ISSN: 1813-4890

Analysis of temporal and spatial evolution of subsidence in Shendong mining area

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Abstract

Aiming at the problem of land subsidence caused by underground mining activities in Shendong mining area, in order to reveal the temporal and spatial evolution characteristics of land subsidence in this area. In this paper, InSAR technology is used to monitor and analyze the land subsidence in the study area from January 2017 to September 2022 for a long time series. The results show that during the observation period, the total subsidence area of the study area accounts for about 44.20 % of the study area. In terms of time, the land subsidence in each mining area from January 2017 to July 2018 was relatively rapid. From the spatial point of view, the eleven mining areas have undergone different degrees of land subsidence. The heavy subsidence areas are concentrated in the Buertai mining area, the Shangwan mining area and the Shigetai mining area. The land subsidence in the western mining area is more serious.

Keywords

Shendong Mining Area; subsidence Monitoring; Temporal and spatial evolution.

1. Introduction

The high-intensity mining of coal resources will inevitably lead to large-scale surface subsidence disasters while ensuring energy security, posing a long-term threat to the ecological environment and infrastructure of the mining area.Shendong mining area is a 200 million tons large-scale modern coal production base, the surface subsidence caused by mining activities can not be ignored[1].Large-scale surface subsidence not only destroys surface vegetation and soil structure, but also aggravates land desertification. It may also damage infrastructure such as roads and pipelines, which seriously threatens the ecological environment safety and sustainable development of mining areas[2].Synthetic Aperture Radar Interferometry (InSAR) technology has become a revolutionary tool for deformation monitoring in mining areas due to its advantages of large range, high precision and not affected by weather. However, the surface of Shendong mining area is covered with sand dunes and vegetation. Traditional D-InSAR technology and PS-InSAR technology are easy to fail, and most of them are used for surface subsidence monitoring in a short time[3].SBAS-InSAR technology can effectively solve the problem of spatial and temporal coherence by combining a series of short spatial baseline interferometry pairs, and can use redundant observation data to separate atmospheric phase error and nonlinear deformation. It can keenly capture small ground displacement changes, and the measurement accuracy reaches the millimeter level. In recent years, this technology has been widely used in monitoring ground deformation along railways[4] and subways[5], subsidence in urban areas [[6],[7]], and landslides in reservoirs[8]and rivers[9].For example, Ma Gang et al.[10]combined with InSAR technology to study and monitor the deformation of the core wall rockfill dam in Lianghekou.At present, although some studies have applied InSAR technology to Shendong mining area, most of them focus on short-term monitoring or accuracy verification of a single working face, and lack systematic analysis of the subsidence process and long-term sequence of multiple working faces from the mining area scale. In this paper, SBAS-

ISSN: 1813-4890

InSAR technology is used to continuously monitor the time series ground deformation information of 11 mining areas such as Buertai in Shendong mining area from January 2017 to September 2022, and to explore the spatial and temporal characteristics of land subsidence in each mining area, so as to provide a basis for ecological restoration and management in the future.

2. Research methods

Shendong mining area is located in the north of Yulin City, Shaanxi Province and the south of Ordos City, Inner Mongolia Autonomous Region. The study area is 11 mining areas including Buertai, Liuta, Shangwan and so on in Shendong mining area. The general situation of the study area is as follows,see Fig. 1.

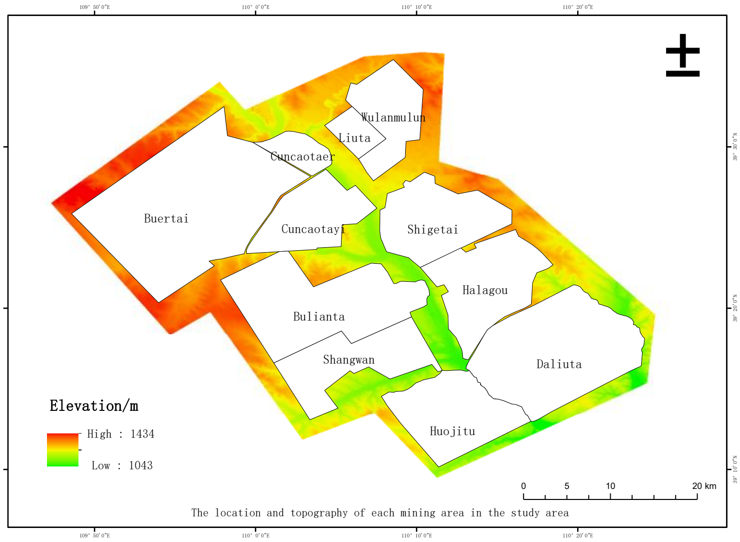

Fig. 1 Overview map of the study area

The process of subsidence monitoring and analysis in this mining area is as follows ,see Fig. 2 Process of subsidence monitoring and analysis in mining area.

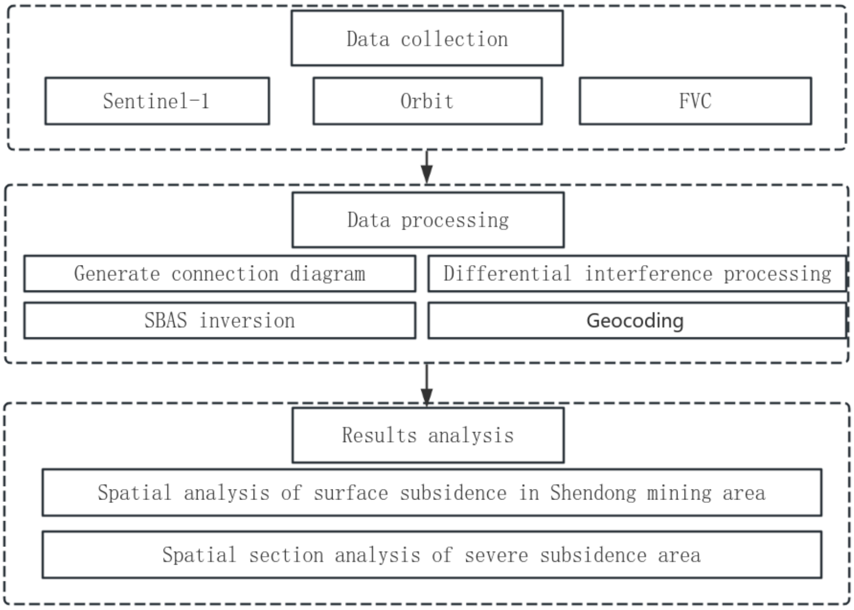

Fig. 2 Process of subsidence monitoring and analysis in mining area

3. Results and analysis

3.1. The evolution characteristics of subsidence time in Shendong mining area

In order to ensure the accuracy of the time series deformation results of Shendong mining area, according to SBAS-InSAR technology, the mean coherence coefficient is used to determine the stable point, and the internal test of the time series subsidence results of Shendong mining area is carried out [11]. The lush vegetation in summer has seriously affected the coherence. The coherence in summer within one year is generally the lowest, but the coherence in the study area is also maintained at 0.5 and above, which ensures the accuracy of the research results.The study area is mainly underground well mining area, and the number of open-pit mining areas is rare. It is scattered in the south of Shangwan mining area, the northeast of Daliuta mining area and the east of Cuncaota mining area.The area observed by SBAS-InSAR technology is about 1436.07 km^2. Considering that the ground itself may undergo weak deformation, the area with land subsidence greater than -20 mm is identified as land subsidence area. On this basis, according to the monitoring situation of SBAS-InSAR, the subsidence is divided into five classification levels : ground surface uplift area, non-deformation area, mild subsidence area, moderate subsidence area and heavy subsidence area. The area with subsidence below -300 mm is heavy subsidence area, and the area with subsidence between -300 mm and -100 mm is moderate subsidence area. The area between -100mm ~ -20mm is a mild subsidence area, the -20mm ~ 20mm is undeformed area, and the area above 20mm is a ground uplift area, including the time changes of the area and its proportion of each subsidence magnitude, see Fig. 3 and Fig. 4.

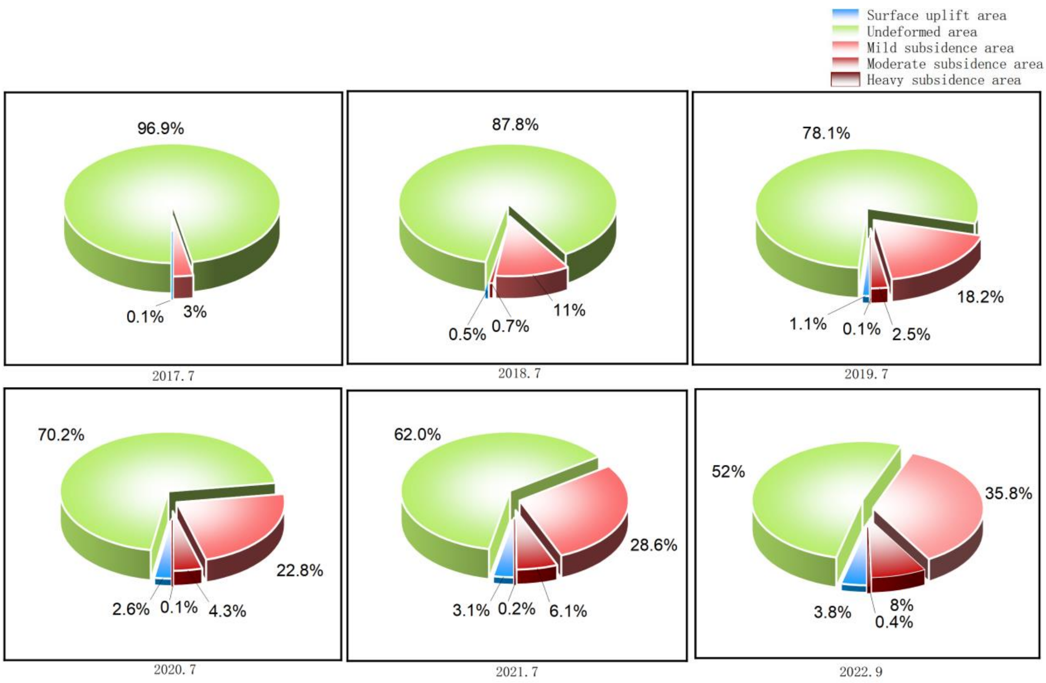

Fig. 3 Different surface deformation area ratio pie chart

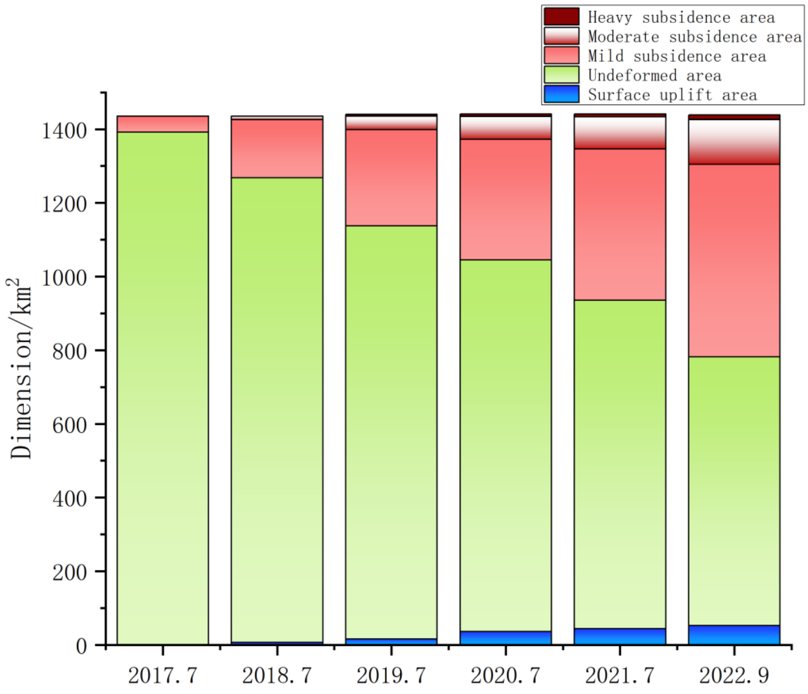

Fig. 4 Different surface deformation area ratio histogram

By the end of the observation period, the maximum cumulative subsidence of the ground in the study area was -761.47mm, the maximum subsidence rate of the ground was-133mm / a, and it was located in the Shangwan mining area.The study area generally shows a pattern of continuous decrease in the area of undeformed areas, continuous expansion of subsidence areas at all levels, especially moderate and mild subsidence areas, and slow increase in the area of surface uplift areas. The surface deformation of Shendong mining area is increasing year by year and the shape is complicated.The area of the surface undeformed area continues to decrease, which indicates that more areas of the mining area have undergone varying degrees of deformation over time.During the observation period, obvious land subsidence occurred in 11 mining areas such as Buertai in the study area. Among them, the land subsidence of Buertai, Shangwan and Shigetai was the most serious, and the heavy subsidence first appeared in 2019, that is, the third year of the observation period.The maximum subsidence point of the core subsidence area of the eleven mining areas in the study area was selected as the characteristic point, and the subsidence observation rate diagram of the cumulative subsidence with time was drawn. See Fig. 5, each characteristic point maintained the overall subsidence trend during the observation period. The cumulative subsidence of Shangwan, Buertai, Shigetai, Daliuta and Cuncaotayi reached - 300mm at the end of the observation period.

3.2. Spatial evolution characteristics of subsidence in Shendong mining area

In order to better understand the subsidence in the study area, this study screened the subsidence of the study area at six different times for display. The time series of land subsidence is shown in Fig. 6.From January 2017 to September 2022, obvious land subsidence occurred in 11 mining areas in the study area in five years and eight months. From the perspective of spatial distribution, the land subsidence in the mining area on the west side was more serious.From January 2017 to July 2018, the land subsidence in each mining area was relatively rapid in the past one and a half years. Compared with other mining areas, the land subsidence in the four mining areas of Buertai, Shangwan, Huojitu and Bulianta was the most rapid.From July 2018 to September 2022, the subsidence rate of Bulianta mining area slowed down significantly in these four mining areas. There are many obvious land subsidence areas in Buertai mining area

ISSN: 1813-4890

and Shangwan mining area, but after 2020, the rate of land subsidence in these two mining areas is obviously alleviated.The subsidence rate of Shigetai mining area and Daliuta mining area was relatively rapid before July 2021, but after that, the subsidence rate of these two mining areas was significantly alleviated, and many obvious land subsidence areas appeared in the mining area.During the observation period, there were also obvious subsidence in the Cuncaotayi, Cuncaotaer, Halagou, Liuta and Wulanmulun mining areas, but the scale and speed of subsidence were slower than other mining areas.

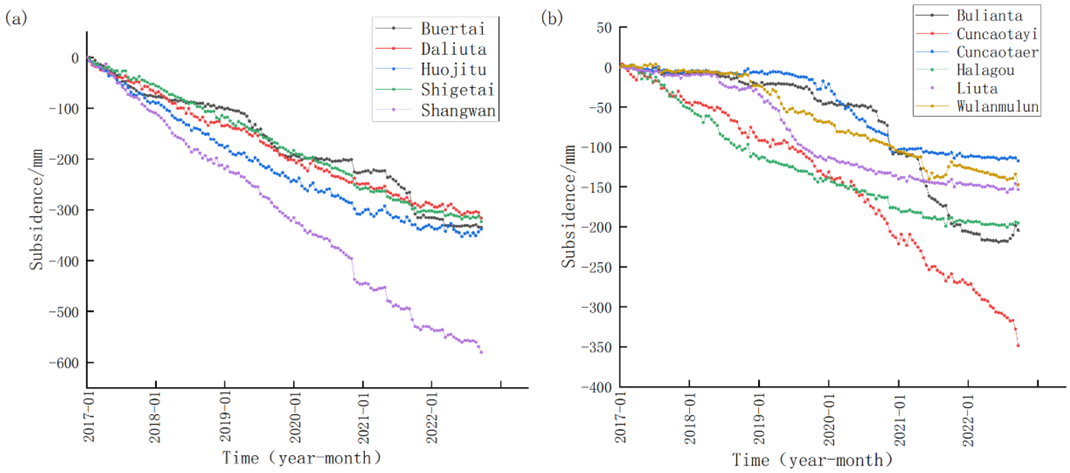

Fig. 5 Land subsidence rate map of feature points

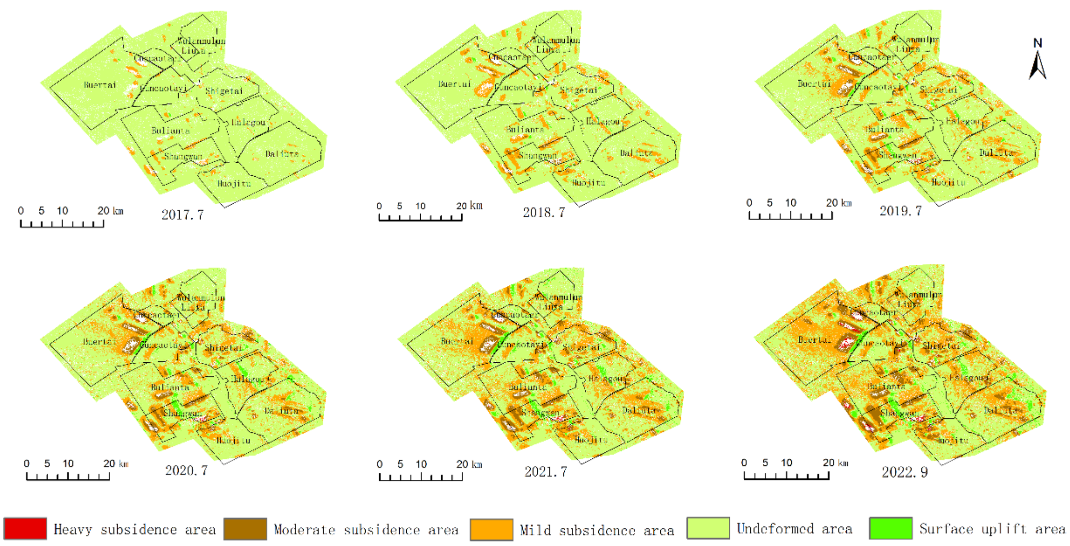

Fig. 6 Time series subsidence map of Shendong Mining area from January 2017 to September 2022

The heavy subsidence area first appeared in the Shangwan mining area in July 2019, two and a half years after the observation began. By September 2022, the Buertai mining area, Shangwan mining area, Shigetai mining area, Huojitu mining area and Daliuta mining area had obvious heavy subsidence.During the observation period, with the passage of time, the mild ground subsidence experienced the diffusion from point to surface, expanding from the center of each mining area to the edge of each mining area year by year. The moderate subsidence area first appeared in the Shangwan, Buertai and Bulianta mining areas in July 2018, a year and a half after the observation began, and then expanded over the next few years.During the observation period, the area of land subsidence in each mining area continued to expand, and the expansion direction of land subsidence in each mining area was roughly as shown in Fig. 7. The Buertai mining area with large subsidence area and serious subsidence generally subsided from northeast to southwest during the observation period ; the subsidence direction of Shangwan and Daliuta mining areas is roughly from southeast to northwest ; the subsidence direction of Shigetai mining area is roughly from southwest to northeast ; the subsidence direction of Huojitu mining area is roughly from northwest to southeast.

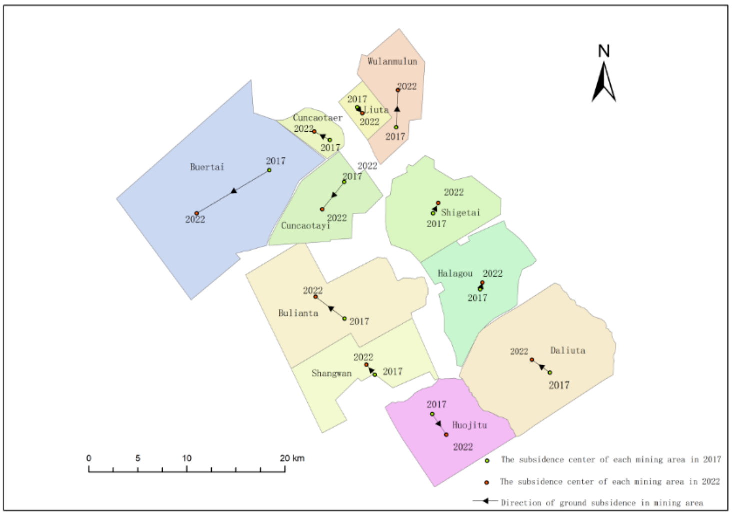

Fig. 7 Expansion direction of ground subsidence in each mining area

3.3. Spatio-temporal characteristics of heavy subsidence

In order to study the characteristics of time series subsidence in Shendong mining area, this study selected the Shigetai mining area, which is located in the east of Shendong mining area. The maximum annual average subsidence rate of the mining area is about - 56.20 mm / a, and the maximum cumulative subsidence is about - 489.46 mm. In order to further study the subsidence of Shigetai mining area, the cumulative subsidence profiles in a-b and c-d directions are drawn respectively, see Fig. 8 and Fig. 9.

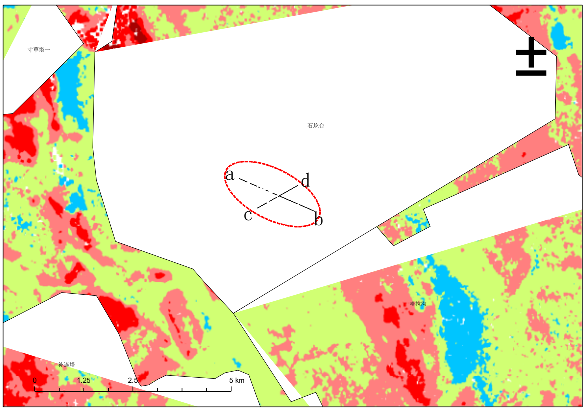

Fig. 8 Shigetai mining area subsidence profile

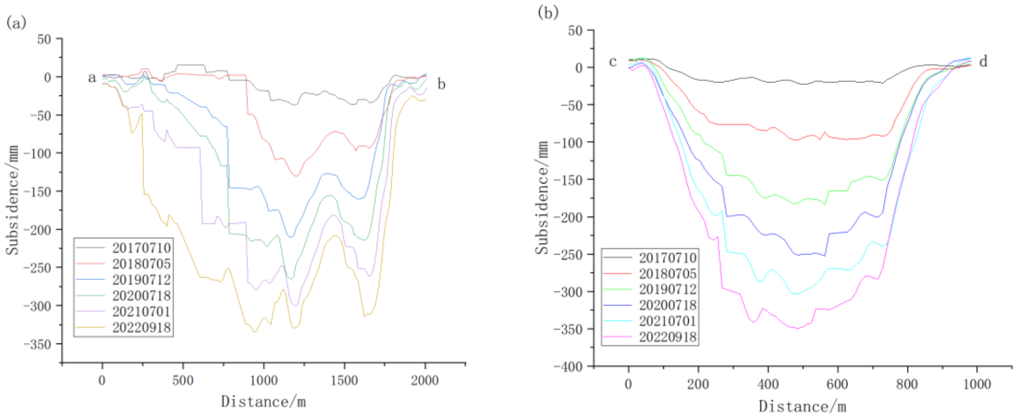

Fig. 9 Cumulative subsiding profile in a-b and c-d directions of Shigejtai

It can be seen from the above figure that an obvious subsidence funnel is formed in this area. The subsidence rate in the a-b direction first increases gradually. When the distance from point a is about 1000m, the peak value of the subsidence rate exceeds -60mm / a, and the cumulative subsidence amount is about - 350mm. The subsidence rate in the c-d direction first increases gradually and then decreases gradually. When the distance from the observation starting point c is about 500m, the peak value exceeds - 60mm / a, and the cumulative subsidence amount is about - 350mm.Although the subsidence funnel in this area continues to extend downward, the degree of extension is decreasing year by year.

4. Conclusion

By the end of the observation period, the maximum cumulative subsidence of the ground in the study area was - 761.47mm, and the maximum subsidence rate of the ground was - 133mm / a, and it was located in the Shangwan mining area. Until the end of the observation period, the area of land subsidence in the study area was about 653.61km^2, accounting for about 44.20 % of the total area of the study area. In terms of time, the heavy subsidence area and the moderate subsidence area continued to settle during the observation period. The heavy subsidence area first appeared in the Shangwan mining area two and a half years after the observation began, that is, in July 2019, until September 2022 at the end of the observation period. Obvious heavy subsidence occurred in Buertai mining area, Shangwan mining area, Shigetai mining area, Huojitu mining area and Daliuta mining area. From January 2017 to July 2018, the land subsidence in each mining area was relatively rapid. From the spatial point of view, the eleven mining areas have undergone different degrees of land subsidence. The heavy subsidence areas are concentrated in the Buertai mining area, the Shangwan mining area and the Shigetai mining area. The Buertai mining area subsidence from the northeast to the southwest during the observation period ; the subsidence direction of Shangwan and Daliuta mining areas is roughly from southeast to northwest ; the subsidence direction of Shigetai mining area is roughly from southwest to northeast ; the subsidence direction of the Huojitu mining area is roughly from the northwest to the southeast. The land subsidence in the mining area on the west side is more serious.

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