Study on Early Identification of Landslide Hazard in Mountain Valley Area based on InSAR and Optical Remote Sensing Technology

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Abstract. Landslide geological hazards are widely distributed and frequently occur in China, especially in the western high mountains and valleys where the terrain is steep and the vegetation is dense and also a large number of hidden and large-scale landslide geological hazards. To solve the problems of the early identification of landslide, we took the high mountain valley area of the Shimian–Hanyuan section of Dadu River as the research object. To conduct an early identification study of landslide hazards in the research area, we used interferometry synthetic aperture radar (InSAR) technology and optical remote sensing technology. The results of our study show that by comparing the identification results of D-InSAR, PS-InSAR, and SBAS-InSAR, we can confirm that the identification effect of SBAS-InSAR technology on landslide geological hazards in mountain valley area is the best. The comparison of the interpretation results of optical remote sensing technology and InSAR technology shows that the optical remote sensing technology can identify the landslide with obvious signs of deformation, and the InSAR technology can identify the geological hazard of the deformation landslide. Furthermore, InSAR technology and optical remote sensing technology can be used synthetically to achieve the early identification of landslide geological hazards.

1. Introduction
Because of the complex terrain and well-developed geological structure in southwest China, it has been a frequent occurrence of a geological hazard. Hence, it is difficult to conduct the traditional landslide survey technology there because it needs a lot of manpower and material resources. In recent years, with the development of remote sensing technology, landslide hazard identification using remote sensing technology has become a research hotspot \cite{1}. Remote sensing technology mainly includes optics and microwaves. Optical remote sensing requires operators to have solid geological knowledge and rich experience in landslide identification through visual interpretation of optical images. Microwave remote sensing is mainly represented by interferometry synthetic aperture radar (InSAR) technology, which can identify landslides by monitoring the tiny deformation of the surface \cite{2}. InSAR technology uses two SAR complex images data from the same area for coherent processing, obtaining surface elevation information and deformation information through phase information.
With the development of high-resolution optical satellites used at home and abroad, optical remote sensing technology has been widely used in the field of geological hazards. From the development status, the optical remote sensing satellite has the characteristics of “three highs” [3]: (1) high spatial resolution, having an accuracy up to 0.3 m, such as GF-1, GF-2, GJ-1, Wordview-3, and Wordview-4; (2) high temporal resolution, having a revisit period up to 1 day, such as planet-satellite cluster; and (3) high spectral resolution, having a comprehensive spectral range of hundreds of optical remote sensing satellites at home and abroad. It can be seen that high-resolution optical remote sensing satellite can provide a large number of data sources and continuous remote sensing interpretation basis for early identification of geological hazards.

In contrast, InSAR technology belongs to the microwave remote sensing technology as “old trees sprouting new shoots.” The application of InSAR technology in the field of Geosciences can be traced back to the end of the 1960s, in which some people used the InSAR technology in obtaining high-precision surface models [4]. Gabriel et al. [5] first demonstrated that InSAR technology could obtain centimeter-scale deformation; however, it did not attract enough attention at that time. It was not until Massonnent et al. [6] obtained the deformation field of the 1992 Landers earthquake by using the ERS-1 data, which shocked the international seismic community and has made the InSAR technology widely concerned. With the continuous development of InSAR technology, it has been widely used in volcanoes, earthquakes, glaciers, land subsidence, landslides, frozen soils, and other geological hazard monitoring fields.

As early as the beginning of the 21st century, China has carried out researches on InSAR technology in landslide geological hazard monitoring. These include InSAR measurements of the Three Gorges New Beach and Lianzi Cliff corner reflector, which have opened up the continuous research on InSAR monitoring of geological hazard for many years. In terms of technical exploration, method test, activity feature recognition, large deformation measurement and joint application with the ground, and other means, many basic questions, such as what can be measured, how large can be measured, how accurate can be measured, and what method can be used, were answered [7]. However, InSAR technology was not widely used in the field of geological hazard because of the influence of radar satellite data sources, especially the 6.24 landslide in Maoxian county, Sichuan province [8, 9], the 8.28 large-scale collapse in Nayong county, Guizhou province [10], and the Baige landslide in Jinsha River [11]. Since the occurrence of major geological hazards, many well-known experts in China have put forward suggestions on using InSAR and other technical means to carry out landslide identification and hidden danger investigation in high-altitude areas from different aspects. On the other hand, with the promotion of many InSAR satellite data companies, the application of InSAR technology in geological hazard has aroused strong repercussions in the field of geological hazard remote sensing and set off a wave of InSAR learning upsurge.

Through comparison, it is found that optical remote sensing technology mainly focuses on the visual morphology of landslides, which has strong advantages in the identification of ancient and old landslides; however, it is difficult to identify potential landslides, which requires higher geological professional requirements of interpreters. The advantages of InSAR are mainly reflected in its accurate acquisition of small deformation information in all weather and all day; however, it is difficult to master this technology, and many operation processes need professional interpretation experience. At present, it is an urgent problem how to study the two technologies comprehensively and improve the comprehensive application ability of optical remote sensing technology and InSAR remote sensing technology in landslide geological hazards.

This study takes the Shimian–Hanyuan section of Dadu River as the research object, comprehensively applies InSAR remote sensing technology and optical remote sensing technology, and combines with the actual field investigation to explore the comprehensive application ability of InSAR technology and optical remote sensing technology in geological hazard.
2. Overview of the study area

The study area is dominated by erosion denudation high mountain-canyon landform and river erosion accumulation landform (Figure 1). Erosion denudation high mountain-canyon landform is mainly located in the mountainous area along the Dadu River, with cutting depth greater than 800m. River erosion accumulation landform is mainly located in the gentle area at the foot of the mountain on both sides of Dadu River and its tributaries, with an elevation of 800–1000m. The high-mountain and steep slope landform in the study area provides good free conditions for the development of landslide geological hazard.

![Figure 1. Topographic map of the study area](image)

In the study area, there are mainly Quaternary loose deposits; Neogene semi-cemented sandstone; Jurassic, Triassic, and Permian sedimentary rocks; and Silurian, Ordovician, Cambrian, and Sinian metamorphic rocks. The main faults include Dagoutou fault, Meiluo fault, Hanyuan-Zhaojue fault, Shunhe fault, Shichagou fault, and Guixian fault. The changeable lithologic combination and highly developed structural faults provide favorable geological conditions for the development of landslide geological hazards.

3. Research ideas and methods

InSAR technology uses the coherent processing of two SAR complex images data observed in the same area and obtains the surface elevation information and deformation information through the phase information. According to the classification of imaging time, InSAR can be divided into single orbit mode and repeated orbit mode. In single orbit interference, two antennas are loaded on the same airborne or satellite platform. One antenna transmits signals, and both antennas receive ground echo signals; the acquired data are used for interference processing. In repeated orbit interference, the same sensor or similar sensor images the earth twice according to the parallel orbit, sends and receives signals, respectively, and uses the obtained data for interference processing. At present, the commonly
used InSAR surface deformation monitoring is usually the spaceborne SAR repeated orbit mode, and its principle is shown in Figure 2.

Figure 2. InSAR geometry schematic design

The InSAR technical data processing of the research area selects Sentinel-1A satellite data launched by the European Space Agency in 2014, which includes 129 images of orbit ascending and descending data. Among them, we collected 84 scenes of ascending SAR data from October 14, 2014, to August 30, 2018, and 45 scenes of descending SAR data from February 19, 2017, to September 6, 2018. D-InSAR (differential InSAR), PS-InSAR (persistent scatterer InSAR), and SBAS-InSAR (small baseline subsets InSAR) are selected as the InSAR processing methods. Among them, D-InSAR is a technical means to obtain the surface deformation information of ground objects through two or more differential interferometry using SAR images of different time phases in the same area. D-InSAR technology can obtain relatively stable interferometric observation results and interpret short-term deformation results in the region; this technology can monitor the surface deformation of centimeter (cm) level or less in the direction of radar line of sight, but the accuracy and reliability of deformation measurement are seriously affected by spatial incoherence and atmospheric delay. PS-InSAR technology is suitable for monitoring long-term small linear deformation and nonlinear deformation of local key parts, and its monitoring accuracy reaches millimeter (mm) level, which can effectively monitor the deformation of highly coherent strong scatterers (such as artificial buildings and exposed rocks) in the study area. However, it is difficult to extract PS points in the areas with complex terrain, high vegetation coverage, and limited SAR data; moreover, monitoring the surface deformation is difficult. In SBAS-InSAR technology, all SAR images are divided into different short baseline subsets according to the position and time baselines. The images of each subset are processed by differential interferometry to improve the coherence and increase the number of differential interferograms under the condition of a single main image. Then, the entangled interference phases are unwrapped. According to the relationship between the phase of each coherent pixel and the observation time, singular value decomposition (SVD) is used to link each differential interferogram to suppress the influence of DEM error and atmospheric phase delay on the deformation signal, thus obtaining the least square solution. The deformation rate of SBAS-InSAR technology is generally 1 cm–1 dm/a, which can effectively overcome the problems of poor coherence of radar signals and the difficulty in accurate calculation of surface deformation in complex terrain areas; also, it can effectively monitor the deformation area of a landslide in the region.
4. Processing results and analysis of InSAR Technology in the study area

4.1 D-InSAR data processing results and analysis

D-InSAR is a method developed from traditional InSAR technology. The terrain phase of the InSAR interferogram is removed by introducing external DEM, and then the differential interferogram is obtained. D-InSAR technology can obtain stable interferometric observation results and interpret short-term deformation results in the region. This technology can monitor the surface deformation of centimeter (cm) level or less in the radar line of sight direction. According to the characteristics of D-InSAR technology and the data coverage in the study area, 10 images are selected for D-InSAR data processing. A total of six pairs of interference pairs are combined. The information of interference pairs is shown in Table 1, and the interferogram is shown in Figure 3.

Table 1. Information table of differential interference pairs in the study area

| InSAR images | Course  | Date (mm/dd/yyyy) | Position baseline (m) | Time baseline (day) |
|--------------|---------|-------------------|-----------------------|--------------------|
| 1            | Ascending | 01/18/2015 08/30/2018 | -39.4               | 1320               |
| 2            | Ascending | 01/13/2016 03/01/2016 | -102.42              | 48                 |
| 3            | Ascending | 01/15/2017 12/21/2017 | 86.84                | 36                 |
| 4            | Descending | 02/19/2017 09/06/2018 | 79                   | 564                |
| 5            | Descending | 02/19/2017 03/27/2017 | 87.7                 | 36                 |
| 6            | Descending | 08/01/2018 09/06/2018 | 142.32               | 36                 |
Figure 3. D-InSAR interferogram of the study area

Figure 4. Ascending 20160113_20160301 interpretation map of landslide

Figure 5. Descending 20170219_20180327 interpretation map of landslide

It can be seen from the D-InSAR interferogram of the study area that when the time interval of the interference image pair is shorter, it has a better interference effect. In the first half of the year, the interference effect is better than that in the second half of the year. This study has a good interference effect on the ascending 20160113_20160301 image pair and the descending 20170219_20180327 image pair, which has carried out remote sensing interpretation for early identification of landslide geological hazards, identifying 22 and 17 landslides, respectively; however, only two landslides were located in the same location (Figures 4 and 5). This shows that the interference of a single orbit in the same area cannot fully and effectively interpret all landslides. To effectively identify the geological hazards of landslides in the region objectively and comprehensively, we need to integrate the InSAR data of ascending and descending to interpreting all landslides. D-InSAR technology has identified 37 landslides in the study area.

4.2 PS-InSAR data processing results and analysis

PS-InSAR technology is suitable for monitoring long-term small linear deformation and nonlinear deformation of local key parts, and its monitoring accuracy reaches the millimeter (mm) level. It can
effectively identify the deformation of strong scatterers with high coherence in the study area. The PS-InSAR data processing in this study area mainly selects Sentinel-1A data of 45 scenes from February 19, 2017, to September 6, 2018. The critical baseline threshold of PS-InSAR data processing is set at 500%, and the generated data pair connection diagram is shown in Figures 6 and 7. A total of 44 pairs of data pairs are generated, of which the longest time baseline is 288 days, and the largest position baseline is −124.85 m.

![Figure 6. PS-InSAR time (baseline map)](image)

![Figure 7. PS-InSAR time (position map)](image)

After interferometry, inversion, and geocoding, we obtained the PS-InSAR deformation rate map of the study area. There are 172559 effective PS points in the study area, and the deformation rate is −25.57 to 23.42 mm/a. All PS points are equally divided according to 5 mm/a, and thus, the PS points with deformation rate greater than 10 mm/a and less than 10 mm/a are 1522. According to the deformation rate diagram, the landslide deformation areas in the study area were identified and interpreted, and 28 landslide deformation areas were obtained (Figure 8).

![Figure 8. Landslide deformation areas](image)
Figure 8. PS-InSAR landslide interpretation map in the study area

It can be seen from Figure 8 that PS points generated by PS-InSAR are mainly distributed on both sides of the river valley and areas with intensive human engineering activities, whereas only a few PS points can be generated in medium and high mountain areas with dense vegetation. In the interpretation of landslide geological hazards, it is difficult to identify landslides in areas with few PS points effectively. Therefore, most of the landslides identified by PS-InSAR are concentrated in the areas with dense PS points.

4.3 SBAS-InSAR data processing results and analysis

SBAS-InSAR technology mainly uses short baseline image pairs for interference and uses the SVD method to obtain regional time series surface deformation. It can effectively overcome the problems of poor coherence of radar signals and difficulty in accurate calculation of surface deformation in complex terrain areas and can effectively identify landslide deformation areas in the region. For the SBAS-InSAR data processing in this study area, we selected 84 scenes of Sentinel-1A data from October 14, 2014, to August 30, 2018.

Figure 9. SBAS-InSAR time (baseline map)  Figure 10. SBAS-InSAR time (position map)
A connection graph matched the data of 84 scenes. The time baseline threshold was set to 200 days, and the position baseline threshold was set to 5%. A total of 956 pairs of image pairs were generated; the time baseline range was −195.273 to 195.023 days; and the position baseline length was −136.286 to 153.473 m. After interference, orbit refining, and re-leveling, the interference pairs with poor coherence are eliminated, and finally, 350 pairs of image pairs are retained. The spatiotemporal baseline connection diagram is shown in Figures 9 and 10. Then, the SBAS-InSAR deformation rate map of the study area is obtained by inversion and geocoding. The deformation rate of SBAS-InSAR in the study area is −185 to 175 mm/a; according to the deformation rate, the landslide deformation areas are identified and interpreted, and 86 landslide deformation areas are obtained (Figure 11).

As can be seen from Figure 11, SBAS-InSAR has carried out effective monitoring for the whole study area, and only local middle and high mountain areas have monitoring data loss. On the whole, the SBAS-InSAR deformation monitoring results can effectively identify and interpret the landslide geological hazard in the study area.

4.4 Comparative analysis of InSAR data processing results

According to the results of three kinds of InSAR technology interpretation and identification of landslide geological hazards, D-InSAR, PS-InSAR, and SBAS-InSAR identified 37, 28, and 86 landslide deformation areas, respectively. Through superposition analysis, the overlapping recognition areas were eliminated. In this study area, a total of 121 landslide deformation areas were identified by InSAR technology. Through comparative analysis, it can be seen that D-InSAR technology is seriously affected by spatial incoherence and atmospheric delay because of its accuracy and reliability of deformation measurement. It is only suitable for carrying out short-term early identification of landslide geological hazards in the region. PS-InSAR technology is affected by its inherent technology. It is difficult to extract effective PS points in areas with complex terrain and high vegetation coverage, and it is difficult to identify landslide geological hazards early. SBAS-InSAR technology can effectively overcome the problems of poor coherence of radar signals and difficulty in accurate
The calculation of surface deformation in complex terrain areas because of its “short baseline” connection and pairing and can effectively identify the landslide deformation area in the region. The following are the main reasons for the incoherence of InSAR monitoring in the study area.

1. The vegetation coverage rate of the study area is high, most of the area is original deep forest, the tree height is more than 3 m, and there is only partial bare land. The data source of InSAR technology research is a C-band Sentinel-1A image, and C-band can only penetrate a small number of leaves and cannot penetrate the trunk to the ground in obtaining the ground deformation information.

2. The precipitation in the study area is concentrated from March to November, accounting for 85% of the whole year. There are cumulus, stratocumulus, and cumulus clouds all-year-round in the study area: many cumulus clouds on sunny days in summer, multi-layer cumulus and broken stratiform clouds on rainy days, and stratocumulus and cataclastic rain clouds, which are the main low clouds in the whole year. Although the radar satellite can penetrate the influence of rain, snow, cloud, and fog, it is less affected by the atmosphere and has the ability of all-weather and all-days’ work. However, when the electromagnetic wave signal transmitted by the satellite radar passes through the earth's atmosphere, the ionospheric delay and tropospheric delay will occur. The ionospheric delay is related to the electronic activity of the atmospheric ionosphere, which is relatively significant in the equatorial and polar regions. Its magnitude is inversely proportional to the square of the carrier signal frequency. It appears as a large-scale, longwave signal in the interference image. When detecting and monitoring small spatial scale ground objects such as landslides, their influence can be ignored. In the region with abnormal ionospheric activity, the ionospheric delay can be eliminated by frequency division and linear combination.

In summary, through the analysis of InSAR processing results, the landslide deformation area in the study area can be obtained intuitively according to the shape variable interpretation. However, these “landslide deformation areas” include but are not limited to landslide geological hazard, and also other surface deformation, such as land subsidence, reservoir bank filling, and mine waste slag. Therefore, the “landslides” identified by InSAR technology need to be combined with other technical means (such as optical remote sensing technology) for further early identification of landslide geological hazards.

5. Interpretation results and analysis of optical remote sensing technology in the study area

5.1 Landslide recognition based on optical satellite images

Using optical remote sensing technology, we interpreted the landslides, combined with rich experience of remote sensing interpretation of landslides, mainly including optical remote sensing interpretation of ancient (old) landslides and remote sensing identification of potential landslides. The optical remote sensing data source in the study area is Google Earth 3D stereo optical remote sensing data, which is free of charge in the world. The same region has multiple historical images, which can interpret the characteristics of landslide changes in the region.

The landslides identified by InSAR in the study area were interpreted by multi-stage optical satellite images: 29 landslides were identified, and the remaining deformation areas included 75 unstable slopes, 5 collapses, 8 land subsidence, 2 reservoir bank slopes, and 2 spoil grounds. At the same time, 74 landslides without InSAR deformation in the study area were interpreted by optical satellite images (Figure 12).
Figure 12. Interpretation of landslide map by optical remote sensing

For example, in Figure 13, from the optical image, the landslide has an obvious boundary contour, and the texture of the landslide area is relatively rough, which forms a sharp contrast with the surrounding area. However, InSAR technology has no obvious response in the landslide area, and the deformation displacement rate monitored is ~10 to 10 mm/a. This shows that the landslide is in a stable state at present; InSAR technology cannot effectively identify; and optical remote sensing technology can be directly identified by morphological contour.

According to the results mentioned previously, using optical satellite images to interpret landslides in the deformation area identified by InSAR can effectively identify the geological hazards of landslides under deformation in the study area. At the same time, on the basis of optical remote sensing technology, it can also identify that there is no deformation landslide geological hazard in the study area. The comprehensive application of InSAR technology and optical remote sensing technology can achieve the purpose of early identification of landslide geological hazards.
Figure 13. Typical optical remote sensing interpretation of landslides

5.2 Landslide recognition based on unmanned aerial vehicle (UAV) images

Also, to further identify and verify the interpretation of landslides in the study area and analyze the characteristics and methods of landslide deformation, we selected Liyuancun landslide and Tongzipo landslide as two typical landslide hazards for UAV aerial photography (Figures 13 and 14).

Figure 14. UAV image of Liyuancun landslide

Figure 15. UAV image of Tongzipo landslide
It can be seen from Figure 14 that the Liyuancun landslide is in the shape of an irregular armchair. Through UAV images, it is found that there are many landslides and sliding phenomena in different scales on the landslide mass; there are many tensile cracks with different lengths in the front and middle of the slope, with the maximum tensile crack length of approximately 80 m and width of 5–25 cm; there are many falling platforms at the middle and rear of the slope, with the maximum height of 2.5 m and horizontal extension of approximately 20 m.

It can be seen from Figure 15 that the boundary of Tongzipo landslide is irregular, with narrow trailing edge and wide front edge, and the rear boundary of landslide overlaps with the back wall of the landslide. The results show that there are obvious deformation signs and obvious sliding deformation signs. The UAV aerial images can directly determine the landslide boundary, landslide mass, landslide wall, landslide steps, tension cracks, trailing edge depression, landslide shear outlet, and other landslide elements.

6. Conclusions

In conclusion, it is feasible to use InSAR technology and optical remote sensing technology in the early identification of landslide geological hazards in high mountains and valleys. Firstly, the InSAR technology is used to process the interferogram and deformation map of the study area for landslide recognition; then, the landslide geological hazards are interpreted according to the multi-stage optical satellite images of the study area; finally, the landslide geological hazards are comprehensively identified by combining InSAR technology and optical remote sensing technology. This study mainly draws the following conclusions.

(1) In the InSAR technology, D-InSAR, PS-InSAR, and SBAS-InSAR are used to identify 37, 28, and 86 landslide deformation areas, respectively. Through superposition analysis, we eliminated the overlapping recognition areas. In this study area, a total of 121 landslide deformation areas are identified by using InSAR technology.

(2) Through comparative analysis, it can be seen that D-InSAR technology is seriously affected by spatial incoherence and atmospheric delay because of its accuracy and reliability of deformation measurement. It is only applicable to carry out short-term early identification of landslide geological hazards in the region. PS-InSAR technology is affected by its inherent technology; it is difficult to extract effective PS points in areas with complex terrain and high vegetation coverage, and it is difficult to identify landslide geological hazards early. SBAS-InSAR technology can effectively overcome the problems of poor coherence of radar signals and difficulty in accurate calculation of surface deformation in complex terrain areas because of its short baseline connection and pairing and can effectively identify landslide deformation areas in the region. Generally speaking, SBAS-InSAR technology has the best effect on the identification of landslide geological hazards in high mountain-canyon areas.

(3) It is found that the interpretation effect of optical remote sensing technology on recent landslides is better than that of ancient (old) landslides in high mountain-canyon areas, especially for recent landslides with a certain scale. Thus, the optical remote sensing technology can identify the landslides with obvious deformation signs and the ancient (old) landslides with clear shape and contour in high mountain-canyon areas.

(4) InSAR technology can be used to identify the deformation of landslide geological hazards in high mountain-canyon areas, especially for landslides with a certain amount of deformation. This study found that when the slope deformation is between 10 and 100 mm, InSAR technology can effectively identify. When the slope deformation is less than 10 mm or more than 100 mm, there are incoherence or monitoring errors in InSAR monitoring, leading to the error of InSAR recognition results.

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