Monitoring and Stability Analysis of the Deformation in Woda Landslide Area in Tibet, China by the DS-InSAR Method

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ABSTRACT

The upper-Jinsha River region has steep terrain and broken structures, causing landslide disasters frequently. Thus, it is important to monitor the surface deformation and analyze the stability in this area. Here we use the distributed scatterer interferometric SAR (DS-InSAR) method is used to monitor and analyze the Woda landslide area. Employing the hypothesis test of confidence interval (HTCI) algorithm we select the statistically homogeneous pixel (SHP) and using adaptive spatial nonlocal filtering method based on the identified SHP for phase optimization to select DS points. The obvious advantage is that DS points are used together with persistent scatterer (PS) points to increase the density of monitoring points in the study area. By the DS-InSAR method, we derive the deformation of the Woda landslide area from 106 Sentinel-1A ascending images acquired in 2014/11/05~2019/09/04 and 102 Sentinel-1A descending images acquired in 2014/10/31~2019/09/11. The two-dimensional deformation of the landslide area shows that the maximum surface deformation rate in the normal direction is -80.3 mm/yr, and in the east-west direction is 117.7 mm/yr. In addition, according to the rescaled range (R/S) analysis, the Hurst index of the deformation trends are all greater than 0.5, which means the deformation trend will continue for some time. Our monitoring results can be used for landslide disaster prevention in mountainous areas.

INTRODUCTION

Vigorous tectonic movements and natural erosions shaped the complex landform of Southwest China, where mountains, plateaus, and vertical and horizontal surface gullies are widely distributed. The Qinghai–Tibet Plateau, known as the 'roof of the world', has obvious crustal uplift and strong and rapid rivers, resulting in frequent geological disasters on both sides of the rivers. Landslide disasters are easily triggered in areas with lush natural or planted forests or in steep areas, especially after extreme events. In eastern Tibet, continuous landslide disasters have seriously affected social and economic development and people's lives. The region along the Jinsha River and its tributaries has steep terrains and broken structures, so geological disasters such as ground fissures and landslides have occurred frequently. Since the 1980s, 61 landslides have been recorded. The slope blocked the Jinsha River and damaged many roads, bridges, and buildings. Such major geological disasters may impact the areas hundreds of kilometers upstream and downstream. Therefore, monitoring the long-term surface deformation of the Woda landslide area is of great significance for preventing and controlling the occurrence of geological disasters.

In 2000, Ferretti et al. proposed the theory and method of persistent scatterer InSAR (PS-InSAR), suitable for monitoring targets with stable radar scattering characteristics, such as buildings and bridges in urban areas, but it is difficult to effectively apply it in areas such as farmland and woodland. In 2011, Ferretti et al. proposed the second-generation permanent scatterer technology (SqueeSAR) and related scholars around the world began to shift their research focus to distributed targets with relatively weak backscatter. In recent years, the distributed scatterer InSAR (DS-InSAR) method based on SqueeSAR technology was introduced to the research in low-coherent areas with weak backscattering. In addition, time series InSAR technology can only extract the deformation rate and the deformation time series along the line of sight (LOS) direction. In fact, real space deformation is three-dimensional, namely in the vertical, east–west, and north–south directions. The vertical direction is usually longer than the other two directions.

OBJECTIVE

In view of the fact that the time series and two-dimensional studies of the Woda landslide area are relatively few, in this study, the DS-InSAR method was applied to monitor and analyze the deformation in the Woda landslide area using the ascending and descending Sentinel-1A images. The HTCI algorithm with the highest computational efficiency was used to select SHPs, and the adaptive spatial nonlocal filtering method was constructed based on the results of the SHP selection to perform phase optimization. We analyzed the deformation characteristics and inducing factors of the landslide area, which can provide reference and guidance for the early investigation, monitoring, and timely warning of densely vegetated landslides.

The study area is the Woda village and its surrounding areas in the upper reaches of the Jinsha River. The Woda village is located in Yanbi Town, Changdu City, Tibet, China (Figure 1a). There are two closely distributed landslides in the area, named landslide bodies 1 and 2, along the Jinsha River (Figure 1b). The front edges of the landslides are steep and reach the Jinsha River valley at the toe, but the middle and rear parts are relatively flat (Figure 1c).

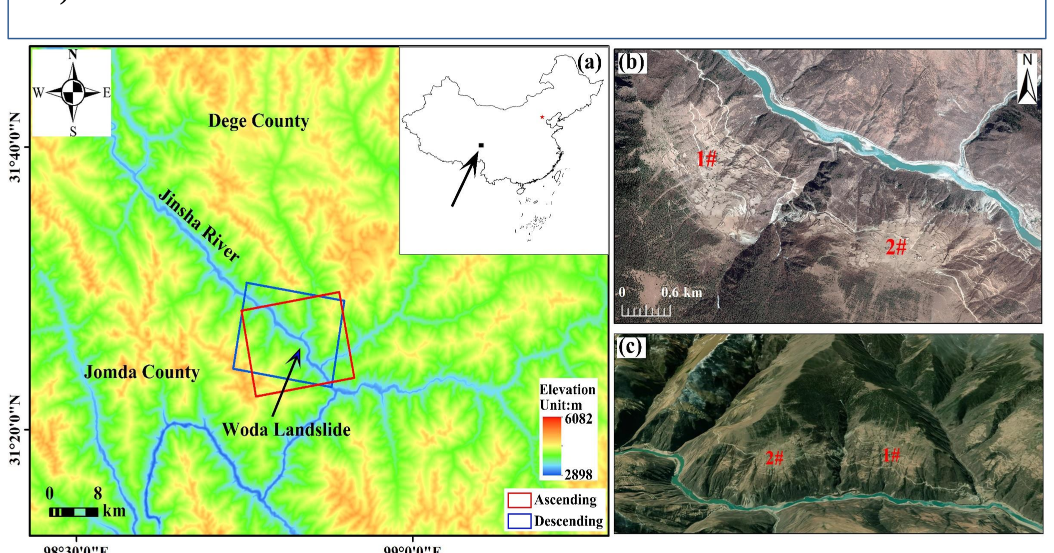


Figure 1. (a) Location of the study area in Tibet Autonomous Region, China, and SRTM-derived topographic map of the Woda landslide area (Jomda County). The red and blue boxes indicate the coverage of Sentinel-1A ascending and descending data, respectively. (b) Two-dimensional Google map imagery of the study area. (c) Three-dimensional Google map imagery of the study area.

METHOD

In this study, we used the DS-InSAR method to monitor the Woda landslide area, and the specific data processing flowchart is shown in Figure 2. Firstly, SAR images were registered and clipped by using precise orbit and DEM data, and then differential interferogram pair sequences were generated. When setting the temporal and space baseline thresholds to 72 days and 200 m, the 106-scene ascending SAR images generated 209 interference pairs; when setting the temporal and space baseline thresholds to 96 days and 200 m, the 102-scene descending SAR images generated 201 interference pairs. Then, we selected the PS and DS points and extracted their phase and elevation information to calculate the deformation. Finally, we combined the precipitation data and geo-logical map to analyze the deformation of the landslide area in detail.

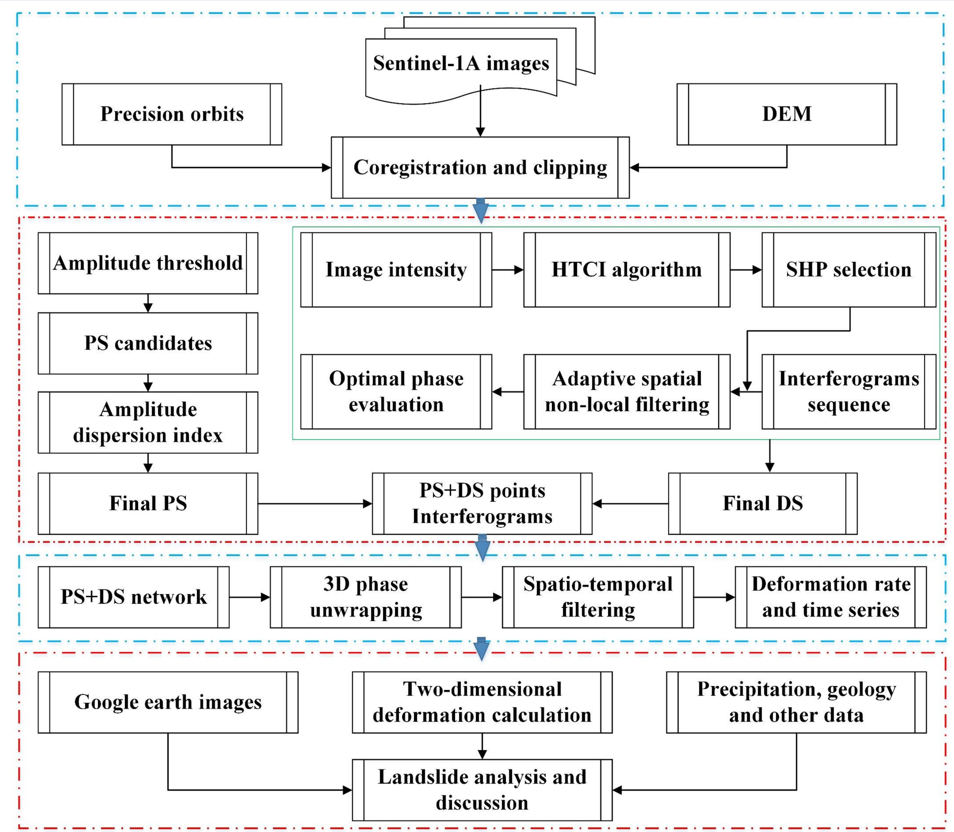


Figure 2. The flowchart of landslide monitoring by the DS-InSAR method.

According to the geometric relationship of radar imaging, the surface deformation monitored by the ascending and descending SAR images were both in the LOS direction. LOS direction can be decomposed into the deformation in the vertical, east–west, and north–south directions (Figure 3). We analyzed the stability of the Woda landslide area by the rescaled range (R/S) analysis method. The R/S analysis method is a time series fractal statistical method based on fractal theory. The calculated Hurst index value ranges between 0 and 1. Only when the value is greater than 0.5, the monitoring time series deformation has a long-term correlation, and the current deformation trend will be maintained in the future. The closer the Hurst index value is to 1, the more reliable and stable the correlation and consistency are.

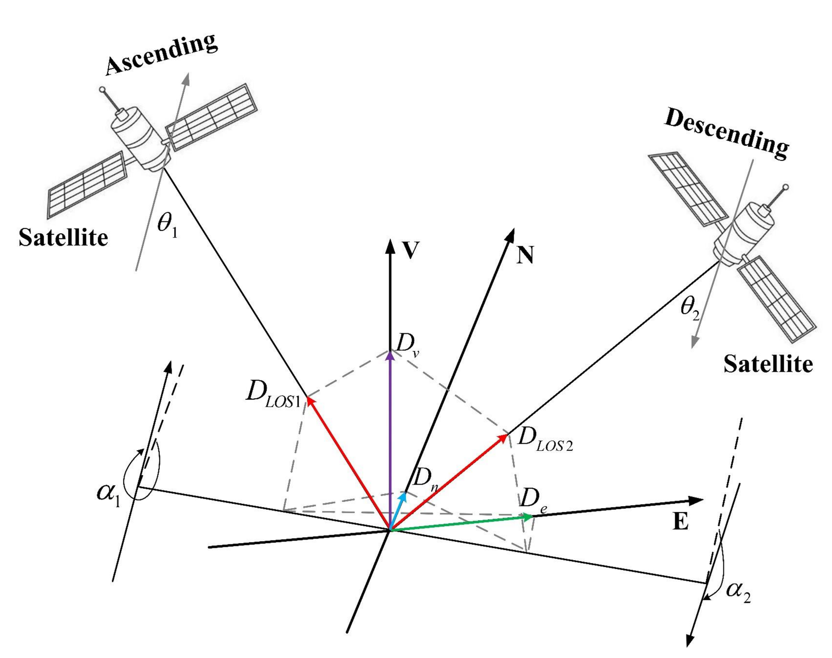


Figure 3. Three-dimensional spatial decomposition model of the LOS deformation.

RESULTS

Figure 4 shows the LOS deformation rate of the study area obtained by different methods. The Woda landslide area is mainly mountainous and lacks strong scatterer point targets, such as buildings and bare rock. So, the point targets obtained by the tradi-tional PS-InSAR method are sparse (Figure 4b,d) and cannot be used for analysis.

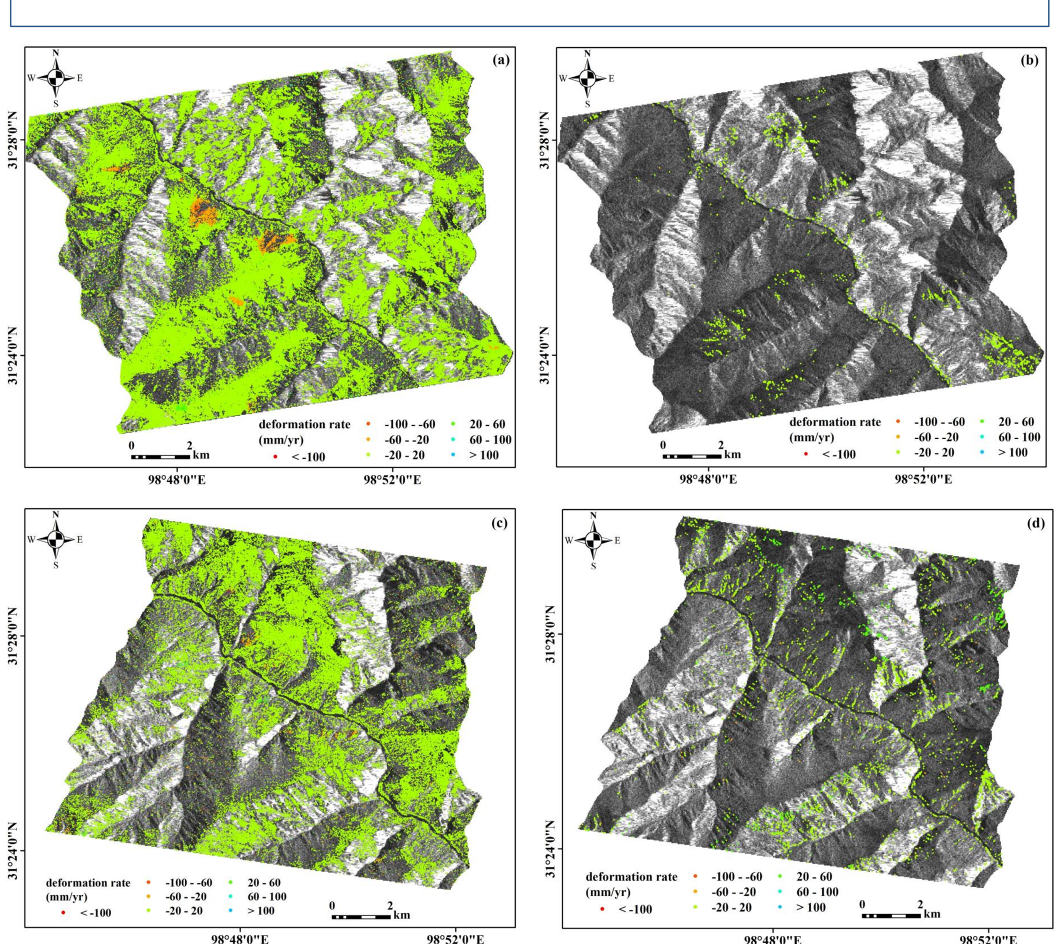


Figure 4. The LOS deformation rate maps of the Woda landslide area (a) derived from ascending data using the DS-InSAR method; (b) derived from ascending data using the PS-InSAR method; (c) derived from descending data using the DS-InSAR method; (d) derived from descending data using the PS-InSAR method.

we obtained the normal deformation and the east–west. As shown in Figure 5 a,b, the two landslide bodies have obvious deformations, but the other regions are stable. The maximum surface deformation rate in the landslide bodies was −80 mm/yr in the normal direction and 118 mm/yr in the east–west direction. To analyze the surface deformation characteristics more clearly and intuitively, the region in the red dashed box was displayed in a three-dimensional map, as shown in Figure 5 c,d.

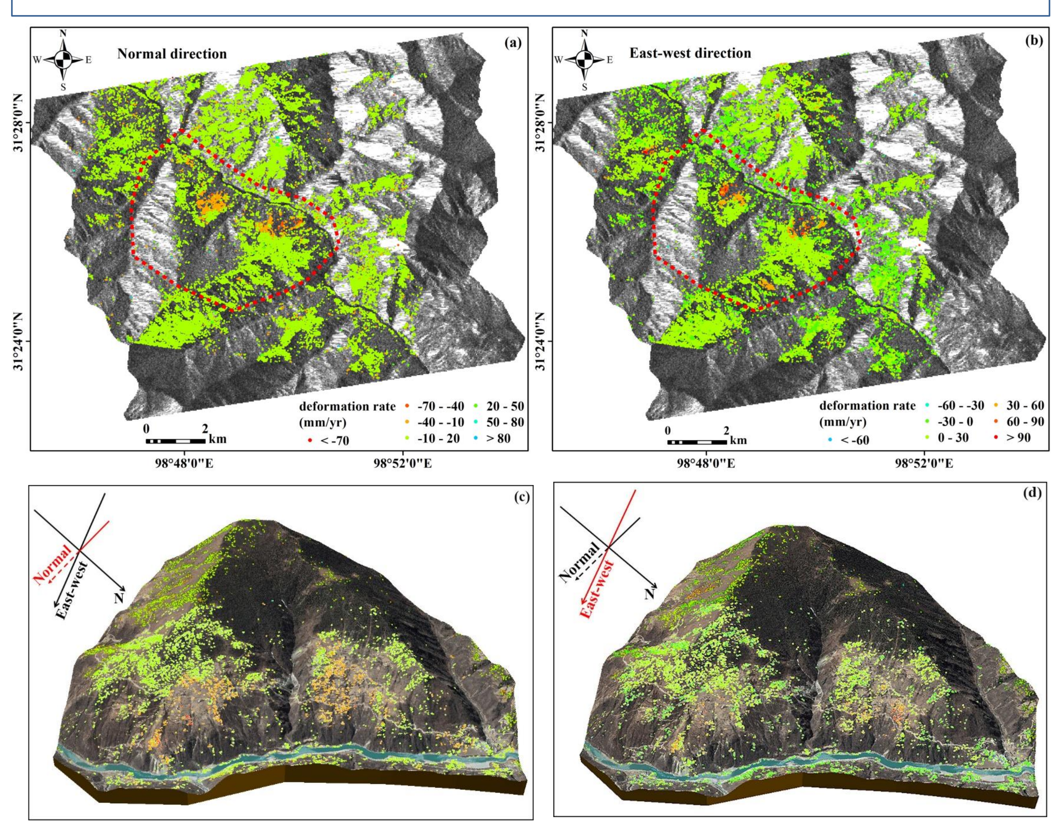


Figure 5. Two-dimensional deformation results (a) in the normal direction and (b) in the east–west direction. Three-dimensional model of the deformation (c) in the normal direction and (d) in the east–west direction.

In order to further study and analyze the surface stability of landslide bodies 1 and 2, we analyzed the stability of the P1–P6 feature points. For the R/S analysis of feature points, we acquired 106 images from 5 November 2014 to 4 September 2019, which imposed a huge calculation burden. We divided the study period into six segments and calculated the Hurst index of each segment separately. The results in the normal direction and east–west direction are shown in Figure 6.

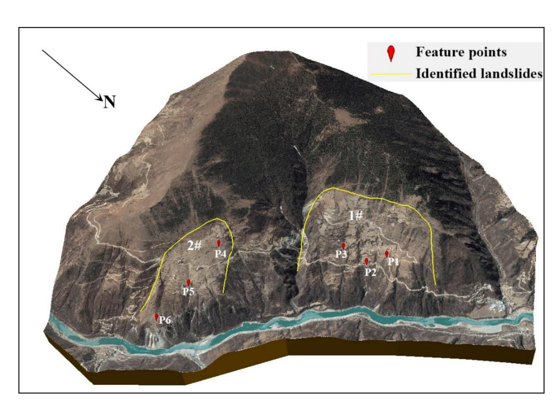
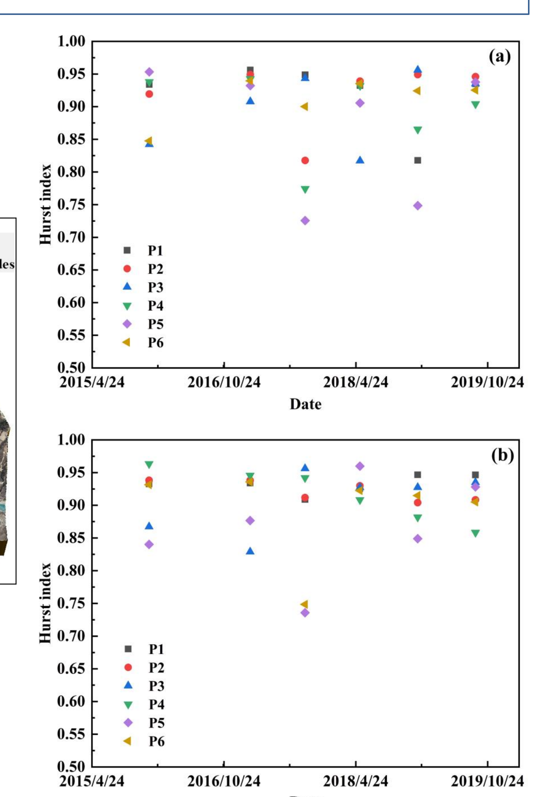


Figure 6 Hurst index values of P1–P6 feature points:(a) in the normal direction and (b) in the east–west direction.



DISCUSSIONS

- surface deformation monitoring and stability analysis of the Woda landslide area were successfully carried out. It is undeniable that this study has certain limitations.
- In future research, with the development of new observation platforms, such as the BeiDou Navigation Satellite System (BDS) and UAV.

CONCLUSIONS

This study adopted the state-of-the-art of DS-InSAR method to extract the surface de-formation of the Woda landslide area. The HTCI algorithm was used to select SHPs, and the adaptive spatial nonlocal filtering method was combined with the SHP selection result to optimize the phases. Both DS and PS points were used to increase the density of monitoring points in the study area.

The two landslide bodies have obvious deformations, but the other areas are stable. Compared to the traditional PS-InSAR method, the DS-InSAR method increased the monitoring points density significantly. The obtained two-dimensional deformation model shows that the maximum deformation rate of the normal direction is −80 mm/yr, and for the east–west direction, it is 118 mm/yr. The stability analysis results show that the current deformation trend is sustainable.

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