fig. 3. Surface displacement of Langar water reservoir (ascending).

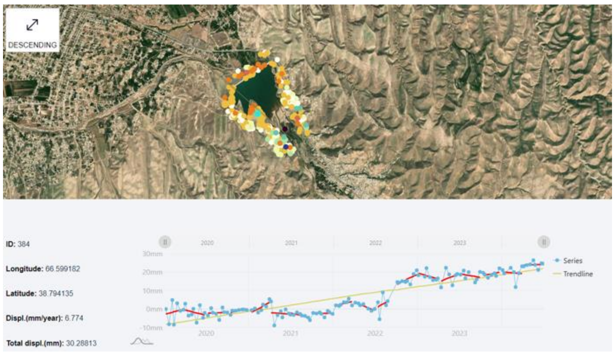

Fig. 4. Surface displacement of Langar water reservoir (descending).

Both ascending and descending orbits provided consistent results, affirming the stability of the Langar reservoir area during the study period. The highest upward displacement of +37 mm and the highest downward displacement of -44.96 mm were found in isolated points, unrelated to any broader landslide activity.

5. Discussion

The results of this study indicate that the Langar water reservoir is currently stable, with no significant signs of landslide activity. The use of both ascending and descending tracks allowed for comprehensive coverage of the region, and the PSI method proved effective for identifying even minor surface displacements.

Comparing these results to studies in other water reservoir regions (e.g., Dai et al., 2016; El Nahry et al., 2019) highlights the variability in ground stability around reservoirs. While many studies have detected significant ground movement in such areas, the Langar reservoir appears to be more stable, likely due to its relatively steady water levels and lack of large seismic activity.

The robustness of the StaMPS software for PSI analysis was also demonstrated. The ability to remove atmospheric distortions and noise allowed for precise measurements of ground displacement.

6. Conclusions

This study successfully applied Sentinel-1 SLC imagery and the PSI method using StaMPS for the identification and monitoring of potential landslides around the Langar water reservoir. Over the four-year observation period, no significant landslide activity was detected, indicating the stability of the region. The methodology presented here can be applied to other landslide-prone areas for long-term monitoring and risk assessment.

Further research could include the integration of optical imagery and in-situ data to provide additional insights into potential landslide triggers. Monitoring should continue, especially during periods of increased water levels or seismic activity, to ensure any changes in ground stability are detected early.

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