Remote Sensing Dynamic Monitoring on the Land Destruction and Recovery of Green Mines

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Abstract. The construction of green mine is the only way to promote ecological civilization and realize the harmonious development of man and nature. This paper introduces the methods and steps of using remote sensing technology to carry out dynamic monitoring on green mines, and summarizes the main monitoring elements of green mine environment, and analyse the status quo and dynamic changes of land destruction and recovery of green mines according to the monitoring results. On the whole, the land recovery rate of green mines is low in China, and the level of land recovery is uneven in different regions, mines and minerals. The result shows a tendency that the land occupation of green mines has changed from the extension of the land destruction in the early stage to the recovery of the stock mining land. The main recovery modes of green mine include prevention engineering, ecological protection engineering, functional restoration and reconstruction, land reclamation, soil restoration and so on. It is necessary to strengthen the application of radar data to monitor mining subsidence area and the application of hyperspectral data to enhance the monitoring of mine recovery effect.

1. Introduction

Building an ecological civilization is a thousand-year plan for the sustainable development of the Chinese nation. At present, the society attaches great importance to the construction of ecological civilization, strives to practice the concept of "green water and green mountains are gold and silver mountains", and unswervingly promotes the development of green mining industry. "Green mine" refers to the mine that implements scientific and orderly mining in the whole process of mining, controls the disturbance of the ecological environment in the mining area and surrounding areas within a controllable range, realizes the ecological environment in the mining area, scientific mining method, efficient resource utilization, digitized management information and harmonious mining community [1].

At present, China has formed a green mine construction standard for coal, sand and gravel, petroleum, cement and limestone, metallurgy, nonferrous metals, gold, chemical industry, non-metal and other nine industries. The main standards for the construction and assessment of green mines include following aspects: mine operation according to law, standardized management, comprehensive utilization, technological innovation, energy conservation and emission reduction, environmental protection, land reclamation, community harmony, enterprise culture [2]. Many scholars have carried out fruitful research on green mine construction, which mainly includes three aspects. First, from the perspective of top-level design, the connotation, policies and systems in the process of green mine construction are studied, and the research methods are mainly qualitative [3-7]. Second, from the perspective of evaluation method, the research on evaluation index system and evaluation method of green mine construction is carried out, with a combination of qualitative and quantitative methods.
[8-10]. Thirdly, from the perspective of practical application, many typical mines are selected to evaluate the effect of green mine construction, which has empirical application value [11-12]. However, there is still a lack of rapid, macroscopic and effective monitoring technology for green mines, such as remote sensing dynamic monitoring technology, which is rarely mentioned in previous studies on green mines.

There are a large number of green mines in China. In order to grasp the construction effect and dynamic changes of green mines in real time, such as mine occupied land, mine environment restoration and management status and change information, dynamic monitoring research must be carried out by means of remote sensing. Remote sensing dynamic monitoring can provide scientific, reliable realistic basis for green mine selection and construction effect. Meanwhile, it can objectively reflect the current situation and changes of the green mining development environment in China, and provide the decision-making basis for promoting the scientific development of green mining, the construction and management of green mining.

2. Overview of Green Mines

By 2014, the ministry of natural resources had issued a list of 661 national green mine pilot units in four batches. There are 641 mines, regardless of oil and gas, radioactive mines, with a total area of about 1. 45 million hectares of mining rights, regional covers over 29 provinces, mineral involving energy, ferrous metals, non-ferrous metals, precious metals, rare earth dispersed element metal, metallurgical auxiliary materials, non-metal of chemical raw materials, building materials and other non-metallic minerals. The research object of this paper is the 641 green mines.

From the spatial perspective, the overall distribution of green mines in the eastern, central and western regions is relatively uniform, but there is a big difference between provinces. The green mines are mainly distributed in Shandong, Hebei, Hubei, Inner Mongolia, Shanxi, Henan and other provinces. In east and north China, there are 163 and 122 green mines, while in other areas, the number of green mines is less than 100. The green mines are mainly energy and metal, the mining method is mainly well work mining. The mineral types are mainly coal, iron and gold. From the perspective of regional distribution, the green mines in the eastern, central and western regions are evenly distributed.

3. Data Sources and Research Methods

3.1. Data Sources

According to the purpose of monitoring, the data sources needed for the monitoring of green mines mainly include three categories. One is the range and location information of all kinds of green mines, mainly including the mining rights information, which are provided by the information centre of the ministry of natural resources. The second is the high-resolution remote sensing data, which mainly includes the high-resolution remote sensing satellite data covering all green mines in 2016 and 2017. The data types include GF1, GF2, ZY3, 02C, BJ2, etc. The resolution of remote sensing image is mainly better than 2.5 meters. Remote sensing data are mainly domestic satellite data, and the main parameters are shown in table 1. Thirdly, in order to judge the mining status, affected objects and other mine environmental information as accurately as possible, auxiliary data such as DEM, administrative boundary, traffic road, residential area, river system and land use type should also be collected.
### Table 1. Main high-resolution domestic satellite parameters

| Satellite type | Parameter | P/MS camera | HR camera |
|---------------|-----------|-------------|-----------|
| ZY1-02C       | Spectral range | Panchromatic | 0.51 – 0.85 μm | Panchromatic | 0.50 – 0.80 μm |
|               |           | Multispectral | 0.52 – 0.59 μm | Multispectral | 0.63 – 0.69 μm |
|               |           |             | 0.77 – 0.89 μm |             |             |
|               | Spatial resolution | Panchromatic | 5 m | Panchromatic | 2.36 m |
|               |           | Multispectral | 10 m | Multispectral |             |
|               | Width     |             | 60 km |             | 54 km (2 cameras) |
|               | Revisit period |             | 3 days |             | 3 days |
| ZY3           | Spectral range | Panchromatic | 0.50 – 0.80 μm | Panchromatic | 0.50 – 0.80 μm |
|               |           | Multispectral | 0.45 – 0.52 μm | Multispectral | 0.52 – 0.59 μm |
|               |           |             | 0.63 – 0.69 μm |             | 0.63 – 0.69 μm |
|               |           |             | 0.77 – 0.89 μm |             | 0.77 – 0.89 μm |
|               | Spatial resolution | Metachromatic panchromatic: 2.1 m | Front and rear 22° panchromatic: 3.5 m | Metachromatic panchromatic: 2.1 m | Front and rear 22° panchromatic: 2.5 m |
|               |           | Elevation multispectral: 5.8 m | Elevation multispectral: 5.8 m | Elevation multispectral: 5.8 m | Elevation multispectral: 5.8 m |
|               | Width     | Front panchromatic: 50 km, single view 2500 km | Front panchromatic: 50 km, single view 2500 km | Elevation multispectral: 52 km, single view 2704 km | Elevation multispectral: 52 km, single view 2704 km |
|               | Revisit period | 5 days | 5 days | 5 days | 5 days |
| GF1           | Spectral range | Panchromatic | 0.45 – 0.52 μm | Panchromatic | 0.45 – 0.52 μm |
|               |           | Multispectral | 0.52 – 0.59 μm | Multispectral | 0.52 – 0.59 μm |
|               |           |             | 0.63 – 0.69 μm |             | 0.63 – 0.69 μm |
|               |           |             | 0.77 – 0.89 μm |             | 0.77 – 0.89 μm |
|               | Spatial resolution | Panchromatic | 2 m | Panchromatic |             |
|               |           | Multispectral | 8 m | Multispectral | 16 m |
|               | Width     | 60 km (2 cameras) | 800 km (4 cameras) |             |             |
|               | Revisit period (when swinging) | 4 days |             |             |             |
| GF2           | Spectral range | Panchromatic | 0.45 – 0.52 μm | Panchromatic | 0.45 – 0.52 μm |
|               |           | Multispectral | 0.52 – 0.59 μm | Multispectral | 0.63 – 0.69 μm |
|               |           |             | 0.77 – 0.89 μm |             |             |
|               | Spatial resolution | Panchromatic | 0.8 m |             |             |
|               |           | Multispectral | 3.2 m |             |             |
|               | Width     | 45 km (2 cameras) |             |             |             |
|               | Revisit period (when swinging) | 5 days |             |             |             |
3.2. Monitoring Elements of Green Mines
The monitoring elements of green mine are all mine environmental elements related to mining. Specifically, the monitoring elements of green mines are mainly divided into stope, transfer site, solid waste, mine construction, collapsed land, contaminated land, and mine recovery. At the same time, it is necessary to analyse the main body of mine economy and mining types. Generally speaking, the area information which is reflected by remote sensing image can be obtained easily. The technical index system of remote sensing monitoring of green mines, including the acquisition ways, monitoring period and monitoring scale of all factors, is shown in table 2.

| Primary factors          | Secondary factors | Monitoring period | Monitoring scale | Access to data                  |
|-------------------------|-------------------|------------------|-----------------|---------------------------------|
| Land occupation         | Economic entity of mine |                 |                 | Mine right                      |
|                         | Minerals          |                  |                 | Mining rights                   |
|                         | Occupied area     |                  |                 | RS                              |
|                         | Previous land type|                  |                 | Land use classification         |
|                         | Subsequent land type|                |                 | RS                              |
| Land damage             | Economic entity of mine |                 |                 | Mining rights                   |
|                         | Minerals          |                  |                 | Mining rights                   |
|                         | Damaged area      |                  |                 | RS                              |
|                         | Previous land type|                  |                 | Land use classification         |
|                         | Subsequent land type|               |                 | RS                              |
| Mine geological hazard  | Subsidence        | Once a year      | The scale is from 1:100,000 to 1:50,000 | RS                              |
|                         | Ground fissure    |                  |                 |                                 |
|                         | Collapse          |                  |                 |                                 |
|                         | The landslide     |                  |                 |                                 |
|                         | Debris flow       |                  |                 |                                 |
| Mine pollution          | Water pollution   |                  |                 |                                 |
|                         | Mine dust pollution|               |                 |                                 |
|                         | Soil pollution    |                  |                 |                                 |
| Mine recovery           | Name of mining enterprise |              |                 |                                 |
|                         | Previous land type|                  |                 |                                 |
|                         | Subsequent land type|              |                 |                                 |
|                         | Recovery area     |                  |                 |                                 |
|                         | Recovery effect   |                  |                 |                                 |

3.3. Research Methods
The technical route combines remote sensing data with multi-source data, computer information extraction with human-computer interactive interpretation, and indoor comprehensive research with field investigation. It is necessary to select remote sensing data reasonably. During the data processing, image correction, colour spatial transformation, image enhancement, data fusion, information comprehensive analysis and other methods are needed to extract environmental information of green mines. Through comprehensive analysis and field inspection, the accuracy of information extraction in green mine is further improved. It mainly includes the following five steps:
3.3.1. Basic data collection. The basic information to be collected includes green mine data, geological data, high-precision DEM, mining rights, residential area, main lines of traffic, river system, land use and other data.

3.3.2. Data reception and processing. It is necessary to obtain high-resolution remote sensing satellite images in 2016 and 2017. The data sources are mainly domestic high-resolution data, supplemented by foreign imported data. The areas without satellite data coverage may be supplemented by UAV data. Based on the existing control points or the corrected remote sensing data and combining with high-precision DEM data, the received remote sensing data are subject to panchromatic and multi-spectral image registration, orthographic correction, data fusion, image Mosaic, image cutting, etc.

3.3.3. Information extraction. The GIS software, such as ArcGIS is used as the platform to extract ground feature information of green mine. Through the superposition of historical vector data, based on the remote sensing images and auxiliary data in 2016 and 2017, the man-machine interaction information was further extracted and assigned attributes to complete the monitoring work of each green mine. The key factors of green mine information extraction include: mining damage land, occupation land, mine geological disaster, mine environmental pollution, mine restoration and control, etc. Typical remote sensing image features of the mining environment of green mines are shown in figure 1.

![Figure 1. Remote sensing characteristics of green mine environmental factors](image)
3.3.4. **Field validation and data post-processing.** Field verification is needed for the map spot in question, especially for the mine recovery area, geological disaster point. Field record forms and record cards must be filled out at each survey site. The purpose of field verification is to supplement the missing information and modify the wrong information. Finally, according to the monitoring results, the land occupied and damaged in each green mine are analyzed.

3.3.5. **Results data production and statistical analysis.** Mining rights, geographical names, interpretation vectors, administrative boundaries, and statistical tables are superimposed on the latest high-resolution remote sensing images to form a map of mine remote sensing monitoring results. Due to the large number of mining rights and the large workload of statistics and mapping, we have also developed software for automatic statistics and mapping of mine environmental information. After the investigation results are normalized and sorted out and the quality is inspected, the status of the damaged land, the occupied land and the recovery of the green mine is analyzed by comparing with the construction and evaluation standards of the green mine.

4. **Results**

4.1. **Status of Land Damaged by Green Mines**

The main ways of occupying and destroying the land in green mines mainly include stope, transfer site, solid waste, mine building and collapse pit. By 2017, the total damaged land area of green mines was 209,931.94 hectares, accounting for 14.48% of the mining right area. Among them, the area and proportion of damaged land in various mines including stope, transfer site, solid waste, mine construction and collapse pit are shown in Table 3.

| Type of land destruction | 2016                  | 2017                   |
|--------------------------|-----------------------|------------------------|
|                          | Destruction land (ha) | The proportion         | Destruction land (ha) | The proportion         |
| Stope                    | 125446.45             | 60.15%                 | 126214.23             | 60.12%                 |
| Transit site             | 30258.91              | 14.51%                 | 30471.15              | 14.51%                 |
| Solid waste              | 35547.88              | 17.04%                 | 34840.98              | 16.60%                 |
| Mine construction        | 7132.90               | 3.42%                  | 7283.12               | 3.47%                  |
| Collapse pit             | 10170.00              | 4.88%                  | 11122.46              | 5.30%                  |
| Total                    | 208556.15             | 100%                   | 209931.95             | 100%                   |

From the perspective of regional distribution, green mines in Qinghai, Inner Mongolia, Anhui, Liaoning, Shanxi, Heilongjiang, Yunnan, Hebei occupied more than 5,000 hectares of land, accounting for about 76.60% of the total land damaged by mines. In terms of the land area occupied by various minerals, energy minerals, metal minerals and non-metal minerals accounted for 23.33%, 27.39% and 49.8% of the damaged land area respectively, among which non-metal minerals accounted for the majority. Potash, coal, iron ore, lithium, copper, gold, phosphate, molybdenum, tin, lake salt and other minerals occupied land area in the top ten of all minerals.

4.2. **Dynamic Change of Land Damaged by Green Mines**

From 2016 to 2017, the area of damaged land in green mines increased by 1,375 hectares, an increase of 0.66% compared with the same period last year. In all kinds of damaged land, the area of stope, transfer site, mine construction and collapse pit all increased, while the solid waste decreased. Compared with 2016, the proportion of stope and solid waste in the total damaged land was slightly reduced. However, the proportion of transfer site, mine construction and collapse pit in the total surface of damaged land all increased slightly.
From the perspective of regional distribution, Qinghai, Anhui, Henan, Jiangxi and Hubei are the top five provinces in terms of land area occupied by mines, while Shanxi, Yunnan, Ningxia, Liaoning and Sichuan have a large decrease in land area occupied by mines. From the growth rate of land occupation, the growth rate of land occupied by mines in Anhui, Chongqing, Henan, Hubei and Jiangxi was higher, reaching 9.80%, 9.66%, 8.57%, 7.39% and 5.45%, respectively.

The land area occupied by potash, bauxite, copper and gold mines increased by 3,282 hectares, 326 hectares, 245 hectares and 233 hectares respectively. The land area occupied by coal, phosphate and iron ore mines decreased by 1955 hectares, 448 hectares and 286 hectares respectively. From the perspective of growth range, the land loss occupied by calcite, bauxite, germanium, talc and diamond mines increased significantly, while the land loss occupied by limestone, barite, phosphate and fluorite mines for construction stone decreased significantly.

4.3. Status Quo of Green Mine Recovery

By 2017, the area of green mines had been restored to 41,800 hectares, with an overall recovery rate of 16.60% and a net increase of 7,501 hectares, over that of 2016. Among them, the energy mine restoration area is the largest, and the green mine recovery area of all kinds of minerals is shown in figure 2. Among all the mines, coal, iron ore, phosphate and copper mines occupy the top four in terms of recovery area, all exceeding 1,000 hectares, accounting for 92.20% of the total area of green mines.

![Figure 2. Statistics of land recovery of various minerals of green mine](image-url)

Between the 641 green mines, 348, or 54.2%, were found to have carried out environmental recovery, an increase of 35% or 11.18% over 2016. From 2016 to 2017, 293 green mines, accounting for 45.71% of the total, were not detected in the recovery project sites. Among the mines where mine recovery projects have been carried out, there are six mines with a total area of more than 1,000 hectares, all of which are coal mines, with a total area of 12,600 hectares, accounting for 30.21% of the total area of green mines. From the point of view of the recovery rate, the recovery level of different mines is quite different, and the vast majority of green mines need to be strengthened.

In the mines that have been restored and treated, the recovery rate of green mines with mudstone, kaolin, andesite for construction, limestone for construction stone, coal, bauxite, antimony, diamond, limestone and phosphate ore are higher, all above 30%.
4.4. Dynamic Changes of Green Mine Recovery

From 2016 to 2017, an additional 7,501 hectares of green mines were restored, accounting for 84.50% of the total area of new mines. Green mining history is long, and it is given priority to underground mining. In addition to the mining cave-in, other kinds of mines occupy less inter annual change. At present, the change of mine occupation has changed from the extension expansion in the early stage of mine development to the restoration and renovation of the stock mining land, and this will be an important land use change trend of green mines in the future. From the perspective of geographical distribution, the change amount of newly restored green mines in Shanxi, Yunnan, Anhui, Ningxia, Inner Mongolia, Shandong, Liaoning, Sichuan, Guangxi and Xinjiang ranks the first in China, accounting for 87.68% of the total newly restored green mines. The status quo and changes of the newly restored green mines in all provinces are shown in table 4.

| Provinces          | Recovery area (ha) | Change values from 2016 to 2017 (ha) |
|--------------------|--------------------|--------------------------------------|
|                    | 2016               | 2017                                |                                |
| Shanxi             | 3116.43            | 5132.17                             | 2015.74                        |
| Yunnan             | 1213.05            | 2291.58                             | 1078.53                        |
| Anhui              | 2646.71            | 3694.20                             | 1047.49                        |
| Ningxia            | 24.86              | 809.86                              | 785.00                         |
| Inner Mongolia     | 4938.67            | 5546.98                             | 608.31                         |
| Shandong           | 9487.07            | 9764.07                             | 277.00                         |
| Liaoning           | 3343.65            | 3594.28                             | 250.63                         |
| Sichuan            | 142.06             | 383.51                              | 241.45                         |
| Guangxi            | 568.47             | 731.00                              | 162.53                         |
| Xinjiang           | 139.66             | 249.85                              | 110.19                         |
| Henan              | 286.61             | 387.52                              | 100.91                         |
| Shaanxi            | 1001.16            | 1098.29                             | 97.13                          |
| Hunan              | 130.65             | 224.37                              | 93.72                          |
| Guizhou            | 87.42              | 172.32                              | 84.90                          |
| Fujian             | 328.41             | 402.04                              | 73.63                          |
| Jiangxi            | 228.31             | 295.71                              | 67.40                          |
| Hebei              | 2674.43            | 2740.56                             | 66.13                          |
| Hubei              | 257.49             | 322.77                              | 65.28                          |
| Beijing            | 245.16             | 306.88                              | 61.72                          |
| Jiangsu            | 1225.10            | 1285.10                             | 60.00                          |
| Gansu              | 1134.41            | 1179.50                             | 45.09                          |
| Zhejiang           | 221.34             | 259.20                              | 37.86                          |
| Guangdong          | 158.67             | 188.19                              | 29.52                          |
| Hainan             | 269.94             | 296.53                              | 26.59                          |
| Heilongjiang       | 98.84              | 113.29                              | 14.45                          |
| Chongqing          | 183.50             | 183.50                              | 0.00                           |
| Qinghai            | 113.21             | 113.21                              | 0.00                           |
| Ji Lin             | 19.06              | 19.06                               | 0.00                           |
| Tibet              | 0.00               | 0.00                                | 0.00                           |
4.5. Land Recovery Mode of Green Mines

At present, the land recovery of green mines mainly focuses on solid wastes and collapse pits, and the land types after restoration and treatment are mainly forest land, grassland, cultivated land and water surface of pits. In 2017, 1,792 projects of green mines were monitored and rehabilitated, 562 more than in 2016, with a total area of 41,800 hectares. Before green mine restoration, the mine covers an area of stope, coal heap, ore heap, coal preparation plant, ore dressing plant, ore dressing pond, drainage yard, tailings pond, coal gangue heap, waste rock heap, surface earth heap, mine building and collapse pit. The recovery and treatment area of solid waste mainly includes the earth dump, tailings pond, surface mound and waste rock heap, accounting for 41.32% of the total area. The second is the collapse pit, the restoration control area accounted for 37.80%.

According to the monitoring results in 2017, green mine recovery mode include prevention engineering, ecological protection engineering, control engineering, repairing function reconstruction and land reclamation, water, soil, rehabilitation, the tailings after green, built mine park, use of land for public facilities, use of land for housing, the use of land for industrial and mining warehouse, use the water for pits, build a road, covering the dust network, to carry out the geological disaster management, implementing joint recovery management, river and flood recovery, natural green, etc., as shown in figure 3. The land use types after restoration mainly include forest land, grassland, arable land, water area and water conservancy facilities, accounting for 26.47%, 22.09%, 15.24% and 15.15% of the total restoration area respectively.

![Figure 3. Land use type statistics after mine recovery](image)

The restoration and treatment of green mines involves 40 kinds of minerals. Among them, coal, iron ore, phosphate ore mine restoration and treatment area is relatively large, more than 1000 hectares. The restoration and treatment of coal mine mainly refers to the backfilling of collapse pits caused by underground mining, or the restoration and treatment of the water surface of pit breeding and the regreening of the drainage site, etc. The recovery of iron ore and phosphate mine mainly refers to the restoration and treatment of the drainage site, tailings pond and waste rock pile.
5. Conclusions

Based on the analysis above, the following conclusions can be drawn:

The distribution of green mines in China varies greatly among provinces, the types of mines are mainly energy and metal, and the minerals are mainly coal, iron and gold. The mining methods are mainly well work mining. The main ways of occupancy of green mines include stope, transfer site, solid waste, mine construction, subsidence area and mine restoration. At present, the changes of land use in green mine has been transformed from the extensive expansion of damaged land in the early stage of mine development to the recovery of the stock mining land, which will be an important trend of the land change of green mine in the future. It is necessary to continue to strengthen the recovery of the land damaged by the existing mines and control the scale of land used by such mines.

At present, the main ways to restore and control green mines are prevention engineering, ecological protection engineering, treatment engineering, functional restoration and reconstruction, land reclamation, soil restoration, etc. On the whole, the recovery rate of green mines in China is relatively low, and there are still a large number of green mines that have not been restored. Moreover, the recovery area of new mines increases greatly, and the environmental recovery level of mines is uneven in different regions, mines and minerals. It is necessary to further clarify the responsibility of land recovery in green mine and strictly supervise the implementation of the green mine restoration plan. It is suggested to improve the relevant governance and acceptance standards, and carry out targeted restoration and land use function replacement based on actual situation.

It is suggested that the areas with low recovery rate should speed up the implementation progress of green mine rehabilitation and governance projects, strengthen the communication and exchange among various regions and types of green mining enterprises and learn from each other, draw on the construction experience and recovery experience of advanced and typical green mines. It is necessary to increase the measures of engineering restoration, and to monitor the recovery area and the effect of land recovery for a long time, so as to prevent the destruction of the controlled area again.

The underground mining activities of green mines need to be supervised, so as to prevent the serious hidden danger of mining cave-in, and control the goaf which has become stable as soon as possible. The mine enterprises should promote the green mining development mode of "developing while governing" and follow the sustainable development path of mineral exploitation and ecological protection. Meanwhile, it is vital to try to use radar satellite data to carry out the hidden danger investigation of the ground subsidence and other geological disasters of green mines, and use hyperspectral satellite data to carry out the monitoring of the recovery effect of green mines, so as to provide technical support for the evaluation of the recovery effect in the later period.

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