Dynamic Monitoring of Typical Geographic Mining Conditions of Yanzhou Coal Field Based on High-resolution Remote Sensing Images

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Abstract. In order to monitor geographic mining conditions timely and dynamically with high accuracy, this paper took relocation of villages with underground coal resources and farmland with seeper and subsidence as typical geographic mining conditions of Yanzhou coal field in China, extracted monitoring information and made corresponding statistical analysis based on the aerial image in 2009 and GF-2 satellite image in 2015, using object-oriented post-classification change detection method on ENVI software. The results show that from the year 2009 to 2015, Yanzhou Coal field totally moved 11 villages, with a total area of 2.53km$^2$, and the average plaque area was 0.23 km$^2$. The villages with deeper subsidence and perennial seeper had been reclaimed to pond and the area was approximately 0.09km$^2$, while those with shallow subsidence had been reclaimed to farmland and the area was approximately 1.81km$^2$. The total area of farmland with seeper and subsidence was basically unchanged and the area that hadn’t been reclaimed decreased 2.744km$^2$.

On the whole, the effects of the reclamation of Yanzhou coal field is remarkable, but there are still 0.63 km$^2$ village and 3.47km$^2$ farmland not yet reclaimed in Xinglongzhuang, Dongtan, Baodian coal mine. Local governments should develop appropriate reclamation plans to improve the efficiency of land use.

Introduction

Mining conditions are the basic situation and information of mining area or mining city, including mineral resource distribution, surface fluctuation, vegetation coverage, traffic and water system, geological disaster, urban expansion and the situation of economy, population, environment, etc. Geographic mining conditions are the study, description and analysis of mining conditions from the perspective of geography. It is a spatial and visual expression of mining conditions. Geographical mining conditions monitoring is to give full play to the "3S" (GNSS, RS, GIS) and other modern surveying and mapping technology to make analysis and expression of spatial, quantitative and dynamic characteristics of natural and human geography elements and their characteristic relationships in mining area or mining city, and finally form a mapping map, database, analysis report and other monitoring results which reflect the spatial characteristics and changes of factors such as mining resource exploitation, environmental change, economic development, urban expansion and so on. These monitoring results provide basic information services for the public and provide data support for rational exploitation of mineral resources and formulation of sustainable development plans for mining areas [1].

Since the China Geological Survey launched the project of "multi-objective remote sensing survey and monitoring of mineral resources" in 2006 [2], some scholars have used high-resolution remote sensing images to monitor geographic mining conditions [3-4]. The results show that the high-resolution remote sensing images are rich in texture and structure information, from which the information of geographic mining conditions elements can be extracted with high accuracy. Using high-resolution remote sensing images to monitor geographic mining conditions becomes a trend with their popularization. The surface subsidence of Yanzhou coal field is deep, damages of buildings in villages with underground coal resources are serious and farmland seeper is serious,
thus, it has the typical characteristic mining conditions of the high groundwater level mine area. Based on the high-resolution remote sensing images and GIS technology, along with the present situation map of land use, coal mining boundary map and survey data, this paper will take Yanzhou coal field as the research area to carry out dynamic monitoring on two typical geological conditions of the relocation of the villages with underground coal resources and farmland with subsidence and seep by object-oriented post-classification change detection method and human-computer interactive interpretation method to provide data support for the local government to grasp geographic mining conditions and promote land reclamation and scientific development in the mining area.

Overview of the Study Area

Yanzhou Coal field is located in the border zone of Yanzhou, Zoucheng and Qufu, Jining municipalities, Shandong Province. It covers an area about 440.4km². The terrain is plain and depressions. It is not only an important grain and cotton planting base in Southwest of Shandong Province, but also rich in coal resources. The coal seam is thick, and the quality is good.

As shown in Figure 1, the Yanzhou coal field consists of 6 coal mines, which are Xinglongzhuang coal mine, Dongtan coal mine, Yangcun coal mine, Baodian coal mine, Nantun coal mine and Beisu coal mine from north to south. The groundwater level is high, and the average depth is about 3-4m. The main forms of land destruction caused by coal mining are collapse and seep, and the residential area is dense. Therefore, the typical characteristics of coal mining in this area are the deep mining subsidence, the damage and relocation of the villages with underground coal resources, the serious seep of the collapsed farmland, and the high reclamation cost.

![Figure 1. Location map of Yanzhou coal field.](image)

**Extraction of Typical Geographical mining Conditions of Yanzhou Coalfield**

**Data Sources**

1. Remote sensing data: The aerial image of Yanzhou Coalfield on August 2009 which contains a total of 3 bands with a spatial resolution of 2.5 m; GF-2 satellite images of Yanzhou coalfield on March 2015 with the 1m spatial resolution of the panchromatic waveband and the four-band multi-spectrum. Its spatial resolution is 4m, and the image width is up to 45km. 2. Map data: The
information includes the distribution map of mineral resources in Jining in 2009, the mining subsidence map in Yanzhou coalfield in 2009, the current land use map in 2009 with the 1: 50,000 scale, mine distribution map and mining right boundary vector diagram. (3) Other supporting data: The information includes coal mining subsidence land reclamation program and population distribution, economic data, meteorology, hydrology and other data in Yanzhou coalfield.

Data Preprocessing

The data with different data format, scale and coordinate system were converted to Xi’an 80 coordinate system. The aerial images in 2009 and the GF-2 satellite images in 2015 were processed for spatial correction, mosaic, registration and fusion according to the land use map in 2009. Based on Yanzhou coal mining rights boundary vector diagram, GF-2 images and aerial image were clipped. And the remote sensing images after pretreatment are shown as follows:

![Figure 2. Aerial image of Yanzhou coal field in 2009(left), GF-2 image in 2015 (right).](image)

Information Extraction of Relocation of Villages with Underground Coal Resources

Coal mining caused surface subsidence and the original village houses appear tilt, cracks, subsidence and other different degree of damage, resulting in villagers unable to live in it and village relocation. The information extraction of the relocated village is obtained by the change detection method of remote sensing image. The images of different phases are superimposed and contrasted, and the features and processes of the change of geographical elements in a certain period are extracted quantitatively[5].

Firstly, the images in 2009 and 2015 are classified by using the post-classification comparison method of ENVI, and compared with each other in order to find out the changes of the land types. The precision of classification results directly influences the change detection accuracy. Then, the change of village residents’ residence in 2009 and 2015 are tested, and the results are checked one by one in 2009 and 2015 to ensure the accuracy of extraction, so as to extract the location, area and other information of the relocation of the villages, as shown in Figure 3,4.
Yanzhou coal field consists of 6 coal mines, which are Xinglongzhuang coal mine, Dongtan coal mine, Yangcun coal mine, Baodian coal mine, Nantun coal mine and Beisu coal mine from north to south. The area of subsided farmland with seeper is distributed on the surface of the coal mining face and the surrounding area. After the underground coal seam is mined, the upper strata and the covering soil lose the support of the original coal seam, breaking the original balance of force and re-adjustment under the effect of gravity and stress. The surface affected by the mining subsides down from the original elevation, when the subsidence is below the dive level, the atmospheric precipitation and surface water can not be discharged smoothly by the original drainage system and accumulate within the scope of the subsidence formed closed water\cite{6}. The water source of the subsidence area is mainly supplied by the shallow groundwater and the precipitation of the atmosphere. The area of the subsided water is related to the thickness of the coal seam and the level of the diving ground. The ratio of the maximum subsidence depth and embedded depth of groundwater level can be used to judge whether the subsidence area has seeper \cite{7}. According to the...
amount of ground subsidence and the depth of the water level, the seeper area can be divided into perennial shallow seeper area, perennial deep seeper area, seasonal seeper area [8].

Based on the classification results, combining with the survey data of subsidence area, land use status map and reclamation data of subsided land of Jining, the identification and extraction of the subsidence area of Yanzhou coal field is established by the interpretation sign of remote sensing image. Yanzhou coalfield is located in "Golden Triangle" (Yanzhou - Qufu - Zoucheng border) which is in the middle of Jining City. It is the main distribution area of subsided farmland with seeper in Jining city, and contains two main parts. One is the area that has not been reclaimed, the image is irregularly closed or semi-closed ring, elliptical, darker color; the other is the area that has been reclaimed, the contour edge of the image is a closed ring or strip, and the surface is smooth, as shown in Table 1:

<table>
<thead>
<tr>
<th>Type of subsidence area with seeper</th>
<th>Interpretation signs</th>
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<tr>
<td>Subsidence area that has been reclaimed</td>
<td>The color is deep, generally dark green or black, the contour line and the surrounding features have obvious gaps, the outline of the edge are independent closed or semi-closed rectangle or ring, smooth edge profile. It is close to industrial and mining land, settlements, roads, rivers and other objects.</td>
</tr>
<tr>
<td>Subsidence area that is not reclaimed</td>
<td>The color is deep, usually dark green or black. There is a clear gap between the contour and the surrounding objects. The edges of the contour are irregularly closed or semi-enclosed with separate rings or ellipses, with rough edges. It located in the vicinity of the village, large tracts of arable land, and far from roads, rivers and other linear objects.</td>
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After extracting the subsidence area, the images are loaded on ArcGIS 10.2 platform, and the information of farmland and water body in the land use status map provided by Jining Municipal Land and Resources Bureau is comprehensively superimposed and further analyzed to exclude the original water body to obtain distribution area of subsided farmland with seeper. There are overlapping areas of the water body in the collapsed water area and the land use status map, and the area containing the topological relation. Therefore, it is necessary to make field investigation to make clear whether the subsidence area is the water of the collapsed farmland or natural water area, eliminating water area of non-cultivated land [9]. The statistics of the spatial distribution and area of the farmland with seeper finally obtained were compared with the data from department of land resources to ensure the overall precision. The plot of farmland with seeper in 2009 and 2015 are shown in Figure 5.
Results Analysis

1) Analysis of the relocation of villages with underground coal resources.

The total area, quantity, average area, regional distribution and so on were further calculated by using the range coordinates and the center position coordinates to calculate the basic information such as the location and area of the relocated villages between 2009 and 2015. Through calculation, we can see that 11 villages with underground coal resources were moved with a total area of 2.53 km$^2$ and average patch area of 0.23 km$^2$. All coal mines except Beisu Coal Mine contain the relocated villages.

It can be seen from the image that after the relocation of the villages, the area with deeper subsidence and perennial water is reclaimed to pond, about 0.09 km$^2$, and the areas with shallow subsidence depth and the areas with seepage were reclaimed into cropland after relocation, about 1.81 km$^2$. There are still some villages have not been reclaimed after moving out, about 0.63 km$^2$.

2) Analysis of the subsided farmland with seepage in Yanzhou coal field.

The farmland with seepage in 2009-2015 is mainly distributed in the south of Xinglongzhuang Coal Mine, Baodian Coal Mine, Dongtan Coal Mine and Nantun Coal Mine. The distribution is relatively dense. Among them, the area of farmland with seepage in 2009 was 6.403 km$^2$, 5.106 km$^2$, 4.4480 km$^2$ and 3.724 km$^2$ respectively, accounting for 30%, 24%, 21% and 18% of the total seepage area. The area of the farmland with seepage in 2015 is 5.380 km$^2$, 4.589 km$^2$, 5.026 km$^2$ and 3.081 km$^2$ respectively, accounting for 26%, 28%, 24% and 15% of the total seepage area. There are less farmland with seepage distributed in Beishu coal mine and Yangcun coal mine, and the area of seepage water in 2009 is 0.939 km$^2$ and 0.472 km$^2$ respectively, accounting for 5% and 2% of the total seepage area, respectively. The area in 2015 is 0.863 km$^2$ and 0.562 km$^2$ respectively, accounting for 3% and 4% of the total seepage area.

Most of the farmland with seepage has been reclaimed. In 2009, the reclaimed area and the unreclaimed area accounted for 71% and 29% respectively, while it is 83% and 17% in 2015, and the proportion of the reclaimed area increased by 12%. The unreclaimed area of the seepage land in 2009 was 6.218 km$^2$, which was 2.744 km$^2$ higher than that of 2015. The spatial distribution of the area was mainly in Dongtan Coal Mine, Baodian Coal Mine, Xinglongzhuang Mine and Yangcun Coal Mine, which were 2.496 km$^2$, 2.466 km$^2$ and 0.812 Km$^2$ and 0.424 km$^2$ respectively. By 2015, the area of unreclaimed farmlands with seepage decreased obviously, which mainly distributed in Baodian, Dongtan and Xinglongzhuang mines and were 1.751 km$^2$, 1.002 km$^2$ and 0.721 km$^2$ respectively. The effective land reclamation measures are adopted, but there is still 3.47km$^2$ of farmland with seepage not reclaimed, and the local government should make corresponding reclamation measures to improve the land use efficiency.
Conclusions

Based on the high-resolution remote sensing image and GIS statistical analysis technology, the object-oriented post-classification change detection and human-computer interaction interpretation are used to monitor the typical geographic mining conditions of Yanzhou coal field, and the following conclusions are obtained:

(1) The effect of village relocation and reclamation of coal mining subsidence area with seep in Yanzhou coal field in 2009-2015 is significant, but there is still 0.63 km$^2$ land has not been reclaimed after the village relocation. In xinglongzhuang, Dongtan, Baodian coal mine, there is still 3.47 km$^2$ farmland with seep that has not been reclaimed. The local government should make the corresponding reclamation plan to improve land use efficiency.

(2) The post-classification change detection method based on high-resolution remote sensing images can monitor the geographic mining conditions in real time, and verify the data submitted by the mining enterprise to the land department to ensure the reliability.

Acknowledgments

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References


