Land Deformation Monitoring in Lanzhou City Based on SBAS-InSAR Technology

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Abstract: With the continuous advancement of urban construction, the original natural landscapes such as wetlands, vegetation, and soil are converted into artificial landscapes such as buildings and roads, resulting in a wide range of changes in urban surface. Monitoring urban surface changes is of great significance to the healthy development of cities and the prevention of geological disasters. The traditional land deformation monitoring technology has the disadvantages of small monitoring range, large workload and low efficiency. Interferometric Synthetic Aperture Radar technology can effectively solve the defects in the traditional deformation monitoring technology. This paper takes Lanzhou as the research area, selects the Sentinel-1A data of 25 scenes from 2014 to 2016, and uses the Small Baseline Subset Interferometric Synthetic Aperture Radar (SBAS-InSAR) for land deformation monitoring. The sedimentation observation results obtained by the SBAS-InSAR technique was analyzed with the methods of statistical analysis and time series analysis. The results show that: (1) The overall urban area of Lanzhou City has been slightly sunk, and the funnel in the deformation area is mainly concentrated in the mountainous areas, new residential buildings and subway stations. (2) From the perspective of each region, Shajingyiin Anning District, near XuanshengRundi in Jiuzhou, near Xiaodaping Driving Test Center, near Xuanmaogou-Badaoping Village in Chengguan, near Donggang Cargo Center, near Fulongping, near Hendafeicuihuating in Qilihe District, near Lanzhou West Railway Station and other places all showed strong subsidence trends, and the area with the highest deformation rate is Xiaodapeng, which maximum average annual deformation velocity can reach 30.8mm/a, and the cumulative deformation is as high as 65.9mm.(3) The land deformation of Lanzhou City shows a non-linear downward trend, and the deformation gradually spreads in the east-west direction. Eventually, deformation also occurred in some foothills in the north and south, and in some urban areas. (4) The main driving factors for settlement in the urban area of Lanzhou are loess soil, rail transportation and urbanization.

1. Introduction

Land Settlement Monitoring is a major engineering geological problem in major cities. It brings great harm to the economy and public safety of the city [¹]. With the continuous advancement of urban construction, the original natural landscapes such as wetlands, vegetation, and soil are converted into artificial landscapes such as buildings and roads, resulting in a wide range of changes in urban surface.
Monitoring urban surface changes is of great significance to the healthy development of cities and the prevention of geological disasters. At present, most of the surface deformation monitoring uses traditional GNSS or level measurement methods \[^2\]. Although these methods have high monitoring accuracy, they have a large workload, high cost, low efficiency, low spatial resolution, and small coverage, and it is difficult to meet the needs of time scale and space scale. Differential Interferometry SAR (D-InSAR) technology is an effective method for surface deformation monitoring in recent years. It can monitor the ground in all weather, wide range and sub-cm level accuracy \[^3\]. However, this technique is susceptible to errors such as orbital errors, atmospheric effects, and spatiotemporal decoherence \[^4\]. This seriously affects the accuracy of monitoring and the reliability of technology. In order to overcome the shortcomings of D-InSAR, a time-series InSAR technique has been proposed. At present, the time series insar technology commonly used is Permanent Scatterer InSAR (PS-InSAR) \[^5\] and Small Baseline Subset InSAR (SBAS-InSAR) \[^6\]. However, PS-InSAR technology generally requires SAR data of more than 25 scenes and it is suitable for urban areas with sufficient stabilization points. And SBAS-InSAR technology not only inherits the advantages of conventional D-InSAR technology, but also overcomes the disadvantages of PS-InSAR technology \[^7\]. SBAS-InSAR is currently the most popular method, and its monitoring accuracy and reliability have been verified \[^8\]-\[^13\]. The geological conditions in Lanzhou are complicated, the slopes near the north and south mountains do not have enough stability points. PS-InSAR is not suitable. Therefore, this paper uses SBAS-InSAR technology to monitor the surface deformation of the main city of Lanzhou and analyze its monitoring results.

2. Study area and experimental data

2.1. Study area

Lanzhou City is located in northwestern China and central Gansu Province. The city center is located at 36 ° 03′N and 103 ° 40′E. Lanzhou is located in the Yellow River Basin. It is higher in the west and south. The urban area is narrow from east to west. The Yellow River runs through the city from west to east. It has the urban characteristics of a banded basin. Lanzhou's engineering geological conditions are complex, and it is one of the few provincial capitals in China that is plagued by geological disasters. In recent decades, along with a series of human activities such as urbanization in Lanzhou, geological disasters in Lanzhou have occurred frequently. Therefore, this paper selects the four main urban areas of Chengguan District, Anning District, Qilihe District and Xigu District of Lanzhou City as the main research areas. The geographical location of the study area is shown in Figure 1.

![Fig. 1. Location of study area](image)
2.2. Experimental data

This paper selects 25 Sentinel-1A ascending orbit image data covering the study area for experiments. The data type is SLC data of IW. The time span is 2014-10-21 to 2016-09-04, and the polarization method is VV. In addition, the Shuttle Radar Topography Mission Digital Elevation Model (SRTM DEM) 30-meter resolution elevation data and the Precise Orbit Ephemerides (POD) data corresponding to each image were used in the experiment.

3. Technical principles and data processing

3.1. Principles of SBAS-InSAR technology

SBAS-InSAR is an InSAR time series method with multiple master images, first proposed by Berardino [6]. It combines all the acquired SAR data to form interference pairs and then sets the spatial baseline and time baseline threshold and obtains several small baseline sets whose spatiotemporal baseline is smaller than the threshold. The surface deformation time series of each set can be solved by the least square method, and then several singular baseline sets are solved by singular value decomposition (SVD). This effectively solve the different small baseline between sets due to baseline caused by the long times discontinuity problem, improve the monitoring time resolution, and reduces the demand for SAR data, and the computational efficiency is high. (Zhou, 2017 a), effectively solve the general equation rank deficient problem, and finally get the sequence covering the whole observation time of ground subsidence.

3.2. Data processing

In this paper, Sentinel-1A data and SBAS-InSAR technology are used to monitor the surface deformation of Lanzhou City. The software used for data processing is SARscape. The main steps are as follows:

(1) Data pre-processing: Import 25 sentinel data into SARscape standard data format, and trim the data to reduce the amount of data and save processing time.

(2) Baseline estimation and generation of small baseline sets: The time baseline threshold is set to 400 days, and the spatial baseline threshold is 2% of the critical baseline. The generated spatial-temporal baseline is shown in Figure 2.

(3) SAR image registration: 20150910 was selected as the super master image. This image is already registered with another image. The registration accuracy is required to be less than 1/8 pixel.

(4) Perform conventional D-InSAR processing on the interference pair set: it mainly includes interferogram generation, flat phase removal, interferogram filtering, coherence coefficient calculation, phase unwrapping, etc. Among them, the interferogram filtering adopts the Goldstein method. The phase unwrapping method is based on the Delaunany triangulation minimum cost flow method (MCF), and the coherence coefficient threshold is set to 0.3. View the generated interference map, coherence coefficient map and unwrapping map, and remove interference image pairs with poor coherence and unwrapping.

(5) Orbit refinement and re-flattening: 30 control points were selected in areas with flat terrain and no phase jumps and distorted stripes. Orbit error and phase offset were estimated using 3 times orbit refinement polynomials to eliminate slope phase, and re-flattening all data based on control points.

(6) Deformation rate and elevation coefficient estimation: establish a model of the deformation rate and elevation coefficient of each coherent point to form a system of equations, and use the SVD method to solve the equations to obtain the deformation and elevation of all interference pairs.

(7) Removal of topographic residual phase and atmosphere phase: Use the estimated residual topography to flattening the interferogram, then re-unwrapping and refine the orbit to optimize the unwrapping result; Based on the first estimated deformation rate, atmospheric time-domain high-pass filtering and space-domain low-pass filtering, estimate the atmospheric phase at each time point to get the final deformation results on the time series.

(8) Geocoding: encode all results generated above into the GCS-WGS-84 coordinate system.
4. Results and analysis

4.1. Analysis of average annual deformation velocity

The average annual deformation velocity in the line of sight (LOS) from 2014 to 2016 in the main city area of Lanzhou obtained by SBAS-InSAR technology was superimposed on the high resolution image, and the results are shown in Figure 3. Negative values in the figure indicate ground subsidence, and positive values indicate ground uplift.
Fig. 3 Map of Lanzhou's average annual velocity from 2014 to 2016

It can be seen from Figure 4 that the average annual deformation velocity range of the main urban area of Lanzhou is [-33.1, -16.8] mm / a. The areas with a large deformation velocity in Lanzhou are mainly distributed in Shajingyi (A) in Anning District, near Xuansheng Rundi in Jiuzhou (B), near Xiaodaping Driving Test Center (C), and near Xuanmagou-Badaoping Village in Chengguan (D), near Donggang Cargo Center (E), near Fulongping (F), near Hendafeicuihuating in Qilihe District (G), near Lanzhou West Railway Station (H), etc. The area with the highest average annual deformation velocity is located near the Xiaodaping Driving Test Center (C), and its maximum average annual deformation velocity can reach 32.8 mm / a.

On the whole, these heavily subsided areas are basically distributed in the foothills of the north and south and the front of the valley terraces. There are three main reasons for these areas to deform. The first is that due to insufficient urban land in Lanzhou City, mountainous land was cut at the foothills of the north and south mountains, which caused many foothills to be unstable and deformed under the influence of rain erosion and artificial irrigation. The second is that the main urban area of Lanzhou is mainly covered by thick loess. Malan loess is a self-weight collapsible loess, which is easily deformed under the condition of increasing surface load and erosion and infiltration of surface water. The third is that rail transit and urbanization construction disrupt the surface stress balance and cause ground deformation. The average annual deformation velocity of the main urban area of Lanzhou City from 2014 to 2016 was divided into intervals, and the percentage of the area of each district was counted. The results are shown in Figure 4.

It can be seen from Figure 4 that during the monitoring period, the average annual deformation velocity in most areas of Lanzhou was distributed in the interval [-10, 0], which accounted for about 69.67% of the total area monitored. The areas with average annual deformation velocity distributions in the interval [10, 17] and [-30, -20] only account for 0.02% of the total area. The area where the average annual deformation velocity is distributed in the interval [0, 10] accounts for 29.42% of the total area monitored. The area where the average annual deformation velocity was distributed in the interval [-20, -10] accounted for only 0.87% of the total area monitored. From the above statistical data, it can be seen that during the monitoring period, most areas in Lanzhou's main urban area experienced slight subsidence, and the ground surface remained basically stable with no obvious abrupt changes.
4.2. Feature point time series analysis

In Figure 3, four B, C, D, and H study areas with a large average annual deformation speed are selected, and three points with the largest cumulative deformation from each area are selected as feature points. The time-varying curve of the shape variable is plotted on the time series as shown in Figure 5. It can be seen from Figure 5 that the cumulative deformation in the area C is about 70 mm at the maximum. The cumulative deformation in areas B and D are about 45 mm, and the cumulative deformation in area H are about 35 mm. From the perspective of changes, areas C, D, and H have been in a state of subsidence, while area B has significantly increased from February 25, 2016 to March 20, 2016. In general, from October 21, 2014 to September 4, 2016, the temporal cumulative deformation trend of the selected feature points in each region is consistent and all show a non-linear decline.
4.3. Time series deformation analysis
Taking 2014-10-21 as the starting time, the time series deformation diagram of other times relative to the starting time is shown in Figure 6. From Figure 6 we can see the spatiotemporal evolution of surface deformation in Lanzhou from 2014 to 2016. From the perspective of time distribution, with the passage of time, the range of deformation in Lanzhou has been expanding, and the amount of deformation has increased. Deformation in Xiaodaping, Kyushu, and Baidaoping Village has been increasing, and there has been no relief. The maximum cumulative deformation is as high as 70mm. From the perspective of spatial distribution, the deformation of Lanzhou City initially appeared only in small areas such as Xiaodaping and Baidaoping, and then gradually spread in the east-west direction. Eventually, deformation also occurred in some foothills in the north and south, and in some urban areas.

![Fig. 6. Time series deformation diagram](image)

5. Conclusion
This paper takes Lanzhou as the research area, selects the Sentinel-1A data of 25 scenes from 2014 to 2016, and uses the BAS-InSAR technology motion monitoring. The sedimentation observation results obtained by the SBAS-InSAR technique were analyzed with the methods of statistical analysis and time series analysis. The results show that: (1) The overall urban area of Lanzhou City has been slightly sunk, and the funnel in the deformation area is mainly concentrated in the mountainous areas, new residential buildings and subway stations. (2) From the perspective of each region, Shajingyi in Anning District, near XuanshengRundi in Jiuzhou, near Xiaodaping Driving Test Center, and near Xuanmagou—
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