MONITORING OF THE GROUND FISSURE ACTIVITY WITHIN YUN Cheng BASIN BY TIME SERIES INSAR

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ABSTRACT:

Yuncheng area is one of the most extensive distributions of ground fissures in Shanxi basin, especially in Yanhu District of Yuncheng, the disaster of ground fissures and ground subsidence are the most serious. According to previous studies, the development and distribution of the ground fissures in this area are mainly controlled by the underlying active faults. In order to provide a better understanding of the formation mechanism, the deformation of ground fissures and its surrounding environment should be taken into consideration. In this paper, PS-InSAR technology was employed to assess the time-series ground deformation of Yuncheng ground fissures and its surrounding area with X-band TerraSAR images from 2013 to 2015. The interaction between ground fissures activity and land subsidence, groundwater, precipitation and surrounding faults will be discussed.

1. INTRODUCTION

Ground fissure is a kind of crack on the surface under the action of natural factors (crustal activity, groundwater effect, etc.) and human activities (such as pumping, watering and excavation). In recent years, under the combined action of dynamic geological geology and human engineering activities, the scale and frequency of ground fissure has gradually increased, causing unpredictable damage to the natural environment and building structure. Therefore, to carry out ground fissure deformation monitoring and study of its activity are effective means of reduction and prevention for disaster.

Yuncheng Basin is located at the southwestern of the Shanxi Basin, with Emei Platform fault in the north, Zhongtiao Mountain in the east and south, and across the the Yellow River and Weihe Basin in the west. The total area is about 600 km². The ground fissures in Fenwei basin are widely distributed. Yuncheng area is one of the most extensive distributions of ground fissures in Shanxi basin, especially in Yanhu District. In this paper, StaMPS technology is used to monitor and analyze the land subsidence and ground fissure activities in Yuncheng area of Shanxi Province using the X-band TerraSAR images, so as to provide a basis for effective disaster reduction and avoidance.

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The core idea of the PS-InSAR method is to use a plurality of SAR images acquired in the same area within a certain time period to identify ground targets with strong reflection characteristics and stable scattering characteristics (that is the permanent scatterer), and then establish a phase model, according to the phase model for time series analysis, to separate the DEM error, atmospheric delay information and other errors and deformation information.

PS-InSAR technology can overcome the effects of atmospheric effects, temporal and spatial disassociation in conventional D-InSAR. Even in the absence of interference fringes, it is possible to acquire millimeter-level deformation monitoring accuracy using PS points with stable phase on time-series SAR images. In 2004, Hooper proposed the StaMPS algorithm and based on the characteristics of the phase. The method selects points with small amplitude and stable phase as the final PS points. The example verified that the method can still select enough PS points in areas that can not be processed by the conventional PS algorithm, which greatly expands the application scope of the PS technology. The basic principles of StaMPS technology is as follows.

In processing, one of the sequenced SAR images is first selected as a common main image, and this image needs to be satisfied the best correlation with other images as a whole. Then by statistically analyzing the relationship between amplitude stability and phase stability, the initial PS points are selected. The amplitude dispersion involved was given by Ferretti et al. in 2001 based on the standard deviation and mean of the amplitude of the SAR images:

\[
D_{\sigma} = \frac{\sigma}{\mu}
\]  
(1)

Where \(D_{\sigma}\) = amplitude dispersion  
\(\sigma\) = standard deviation  
\(\mu\) = mean of the amplitude

The phase components of each pixel are analyzed and the spatially correlated and non-correlated components are further decomposed. Then the criterion for the candidate PS points is obtained based on this criterion. The algorithm uses the amplitude deviation index as the detection threshold of the PS primary selection points. The interferometric phase at the initial detection points is all composed of various phase such as deformation phase, orbit residual error, terrain error and atmospheric delay phase.

\[
\psi_{\text{int},i,j} = W(\phi_{\text{def},i,j} + \phi_{\text{atm},i,j} + \Delta \phi_{\text{orb},i,j} + \Delta \phi_{\text{def},i,j} + \phi_{\text{int},i,j})
\]  
(2)

Where \(\psi_{\text{int},i,j}\) = interferometric phase  
\(\phi_{\text{def},i,j}\) = deformation phase

The deformation of each preliminary point has a high degree of correlation. Based on this assumption, combined with the resolution of the SAR image, adaptive filtering is used to sequentially find the first four spatially relevant parts within a certain correlation space window and eliminate, and simultaneously estimate and eliminate spatially non-correlated incident angle error. This will be an iterative step that estimates the phase noise value for each candidate pixel in every interferogram. After iterate and converge, the residual components are used to estimate the correlation coefficient of the PS candidate points.

\[
\gamma_s = \frac{1}{N} \sum_{i=1}^{N} \exp \left( \frac{\psi_{\text{int},i,j} - \tilde{\psi}_{\text{int},i,j} - \Delta \phi_{\text{def},i,j}}{\sigma_{\text{int},i,j}} \right)
\]  
(3)

Where \(\gamma_s\) is defined as an estimate of the decorrelation noise, which is a representation of variations in the residual phase at the PS candidate pixel. The inner consistency of residual phase for PS pixels is better than other pixels, which is reflected through relatively higher \(\gamma_s\) value.

Hooper et al. (2007) proposed that threshold is selected based on probability statistics, it is considered that non-PS points also have a certain probability of having a higher value. Therefore, it is necessary to set the acceptable probability of non-PS points to be less than a reasonable threshold as a statistical criterion. Its purpose is to preserve the true PS points maximally. The expression of the probability that an acceptable PS point is selected by mistake is shown by equation (4):

\[
\frac{[1 - \alpha(D_{\sigma})]^q}{\int_{0}^{\gamma_s} \gamma_s \, d \gamma_s} = q
\]  
(4)

where q is the maximum fraction of all the selected pixels that we will accept being non-PS pixels (false positives). The pixels with the \(\gamma_s > \gamma_s^{\text{thresh}}\) would be picked up.

2.2. Technology Process

Stamps technology is mainly composed of four parts, as follows:

1. Interferogram Formation. Interferograms generated using Doris software. There are aspects of interferogram formation for PS processing that differ to conventional interferogram formation.

2. PS Identification. We use both amplitude and phase analysis to determine the PS probability for individual pixels. First we make an initial selection based only on amplitude analysis, then we refine the PS probability using phase analysis in an iterative process. Finally, we estimate the PS probability for those pixels not included in the initial selection.
3. PS Selection. We select PS based on their PS probability, rejecting those that appear to be persistent only in certain interferograms and those that appear to be dominated by scatterers in adjacent PS pixels.

4. Displacement Estimation. Once selected, we isolate the signal due to deformation in the PS pixels. This involves “unwrapping” the phase values and subtracting estimates of the various nuisance terms.

The technique flow chart is as follows in figure 1, especially the selection of PS points.

4. RESULT AND ANALYSIS

4.1 Deformation Time Series Analysis

The deformation time series of Yuncheng ground fissures and its surrounding area were obtained through StaMPs technology. As shown in the figure 3, the DEM data was shown as the background and the faults and the main researched ground fissure in the Yuncheng Basin were shown.

It can be clearly seen from the deformation rate map that the most serious deformation areas are mainly located in Boyuan Village and its surrounding areas in Yanhu District, and with this as the center, a very clear oval-shaped subsidence funnel was formed. In addition, a section line analysis was performed on the subsidence funnel, as shown in Figure 4, and the maximum annual rate deformation reached 25 mm.

In order to further analyze the subsidence in the area, several characteristic points in the main study area were extracted for analysis. First, a point located at the center area was extracted in the sedimentation funnel area for analysis. As shown in the figure 5 below, from 2013 to 2015, at the point of the center of the subsidence, the maximum cumulative deformation reached about 30mm.
In addition, there is surface subsidence in Banpo ground fissure and Xian area. It is shown that the deformation time series of characteristic point in Xian area in figure 6. Land subsidence in Xian area is more serious than Yanhu District, and the maximum cumulative deformation can reach nearly 60mm.

4.2 Analysis of Ground Fissure

There are multiple ground fissures in the study area, but this paper focuses on Banpo ground fissure. In order to further monitor the deformation characteristics of Banpo ground fissure, a pair of points were extracted on the two vertical lines along the ground fissure, and deformation time series analysis was performed.

As shown in Figure 3, A1, A2 and B1, B2 are two pairs of points. The deformation time series of these two pairs of points showed a slow downward trend. As shown in Figure 7 and Figure 8, the two points of A1 and B1 are distributed on the south side of the ground fissure respectively, and the deformation is about 20mm. The two points of A2 and B2 are on the north side, and the deformation is greater than 40mm. The land on both sides of the ground fissure showed a slow decline, but there is a clear difference in deformation.

4.3 Factors Analysis of Induced Banpo Ground Fissure

By investigating the fault and Banpo ground fissure, it is found that the location and direction of the Banpo ground fissure are basically the same as the fault. It can be seen that the development and distribution of the ground fissure in this area are mainly controlled by the underlying active faults.

According to the survey, groundwater is over-exploited in multiple areas in the Yuncheng Basin. There are three severely over-exploited areas, include the study area. Overexploitation of the groundwater flow and infiltration of surface water create a large groundwater funnel area over a long period of time. Therefore, groundwater over-exploitation is the main factor for land subsidence and ground fissures in Yanhu District and Xian. The groundwater level is shown in the past 15 years in figure 9.
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