

Identifying and interpreting patterns of ground deformation in Huaibei Plain during 2017-2023 based on MT-InSAR and Independent Component Analysis

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ABSTRACT

Accurately identifying various ground deformation patterns can provide crucial support for the prevention and control of land subsidence disasters and the safeguarding of urban public safety(). The Huaibei Plain in China is a major area affected by subsidence. The interaction of factors such as excessive groundwater extraction, coal mining, and sediment consolidation has led to complex ground deformation patterns driven by multiple factors. This study utilized 572 Sentinel-1 satellite images as data sources and employed the Multi-Temporal InSAR(MT-InSAR) method to invert the ground deformation time series of the Huaibei Plain in Anhui Province from May 2017 to October 2023. By applying Independent Component Analysis(ICA), elastic and inelastic ground deformation signals were effectively separated from the ground deformation time series of the Huaibei Plain. To deeply analyze the temporal patterns of ground deformation, clustering was conducted on the ground deformation time series based on threshold segmentation and contour correlation of time series. Finally, we use the geo-detector method to explore the main influencing factors of ground deformation in the Huaibei Plain. This research not only helps to understand the mechanisms of ground deformation but also holds significant importance for the prevention and control of ground subsidence disasters.

Keywords: Huaibei Plain, MT-InSAR, Ground deformation, ICA, Pattern analysis.

INTRODUCTION

Huaibei Plain is one of the main areas of land subsidence in China. After the 1980s, the Huaibei Plain has been extracting deep groundwater for a long time, and the central urban areas such as Fuyang City and Bozhou City in the Huaibei Plain have shown a continuous trend of land subsidence. However, the implementation of groundwater control in the Huaibei Plain in recent years has led to some areas ground uplifting, which means the ground deformation of the Huaibei Plain is complex. It is urgent to conduct large-scale and long-term continuous monitoring of ground deformation in the Huaibei Plain, analyze the ground deformation patterns in different regions.

METHODS

Small Baseline Subset InSAR(SBAS-InSAR) method reduces the influence of decorrelation and topographic phase by selecting SAR image subsets with small spatio-temporal baselines for interference processing. It is widely applied in regional-scale ground deformation inversion and is therefore applicable to this study.

ICA is a blind source signal separation method, which can separate independent signals from mixed signals without prior information. ICA assumes that the observed signals are formed by several independent source signals through an unknown linear mixing system(Ren et al., 2024).

Time series similarity clustering analysis in this study is based on the contour correlation of time series. These similar time series tend to be proportional to each other, and their values increase and decrease meanwhile.

Geo-detector is a spatial analysis method for detecting spatial heterogeneity and revealing the underlying driving forces(Huang et al., 2025).

RESULTS

From May 2017 to October 2023, the main areas of land subsidence in the Huaibei Plain of Anhui Province were located in Fuyang, Bozhou, and Suzhou City(Fig. 1). The average annual deformation rate in the severely subsidence areas reached -60mm/year.

Using the ICA, the ground deformation signals were decomposed into two components. The first independent component (IC1) represents a linear subsidence, and second independent component (IC2) represents a rebound signal (Fig. 2). IC1 is mainly distributed in areas with large subsidence values such as Fuyang, Bozhou, and Suzhou City. IC2 is mainly distributed in the central area of Fuyang City. By comparing the changes in groundwater storage in Fuyang City in recent years, it can be reasonably inferred that the rebound trend of the ground deformation reflected by IC2 may be related to the rise of groundwater level.

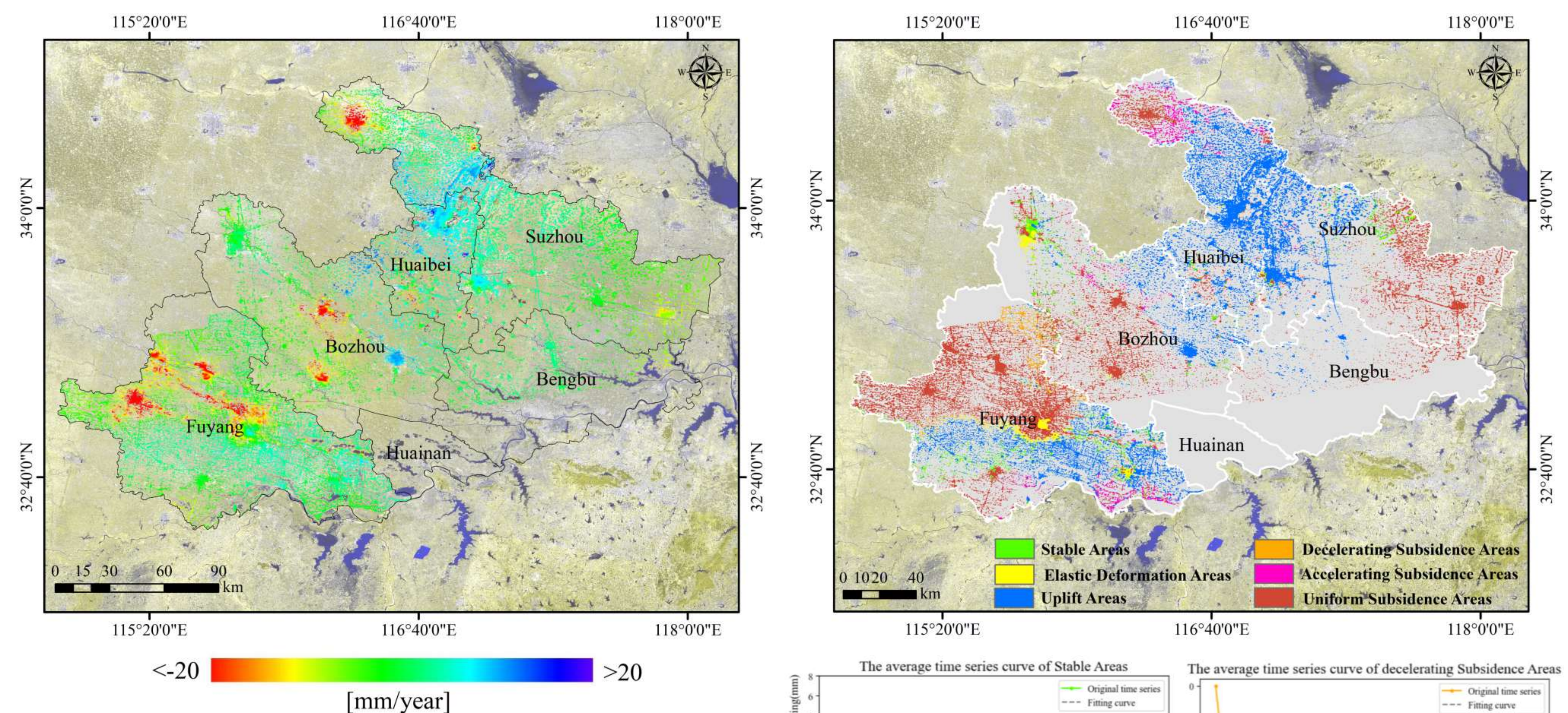


Figure 1. Ground deformation velocity map of the Huaibei Plain, Anhui Province from May 2017 to October 2023.

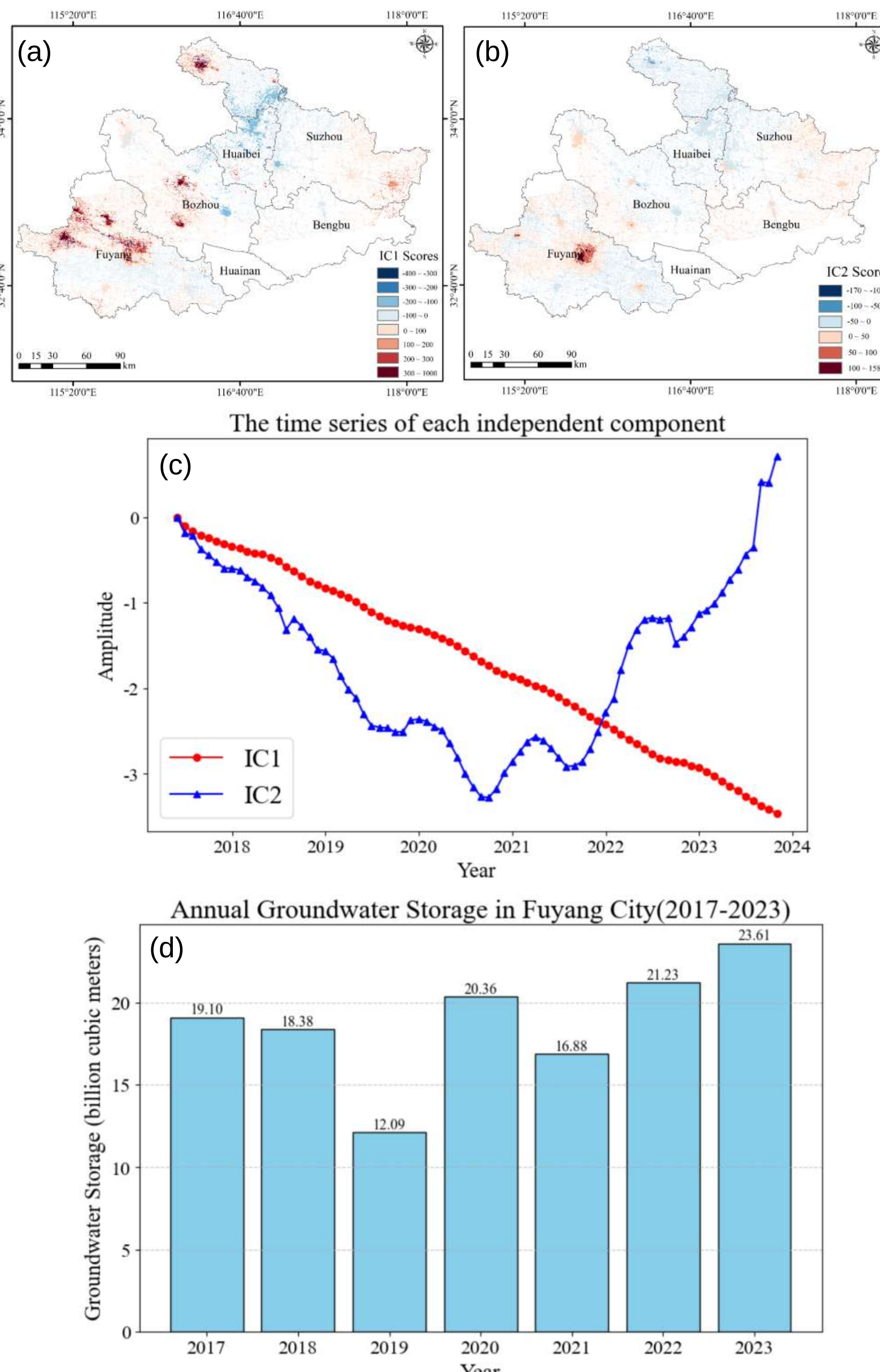


Figure 2. ICA decomposition results of the time series ground deformation: (a) Spatial distribution of IC1; (b) Spatial distribution of IC2; (c) The time series of each independent component; (d) Annual groundwater storage in Fuyang City from 2017 to 2023.

RESULTS

The time series clustering algorithm was used to obtain six typical ground deformation patterns in the Huaibei Plain, including stable areas, elastic deformation areas with initial subsidence followed by uplift, uplift areas, decelerating subsidence areas, accelerating subsidence areas, and uniform velocity subsidence areas (Fig. 3).

The main influencing factors of ground deformation in the Huaibei Plain were identified using the geo-detector method. The results showed that groundwater storage, soil bulk density, and precipitation were the main influencing factors(Fig. 4a). It is worth noting that the global influence considered by the geo-detector, which led to the influence values of the mining areas being very low in the overall results of the Huaibei Plain, because of the relatively limited distribution of the mining areas. In order to analyze the impact of the mining area on ground deformation, we conducted a study on the severely mined Huaibei City. It can be seen from the figure. 4b that the impact of mining activities on ground deformation ranked second.

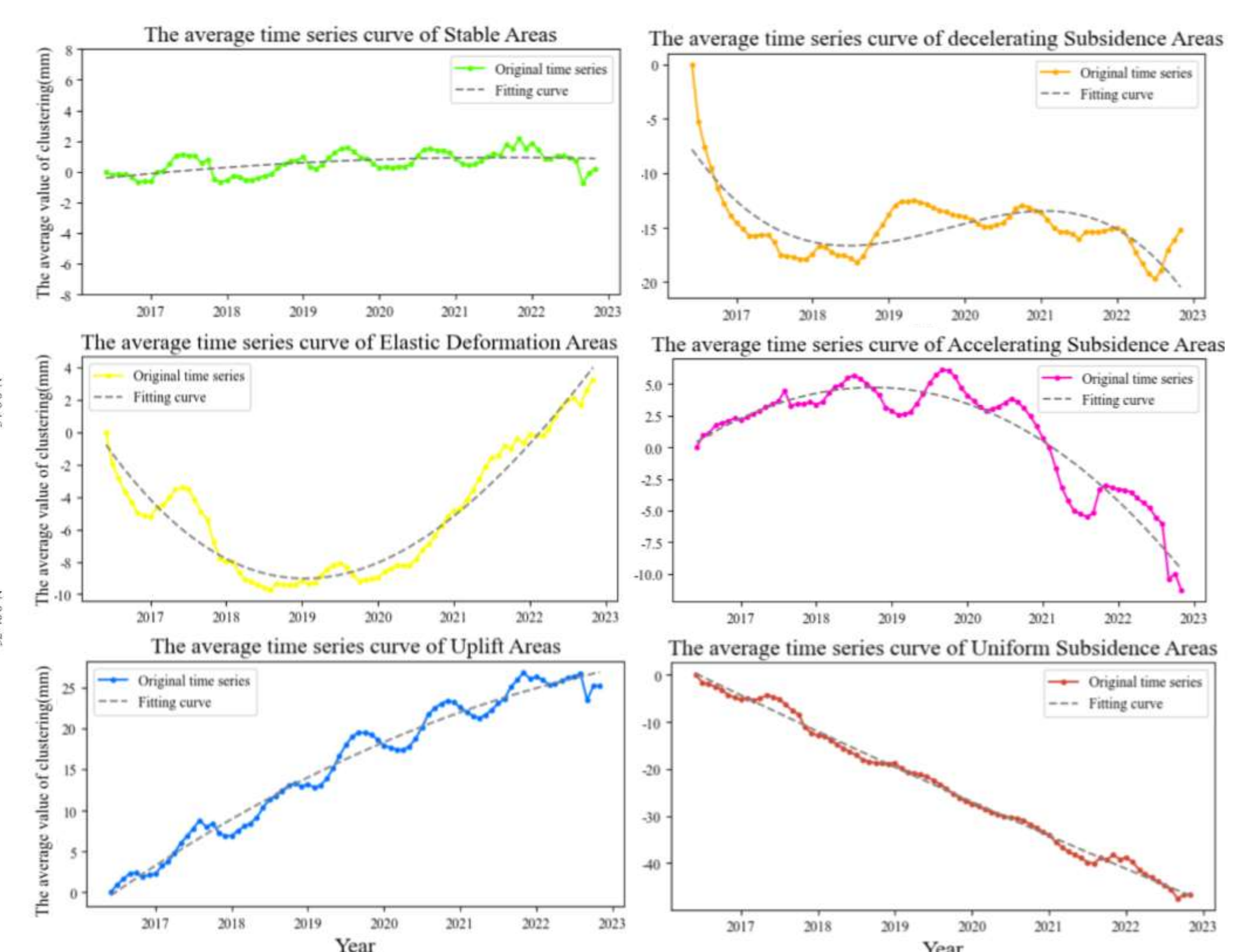


Figure 3. The spatial distribution and time series curves of six ground deformation patterns in the Huaibei Plain, Anhui Province from May 2017 to October 2023.

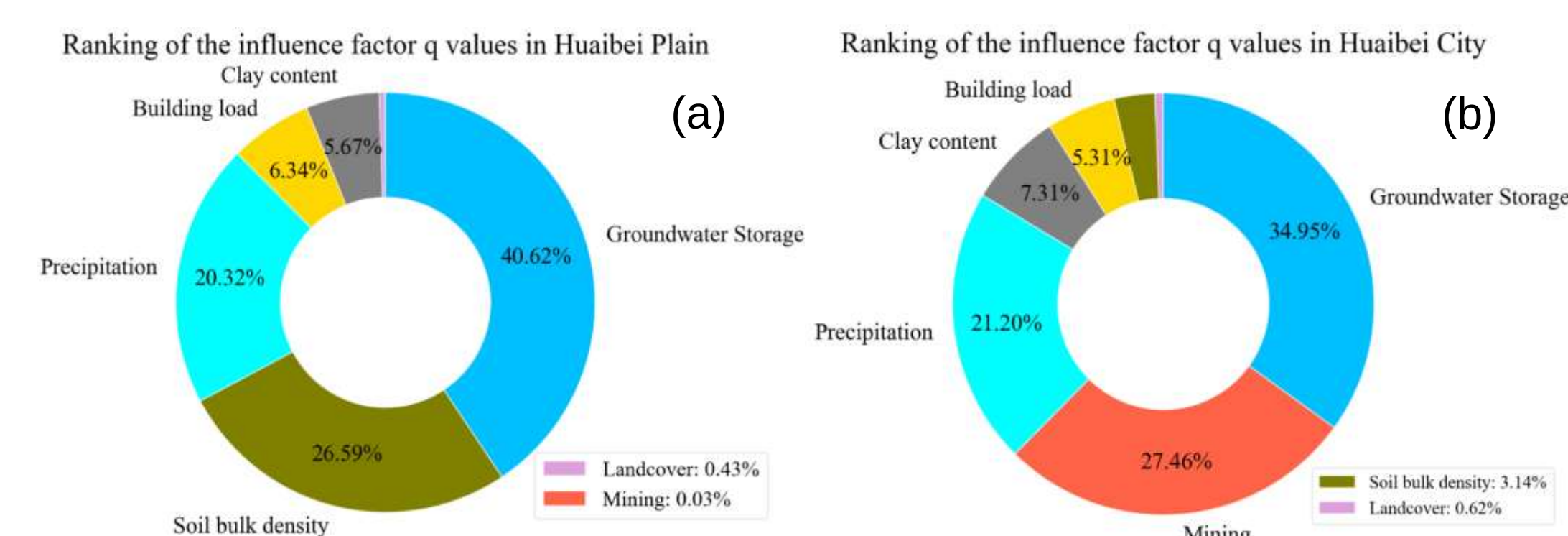


Figure 4. Geo-detector results. (a) Ranking of the influence factor q values in the whole Huaibei Plain; (b) Ranking of the influence factor q values in Huaibei City, which is severely-mined ;

CONCLUSIONS

This study used SBAS-InSAR to invert the ground deformation of the Huaibei Plain in Anhui Province from May 2017 to October 2023. Using the ICA method, the ground deformation signals were decomposed into elastic and inelastic signals. It was reasonably inferred that the elastic uplift signal observed in the center of Fuyang City was related to the rise in groundwater level. The time series similarity analysis method was used to identify different ground deformation patterns, and the temporal and spatial distribution of six types of ground deformation patterns was analyzed, warning the accelerating subsidence areas. Using geo-detector method to analyze the main influencing factors of ground deformation in the Huaibei Plain, the results showed that groundwater storage, soil bulk density, and precipitation were the main influencing factors.

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