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Potential Disaster Inspection and Analysis Around Reservoirs Based on InSAR Technology

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Abstract: Before the occurrence of geological disasters around reservoirs, small deformations occur on the surface or mountains, which are usually difficult to detect. At the same time, geological disasters occur in rainy weather, and traditional monitoring methods and optical satellite monitoring methods are greatly limited. On site monitoring also poses significant safety risks. Therefore, this article uses SAR satellite images and SBAS InSAR method to identify deformation zones in a reservoir and surrounding mountains in Sichuan Province, China, using 58 scenes of Sentinel-1 satellite images from January 2019 to June 2021. The research results indicate that there are 12 areas with significant deformation around the reservoir, with an average deformation rate between -170mm/a and -79mm/a. The cumulative deformation values of P9 and P10 areas exceed 300mm. Combined with geological conditions analysis, these two areas have a certain potential landslide risk and need further monitoring.

Keywords: InSAR (Interferometric Synthetic Aperture Radar), SBASSmall Baseline Subset InSAR, Geological hazards, Deformation monitoring.

1. Introduction

Sichuan Province in China has numerous mountain ranges and a complex natural environment. It is also located on the Sichuan earthquake zone, with frequent earthquake disasters and intense activity of various fault layers, which are also factors that trigger geological disasters such as landslides, collapses, and mudslides. The formation mechanism of geological disasters is complex and the triggering factors are diverse. Landslide geological disasters often occur with weather conditions such as rainy weather. Optical remote sensing methods are affected by cloud cover and cannot be observed. Traditional monitoring methods require the use of traditional monitoring instruments and equipment for regular observation, with a long observation period. Moreover, deformation analysis can only be conducted on monitoring points, which is not conducive to fully understanding the development and development process of landslide disasters. It is time-consuming and labor-intensive, and on-site monitoring has huge safety hazards. Both personnel and equipment are unsafe [1,2]. As a geological structure with a large water storage capacity, the reservoir in this area poses greater risks, therefore, it belongs to the key monitoring area for geological disasters. [3] . With the rapid development of modern satellite remote sensing technology and Synthetic Aperture Radar (SAR) technology, this technology has the advantages of being fast, efficient, low-cost, high-resolution, wide coverage, high accuracy, and all-weather, which can solve the shortcomings of traditional deformation monitoring. With the continuous development and improvement of technology, modern differential interferometry methods such as DInSAR, Differential InSAR [5,6], PS InSAR, Persistent ScattererInSAR [7,8], SBAS InSAR, Small Baseline Subset InSAR [9,10] have been developed. The method of obtaining long-term small deformations of geological disasters such as landslides has become an effective natural disaster monitoring tool. Yang Chengsheng et al. used multiple SAR data to monitor post earthquake landslide disasters and hidden danger points, and analyzed the distribution and deformation characteristics of landslides. They conducted in-depth analysis of typical landslide bodies and obtained good results [11,12]. Zhao Baoqiang et al. used two time-series InSAR methods, PS and SBAS, to process the 56 Sentinel-1A data and 27 Envisat ASAR data obtained. The research results showed good consistency with the field measurement results in landslide areas [13].

This article uses Sentinel-1 satellite remote sensing data to conduct early identification of landslide disasters in the Reservoir and surrounding mountains of the Heishui River, and provides a detailed analysis of sensitive areas, providing an effective means and method for potential landslide analysis and geological hazard warning in the reservoir area.

2. Methodology

2.1. Principle of Time Series SBAS inSAR

The core idea of SBAS InSAR technology is to reorganize and group multi scene Sentinel-1 satellite SAR images based on smaller spatiotemporal baselines, and then perform registration, interferometric generation, and other processing to obtain interferograms with shorter baselines [14]. Due to the short spatiotemporal baseline, the coherence of the generated interferograms is high, which can effectively weaken the impact of decoherence on data accuracy and improve coherence [15]. Connect the isolated interferograms in groups, reduce phase noise by multi view processing of differential interferograms, extract highly coherent pixels, increase the sampling frequency of images, and facilitate the calculation of temporal deformation information. Apply singular value decomposition method and least squares solution in the sense of minimum norm to obtain the surface deformation rate of long time series and the calculation method of deformation time series [16,17].

2.2. Temporal SBAS InSAR Process and Algorithm

2.2.1. Temporal SBAS InSAR processing flow

The temporal SBAS InSAR model is an InSAR processing method that involves impact registration, differential interferometry, filtering, phase unwrapping, and geocoding of

SAR satellite images to obtain surface deformation rates, analyze patterns, and reasons. Firstly, select the primary and secondary images (M+1 scenes) with appropriate temporal distribution within the research area, and then use the reference DEM for image registration and interference processing to remove the influence of terrain phase; By estimating the spatiotemporal baseline, it is determined whether the temporal and spatial baselines of the image pair exceed the limit. Then, the differential method is used to generate a small baseline set of interferograms, and each independent interferogram is connected to form an interferogram pair; By using precise POD orbit refinement parameters and ground control points to improve satellite orbit position accuracy, phase unwrapping is performed to remove atmospheric noise and DEM residual noise effects. Finally, geographic coding conversion is performed to convert the radar coordinate system to the ground coordinate system and obtain ground deformation information. The deformation rate and spatiotemporal laws are analyzed, and the causes of deformation are explained and analyzed [18]. The workflow diagram is shown in Figure 1.

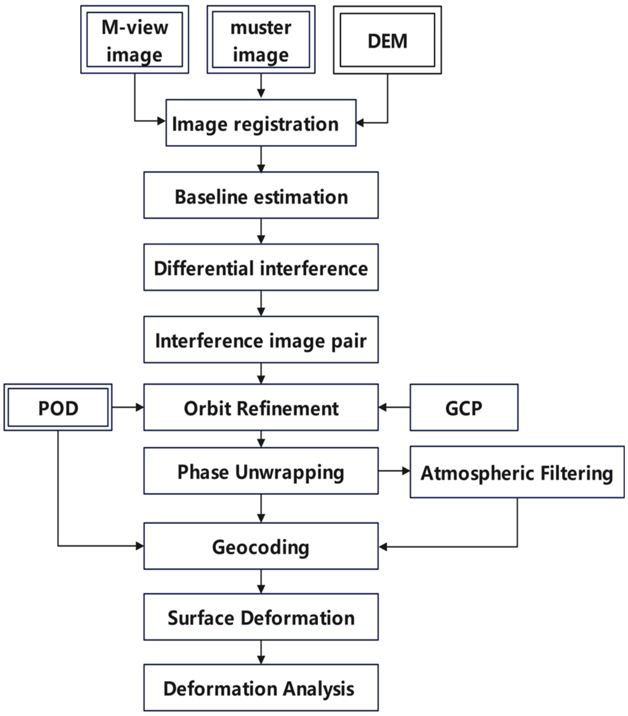

Figure 1. SBAS InSAR data processing flow

2.2.2. Time series SBAS InSAR algorithm

In the processing flow of SBAS InSAR method, statistical analysis is conducted on the coherence coefficient, amplitude deviation and other related parameters of each image pixel, and then the pixels are selected according to the set parameters. The deformation value of the time sequence obtained by phase unwrapping the interference phase [19-20]:

$$\delta\varphi_{def} = [\delta\varphi_{def}(\Delta t_1), \delta\varphi_{def}(\Delta t_2), \delta\varphi_{def}(\Delta t_3), \cdots, \delta\varphi_{def}(\Delta t_M)]^T \quad (1)$$

Among them: $\delta\varphi_{def}$ is accumulate deformation, $\delta\varphi_{def}(\Delta t_i)$ is the deformation of each image pair.

In the SBAS InSAR data processing process, M interferograms are generated, and the matrix composed of the deformation phase of the image at point (x, r) at N time steps is represented by φ (x, r). Therefore, the matrix composed of M interferograms for phase values is:

$$\delta\varphi_{def} = A \cdot \delta\varphi_{def}(\Delta t_i) \quad (2)$$

Among them, A is an M×N matrix When M ≥ N, the deformation time series can be obtained through the least squares method. When M<N, the results obtained by the least squares method are not unique. The singular value decomposition method is used to jointly solve multiple small baselines, and the phase rates obtained in each time period are integrated in the time domain to obtain the deformation values of the entire observation period's deformation time series. Finally, the deformation values of the surface in the time series can be converted through geographic coding processing.

3. Research Area and Data

3.1. Overview of the research area

The research area reservoir is located in Heishui County, Aba Tibetan and Qiang Autonomous Prefecture, Sichuan Province (123°42′34″E, 41°27′37″N). The reservoir area is a Sancha Reservoir built at the confluence of Maoergai River, Xiaoheishui River, and Heishui River. The reservoir area is narrow and stretches for several kilometers, surrounded by mountains that are steep and steep. The terrain slopes from northwest to southeast. The rainfall is abundant from May to September every year, which is the flood season. The flow velocity of the river is 4m/s to 7m/s, and the maximum flow can reach 2000m3/s to 2800m3/s. This is also the time period when deformation disasters are most likely to occur, with heavy precipitation and continuous rainy weather, which is not conducive to the development of optical and traditional monitoring methods for deformation disasters.

3.2. SAR image

Sentinel-1 satellite is an Earth observation satellite system in the European Space Agency's Copernicus Program (GMES) for Environment and Security. Sentinel-1 consists of two satellites equipped with C-band (wavelength 5.6cm) synthetic aperture radar (SAR), which can provide continuous all-weather day and night radar observation images covering land and sea. The Sentinel-1A IW mode satellite uses progressive scanning SAR, which typically consists of three sub frames with a coverage range of up to 250 km and a spatial resolution of 5m × 20m. It is widely used in the study of flood maps, glacier movements, iceberg shedding, detection of maritime vessels, surface monitoring of subsidence, and ground deformation caused by earthquakes and volcanoes. The data can be accessed through the official website of the European Space Agency (https://scihub.copernicus.eu/) Wait for the website to obtain it for free.

To obtain the surface deformation status and deformation information of the research area, this paper selects a total of 58 Sentinel-1A IW SAR ascending orbit images from January 2019 to June 2021 as the time-series InSAR basic data source for deformation monitoring in the reservoir area. The basic parameters of spaceborne SAR image data are shown in Table 1:

Table 1. Basic Parameters of Sentinel-1A IW SAR Image Data

Sens	Track direction	Polarization mode	Wavelength /cm	Spatial resolution /m	Perspective /(°)	Number of images /scenery
Sentinel -1A	Ascending the track	VV	5.6	5m×20m	36°	58

3.3. Other data

(1) Reference DEM

In the process of using InSAR deformation monitoring, it is necessary to refer to Digital Elevation Model (DEM) data. DEM can be used as the terrain phase reference value in SBAS InSAR data processing, and either DEM data or Digital Surface Model data (DSM) can be selected. The terrain phase reference data in this article is selected from the DSM data of ALOS World 3D, abbreviated as AW3D30. The spatial resolution of AW3D30 data is 30 meters and the elevation accuracy is 5 meters. It has rich surface and terrain information, which can effectively reduce the influence of terrain phase on the temporal InSAR monitoring results and improve monitoring accuracy.

(2) Precise orbital data

In addition to SAR data and reference DEM data, in order to calibrate the Sentinel-1 satellite orbit, it is also necessary to download SAR images and POD Precise Orbit Ephemeris data corresponding to the time, which can also be obtained for free from the official website of the European Space Agency.

4. Results and Analysis

4.1. Analysis of deformation space in the storage area

The SBAS InSAR time-series deformation calculation method was used to obtain the average deformation rate of the study area as shown in Figure 3. The research results indicate that the potential deformation direction of the reservoir area is consistent with the LOS direction deformation results of SBAS. The vast majority of the storage area shows a relatively stable state, with a deformation rate not exceeding ± 10 mm/a. However, based on the average deformation rate, a total of 12 obvious potential deformations and deformation groups were identified, with an average deformation rate ranging from -170mm/a to -79 mm/a. The 12 potential deformation zones are mainly distributed along the banks of the reservoir, and the deformation impact range is relatively large. Among them, 8-9 potential risk areas are distributed along National Highway G347, which may be related to the damage to the mountain rock mass caused by the construction of the national highway. Therefore, the destructive effect of highway engineering projects on the mountain has caused the original rock stress of the mountain to be destroyed, and it is believed that these factors have led to potential deformation risks. Therefore, key monitoring should be carried out in these areas.

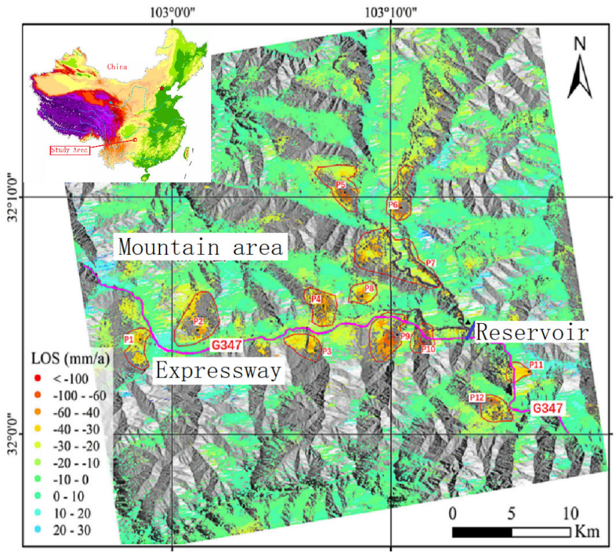

Figure 2. Distribution of Reservoir Deformation and Deformation

In order to further analyze the deformation sensitive areas in the storage area, a time series analysis of cumulative deformation was conducted on the identified potential risk areas. The points near the maximum deformation position of each sensitive area were extracted as the deformation sensitive points in the area for time series deformation analysis. For most of the 12 sensitive areas, the maximum cumulative deformation is between 10cm and 25cm, with relatively small deformation at point P11 and a cumulative deformation of around 100mm during the monitoring period. The cumulative deformation of P9 and P10 zones is relatively large, with cumulative deformation exceeding 30cm and a maximum cumulative deformation of 35cm.

4.2. Analysis of sensitive areas along the national highway in the warehouse area

Based on the average deformation rate map, cumulative deformation analysis map of deformation sensitive areas, and on-site investigation, it can be concluded that there are many potential deformation groups with a large impact range distributed along the two tributaries of Reservoir, mostly on both sides of National Highway G347. The causes of deformation should consider the damage caused by highway construction to the mountain and the potential deformation caused by seasonal rainfall.

4.3. Cumulative deformation analysis of sensitive areas

According to the analysis of the cumulative deformation curve, there is a short period of time from June to August each year with a high deformation rate, and the cumulative deformation shows an increasing trend. The rest of the time periods have a relatively stable trend of change. The increase in deformation rate and cumulative deformation should be mainly attributed to the significant impact of rainy season rainfall. There is a trend of increasing deformation in the deformation zones where P9 and P10 are located, which poses a certain risk of deformation. Since mid June 2020, there has been a significant deformation rate and cumulative deformation value, and around mid June 2021, there has been a huge cumulative deformation amount with certain signs of deformation. The stability of this area has a significant impact on the safety of Reservoir and National Highway G347, and monitoring of these sensitive areas should be strengthened to reduce deformation risks.

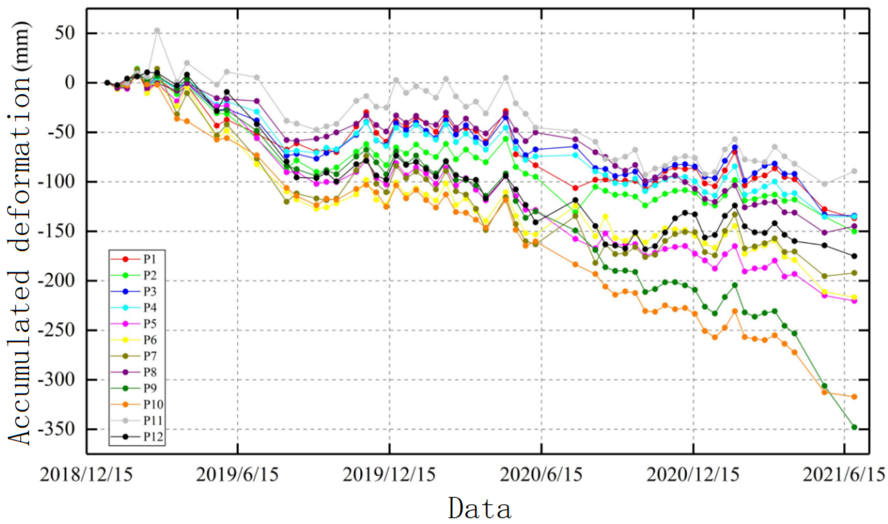

Figure 3. Time series cumulative deformation analysis of the main sensitive areas in the study area

5. Conclusion

This article uses SAR satellite remote sensing technology to identify potential deformation areas and sensitive areas in the reservoir area and surrounding mountains, which has a good risk identification effect. This article obtained the distribution of potential deformation risk areas in the study area through processing and analysis of 58 SAR images, and conducted trend analysis on deformation. The research results indicate that there are 12 deformation sensitive areas around the reservoir area, including two potential risk areas with certain signs of deformation. Through analysis of deformation rate and cumulative deformation, the maximum deformation rate exceeded 100mm/a, and the cumulative maximum deformation value reached 35cm. The use of remote sensing technology can quickly identify the distribution of potential deformation areas, and can better identify the sensitive and risk areas of deformation bodies. This technology can be applied more deeply in the identification of potential geological disaster areas, disaster assessment, and other fields.

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