Article

Application of Domestic High-Resolution Satellite Data in Remote Sensing Geological Survey of the Metallogenic Belt in Zhejiang Province

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Abstract: A metallogenic belt is a metallogenic geological unit with rich mineral resources and potential. The study of metallogenic belts can provide a basis for mineral monitoring and deployment. Research of the metallogenic belt in Zhejiang Province is too deficient. This paper uses the domestic high-resolution satellite data from 2018 to 2021 to carry out the application of remote sensing in a comprehensive geological survey on different metallogenic belts in Zhejiang Province. The survey results show that the area of each metallogenic belt is decreasing year by year, which shows that under the regulation of the natural resources department, the unqualified mining activities in key control areas such as nature reserves, ecological red lines, and the Yangtze River economic belt are timely stopped and forcibly closed, so that the mining development order gradually tends to be good. The restoration and control points show a trend of less in the south and more in the north, mainly distributed in the economically developed areas of the northern, central, and eastern plains of Zhejiang Province. According to the statistics of the degree of mine environment restoration and treatment (treatment percentage), the Taishun-Zhoushan metallogenic belt is the highest, and treatment percentage from 2018 to 2021 is 83.01%, 80.07%, 76.91%, and 73.78%, respectively. For four consecutive years, the number of restoration and treatment projects has been increasing, and the restoration and treatment area has increased significantly. The countermeasures and suggestions for mine environmental restoration in the metallogenic belt have been put forward. In the mining area, if the geological environment is good, the rainfall is sufficient, and so on, then natural re greening can be considered. According to the brief evaluation criteria, a total of 2983 mines can be restored naturally, including 311 in the Si’an-Changxing metallogenic belt, 325 in the Lin’an-Huzhou metallogenic belt, 387 in the Kaihua-Hangzhou metallogenic belt, 598 in the Quzhou-Shaoxing metallogenic belt, 765 in the Longquan-Shangyu metallogenic belt, and 597 in the Taishun-Zhoushan metallogenic belt. A total of 1911 mines were involved within 1 km of the “three zones and two lines”. There are 50 places in the Si’an-Changxing metallogenic belt, 151 in the Lin’an-Huzhou metallogenic belt, 236 in the Kaihua-Hangzhou metallogenic belt, 326 in the Quzhou-Shaoxing metallogenic belt, 513 in the Longquan-Shangyu metallogenic belt, and 635 in the Taishun-Zhoushan metallogenic belt. The survey results and suggestions can provide scientific basis and important reference for the local mining administration department to carry out the restoration of the mine ecological environment in metallogenic belts, and they are of great significance to promote the wide and in-depth application and technological progress of remote sensing technology.

Keywords: domestic high-resolution satellite; remote sensing monitoring; mine geological environment

1. Introduction

Remote sensing is currently widely used in various applications for agriculture, forestry, geology, ocean, meteorology, hydrology, military, and environmental protection. In recent years, with the rapid development of China’s aerospace technology and satellite technology, the satellite remote sensing data independently launched by China have
been more and more favored by users from all walks of life because of their high spatial resolution, wide coverage, and short data acquisition cycle [1–6]. At present, China has independently developed more than a dozen earth observation satellites. Among them, the satellites in orbit and widely used in the geological field mainly include GaoFen-1, GaoFen-2, ZiYuan-3, CBERS-02C, and other satellites. Domestic high resolution satellite data provide strong support for all-weather mine monitoring [7–17]. Li Haiying [18] took the data of the CBERS-02C satellite as the main information extraction source to conduct a remote sensing survey of environmental geology in the Gaoping area of Shanxi Province. The survey results showed that the application of remote sensing can improve the predictability of environmental geological surveys in the study area and guide environmental geological mapping. It is an important means of environmental geological surveys. Wang Longlei [19] systematically established the method system of domestic satellite data in geological disaster information extraction by taking the data of the ZiYuan-3 and the GaoFen-1 satellite as an example. Mei Junjun [20] delineated the boundary, distribution direction, and influence area of the ground collapse in the Tiechanggou coal mine area in Xinjiang by using satellite data such as GaoFen-1 and GaoFen-2. The research results showed that domestic satellites can effectively ensure the accurate remote sensing identification of large and medium-sized ground collapses in the mining area. Deng Shasha [21] carried out a mine environmental investigation and evaluation in Heilongjiang Province, based on satellite data such as ZiYuan-3, so as to provide objective basic data and a decision-making basis for the sustainable development and utilization of mines and the comprehensive improvement of the mining area environment. Fu Yeping [22] carried out environmental information extraction and change monitoring of a mine tailings pond reservoir area in Western Sichuan by using multi-stage domestic high-resolution images. The results showed that domestic high-resolution data can be applied to obtain environmental change monitoring information data of the mine tailings pond reservoir area.

On the basis of predecessors, this paper carried out a comprehensive interpretation of remote sensing about mines from 2018 to 2021 (All years herein refer to the monitoring year), taking domestic high-resolution satellite images as the data source and combining with the distribution of metallogenic belts in Zhejiang Province. Then, we carried out a field investigation to verify the accuracy of the results. The comprehensive analysis of remote sensing geology provides a basis for the planning and deployment of subsequent regional geological and mineral survey projects and the ecological restoration evaluation of mineral resources.

2. Regional Overview

According to the latest research results of its metallogenic geological background, Zhejiang Province is divided into grade I, grade II, grade III, and grade IV metallogenic belts. The grade I metallogenic type belongs to the coastal Pacific metallogenic domain, which is a superimposed metallogenic domain; that is, it is superimposed on the paleo Asian metallogenic domain. According to the tectonic setting of Zhejiang Province, the grade II metallogenic zone is bounded by the Jiangshan-Shaoxing amalgamation zone. The northwest part belongs to the lower Yangtze metallogenic province, and the southeast part belongs to the South China metallogenic province. The grade III metallogenic belt is divided according to the boundary of the secondary structural unit. The Huzhou-Suzhou fault in Northwest Zhejiang and the Lishui-Yuyao fault in southeast Zhejiang are divided into four grade III metallogenic belts, respectively. The grade IV metallogenic zone is further divided according to the secondary fault. The northwest of Zhejiang Province is divided into four grade IV metallogenic sub zones bounded by the Huzhou-Suzhou fault, Changhua-Hangzhou-Wuzhen fault (i.e., the western section of the Changhua Putuo fault zone and the northern section of the Majin-Wuzhen fault zone), and the Quichuan-Xiaoshan fault. The range of the grade IV metallogenic sub belt in southeast Zhejiang is consistent with that of a grade III metallogenic area [23,24]. (Table 1, Figure 1).
### Table 1. List of metallogenic zones in Zhejiang Province.

| I | II | III |
|---|---|---|
| | | Littoral Pacific metallogenic domain |
| | | II-1 Sub-province of Lower Yangtze mineralization |
| I | II | III |
| III-1 | Yangtze Plain Cu–Au–Fe–Pb–Zn (Sr–W–Mo–Sb)–s–gypsum metallogenic belt | III-1-① Si’an-Changxing boron–bentonite–Pb–Zn–Au–Ag–Fe metallogenic subzone |
| II-2 | South China metallogenic province |
| | III-2 | Cu–Pb–Zn–Ag–Au–W–Sn–Nb–Ta–Mn–sepiolite–fluorite–wollastonite metallogenic belt in the north of the eastern Qinhang formation |
| | III-2-① Lin’an-Huzhou W–Mo–Sb–Fe–fluorite–bentonite–pyrophyllite–barite–pyrite metallogenic subzone |
| | III-2-② Kailua-Hangzhou Fe–Cu–Pb–Zn–W–Sn–Mo–Ag–fluorite–phosphate–pyrite–bentonite metallogenic subzone |
| | III-2-③ Quzhou-Shaoxing Fe–Cu–Au–pyrite–phosphate–fluorite–alunite metallogenic subzone |
| | III-3 | Pb–Zn–Cu–Au–Ag–W–Sn–Nb–Ta–pyrophyllite–alunite–fluorite metallogenic belt on the coast of Fujian and Guangdong, Zhejiang |
| | III-3-① Shangyu-Longquan Au–Ag–Cu–Pb–Zn–W–Sn–Mo–Fe–Rare earth–fluorite–pyrophyllite–pyrite–diatomite–bentonite metallogenic subzone |
| | III-4 | The middle Zhejiang–Wuyi uplift, w-Sn –Fo–Mo–Au–Ag–Fo–Pb–Zn–Nb–Ta (pyrophyllite)–fluorite metallogenic belt |
| III-4-① Taishun-Zhoushan Au–Ag–Cu–Pb–Zn–Mo–Sn–Fe–fluorite–pyrophyllite–alunite–pyrite metallogenic subzone |

**Figure 1.** Map of the metallogenic belt division in Zhejiang Province.

### 3. Research Methods

This paper adopted high resolution satellite data and carried out geometric correction, data fusion, and other processing [25,26] supplemented by other data for computer automatic extraction or human–computer interactive interpretation to obtain special information. On this basis, we carried out a mine geological environment development trend analysis, comprehensive research, and an evaluation [27] (Figure 2).
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3.1. Remote Sensing Data Source

This research lasted four years, from 2018 to 2021. Every year, we used high-resolution satellite data of that year, including 1200 image scene data from GaoFen-1, GaoFen-2, ZiYuan-3, CBERS-02C, BeiJing-2, GaoJing-1, and YaoGan-8, as the remote sensing information source. They were mainly composed of images with a resolution of 1 m, and the rest were composed of images with a resolution of 2 m and 0.5 m.

3.2. Remote Sensing Data Processing

In order to ensure the accuracy and comparability of satellite data and information extraction results in these four years, we preprocessed the remote sensing image data.

3.2.1. Orthophoto Correction

High resolution domestic satellites were equipped with rational function model (RFM) coefficients, which have a high positioning accuracy. The RFM was selected for the correction of domestic satellite remote sensing images, which is also the most commonly used technology in remote sensing applications [28].

Gauss Kruger 6-degree zone projection was used for the orthophoto correction based on a topographic map and DEM data. In the correction process, 25 control points were selected, with the distribution of control points as uniform as possible, and the control points were appropriately added in areas with large topographic relief. The result error was less than 1 pixel, which met the accuracy requirements of remote sensing investigation and monitoring of ore mining [29] in metallogenic belts. The distribution of calibration points and check points of one scene image is shown in Figure 3.

Figure 2. Technical flow chart.
Figure 3. Distribution of calibration points (left) and check points (right).

3.2.2. Data Band Selection and Fusion

Satellite data fusion is a multi-level and multi-faceted process of processing multiple sensor data. The objective is to detect, combine, analyze, estimate, and combine the data, then gather the advantages of different data sources as much as possible. In this way, characteristics of the data can be fully used [30]. It can also enhance target features and improve spatial resolution and classification accuracy, so that we can better carry out dynamic analysis and change monitoring.

A histogram can intuitively display the distribution state of quality characteristics and can be clear about the shape, center position, and dispersion degree of data distribution. This paper adopted the synthesis of “red (R), green (G), and blue (B)”, adjusted the histogram of the image through the color scale tool, which can increase the contrast between the light and shade of the image, made it close to the natural color, and had richer layers and uniform tones. Therefore, it was more conducive to the identification and interpretation of mine information. The effect before and after stretching is shown in Figure 4.

Figure 4. Histogram comparison of image stretching.
First, we used Pan sharpening of the original image by PCI GEOMATICA. Then, we realized three different fusion algorithms used, such as Intensity Hue-Saturation (IHS), PC principal component transform fusion (PC), and Gram-Schmidt Spectral Shaping (Gram-Schmidt) by ENVI5.3 (The Environment for Visualizing Images). The effects of three fusions are shown in Figure 5. From a macro perspective, image contrast was enhanced by IHS, but the color of the image is not true because a certain color distortion appeared. By comparison, PC and Gram-Schmidt had a better effect, which can make the figure clearer, and color fidelity is relatively higher (Figure 5).

In this paper, seven statistical parameters were analyzed: mean, standard deviation, average gradient, deviation index, spectral distortion, spectral correlation coefficient, and information entropy. The image effect was quantitatively evaluated from three aspects: spatial detail information, spectral characteristic maintenance, and information amount [31,32]. The results are shown in Table 2. Gram-Schmidt had great advantages in various indicators. Integrating qualitative and quantitative aspects, the Gram-Schmidt method was finally selected as the fusion method of high-resolution satellite data.

| Fusion Method          | Mean     | Standard Deviation | Average Gradient | Deviation Index | Spectral Distortion | Spectral Correlation Coefficient | Information Entropy |
|------------------------|----------|--------------------|------------------|-----------------|---------------------|----------------------------------|---------------------|
| Original multispectral image | 308.91   | 62.31              | 3.57             |                 |                     |                                  | 8.91                |
| IHS                    | 307.25   | 62.53              | 9.51             | 0.29            | 31.36               | 0.76                             | 8.92                |
| PC                     | 308.56   | 58.31              | 7.26             | 0.21            | 20.37               | 0.85                             | 8.69                |
| Gram-Schmidt           | 307.53   | 63.22              | 9.30             | 0.17            | 20.19               | 0.90                             | 8.73                |

3.2.3. Image Mosaic

A remote sensing image mosaic is a technical process of stitching remote sensing images obtained from two or more adjacent scenes under the same or different imaging conditions into a large-scale and seamless image, based on a certain mathematical basis [33] (Figure 6).

In this paper, the method of using stitching lines in overlapping areas and setting a certain feather value was used to eliminate the visual influence and improve the mosaic accuracy. It was better in terms of geometric accuracy, image brightness, and hue.
3.2.4. Remote Sensing Interpretation

Different features can be distinguished in remote sensing images according to their hue, texture, shadow, edge features, shape, and other features. The types of objects that need to be interpreted in mine remote sensing monitoring are complex. Therefore, the establishment of an interpretation marker database with multiple types, obvious characteristics, and an accurate reflection of the actual state of mine features is of great significance for monitoring the mine development status and environmental restoration and management of metallogenic belt (Table 3).

Table 3. List of interpretation signs in the study area.

| Feature Type | Remote Sensing Image | Field Photos | Interpretation Characteristics |
|--------------|----------------------|--------------|--------------------------------|
| Stope        | ![Image](GF-1)       | ![Image](GF-2) | The image shows a negative terrain with bright colors. There are roads connected with it, which is easy to interpret. |

Figure 6. Achievements after a uniform color mosaic of domestic high-resolution satellite images.
Table 3. List of interpretation signs in the study area.

| Feature Type       | Remote Sensing Image | Field Photos | Interpretation Characteristics                                                                 |
|--------------------|----------------------|--------------|--------------------------------------------------------------------------------------------------|
| Transfer site      |                      |              | The ore pile is patchy, and the color is mostly light gray and gray. There is visible transportation equipment, in the shape of eight claws. |
| Waste dump         |                      |              | It is in a regular plane shape, with light color, large scale, and obvious accumulation. It is generally located around the stope, with a concave convex appearance. |
| Waste rock heap    |                      |              | Most of them are crescent shaped and patch shaped, with a sense of accumulation, generally gray or light gray, and the image texture is relatively fine. |
| Mine building      |                      |              | It is a regular rectangle with concentrated distribution. The color of the top of the building is mostly red, blue, or white. It is close to the mining area and easy to interpret. |
| Tailings pond      |                      |              | The reflectivity is higher than the surrounding ground objects, with mirror image characteristics. The tail of the reservoir is arranged in a ladder shape, and the measured tone inside is dark, which is significantly different from that outside. |
| Restoration of governance |              |              | The surface is square and grid, the land is flat, and the texture is regular. The slope after treatment is in a ladder shape, and the vegetation can be seen in the artificially re-greening mine and is arranged regularly and orderly. |
3.2.5. Calculate the Patch Area of Feature Types

We used the calculation geometry function in ArcGIS to calculate the area of the surface feature type vector map spots interpreted by remote sensing and obtained the area of the interpreted map spots.

4. Monitoring Results

4.1. Change Trend of Mine Development Land Occupation

Continuous mining activities are bound to have a certain negative impact on the surrounding ecological environment. Therefore, based on remote sensing images in different periods, the mine development information in the metallogenic area was dynamically monitored. The quantitative monitoring data was used to study the change rule of the mine environment in different periods of time and provide data support and auxiliary decision-making for the natural resources department for the treatment and protection of the ecological environment in the mining area.

According to the statistics of the survey results, the mining area of each metallogenic belt was mainly stope. Among them, the stope area of the Taishun-Zhoushan metallogenic belt was the largest, which is 8489.32 ha, 8529.44 ha, 8310.81 ha, and 8072.33 ha, respectively, from 2018 to 2021. The stope area of the Si’an-Changxing metallogenic belt was the smallest, 901.99 ha, 888.09 ha, 858.50 ha, and 856.03 ha, respectively, from 2018 to 2021. The stopes of the Lin’an-Huzhou metallogenic belt, the Quzhou-Shaoxing metallogenic belt, and the Longquan-Shangyu metallogenic belt all covered an area of more than 2000 ha. The solid waste covered the least area, and the Quzhou-Shaoxing metallogenic belt, Longquan-Shangyu metallogenic belt, and Taishun-Zhoushan metallogenic belt covered an area of more than 100 ha. The area of solid waste in the Si’an-Changxing metallogenic belt was the smallest, unchanged from 2018 to 2021, all of which were 11.55 ha. The Taishun-Zhoushan metallogenic belt covered the largest area of the transfer site, with 2230.39 ha, 2265.15 ha, 2208.66 ha, and 2162.99 ha from 2018 to 2021, respectively. The second was the Longquan-Shangyu metallogenic belt, with 1174.70 ha, 1179.78 ha, 1126.28 ha, and 1101.81 ha from 2018 to 2021, respectively. The transfer sites of the other four metallogenic belts covered an area of less than 1000 ha. The Quzhou-Shaoxing metallogenic belt covered the largest area of mine buildings, with 381.77 ha, 381.75 ha, 380.90 ha, and 374.21 ha from 2018 to 2021, respectively (Figure 7).

Because of the coexistence of abundant and insufficient mineral resources, the lack of energy minerals, the shortage of metal minerals, and the abundance of non-metallic minerals in Zhejiang Province, most of the mining methods are open-pit mining, which completely strip the topsoil and rock strata covered on the deposit. Metal minerals are mostly distributed in the Quzhou-Shaoxing metallogenic belt and Longquan-Shangyu metallogenic belt. With the continuous improvement of China’s urbanization process and the vigorous development of the real estate industry, the demand for building material minerals, such as tuff for construction and limestone for building stones, is increasing, resulting in a large number of open-pit mining stopes. As Zhejiang province insists that green water and green mountains are the development path of Jinshan and Yinshan, most of the land occupied by various mines in the metallogenic belt shows a decreasing trend, indicating that Zhejiang Province has further strengthened the macro-control of mine development.
Figure 7. Comparison of mine land occupation in various metallogenic belts in Zhejiang Province.

(1) Area increment
This index was used to describe the increase or decrease in the floor area of mine development, and its mathematical model is:

$$\Delta S = S_i - S_j$$  \hspace{1cm} (1)

where $\Delta S$ is the change increment of mine development land occupation in different periods, and $S_i$ and $S_j$ are the total area of mine development land occupation in the base period and the end period, respectively.

(2) Change range
This index was used for the increase or decrease of the area per unit time of mine development, and its mathematical model is:

\[ \delta = \frac{|S_i - S_j|}{T} \]  

(2)

where \( \delta \) refers to the change range of the mine development floor area in a certain monitoring period, and \( T \) refers to the monitoring time difference.

(3) Rate of change

This indicator represents the change rate of the increase or decrease of the area of the mine development land in the monitoring period. Based on the total area of the mine development land in the base period, it reflects the increase or decrease degree of the area of different mines. Its mathematical model is:

\[ V = \frac{|S_i - S_j|}{T} \times \frac{1}{T} \times 100\% \]  

(3)

where \( V \) represents the change rate of mine development land occupation.

According to the above mathematical statistical model, the change degree of mine development land occupation in the metallogenic belt of Zhejiang Province from 2018 to 2021 is shown in the table (Table 4) (ha year\(^{-1}\) indicates the change of mine development land occupation).

**Table 4.** Change degree of the land area of mine development in the Zhejiang metallogenic belt from 2018 to 2021 (Company: ha year\(^{-1}\)).

| Metallogenic Belt | Area Variation | Stope | Transfer Site | Solid Waste | Mine Building |
|-------------------|----------------|-------|---------------|-------------|--------------|
| Si’an-Changxing    | Area increment | −45.96| −23.28        | 0.00        | −20.73       |
|                    | Change range   | 11.49 | 5.82          | 0.00        | 5.18         |
|                    | Rate of change | 2.87  | 1.46          | 0.00        | 1.30         |
| Lin’an-Huzhou      | Area increment | −184.82| −15.40       | −1.48       | −56.75       |
|                    | Change range   | 46.20 | 3.85          | 0.37        | 14.19        |
|                    | Rate of change | 11.55 | 0.96          | 0.09        | 3.55         |
| Kaihua-Huzhou      | Area increment | 39.92 | −18.88        | −2.38       | −8.51        |
|                    | Change range   | 9.98  | 4.72          | 0.60        | 2.13         |
|                    | Rate of change | 2.49  | 1.18          | 0.15        | 0.53         |
| Quzhou-Shaoxing    | Area increment | −204.05| −96.93       | −0.72       | −7.56        |
|                    | Change range   | 51.01 | 24.23         | 0.18        | 1.89         |
|                    | Rate of change | 12.75 | 6.06          | 0.04        | 0.47         |
| Longquan-Shangyu   | Area increment | −111.93| −72.89       | −3.97       | −0.22        |
|                    | Change range   | 27.98 | 18.22         | 0.99        | 0.05         |
|                    | Rate of change | 7.00  | 4.56          | 0.25        | 0.01         |
| Taishun-Zhoushan   | Area increment | −416.99| −67.40       | 19.20       | −15.66       |
|                    | Change range   | 104.25| 16.85         | 4.80        | 3.92         |
|                    | Rate of change | 26.06 | 4.21          | 1.20        | 0.98         |

It can be seen from Table 4 that different types of mining development and land occupation in the metallogenic belt show different area increment, change range and change rate, and the area of each metallogenic belt is decreasing year by year, indicating that under the regulation of the natural resources department, the unqualified mining activities in key control areas such as natural reserves, ecological red line and Yangtze River economic belt are stopped in time. Forced closure makes the order of mining development tend to be good gradually.
The area increment value of the Taishun-Zhoushan metallogenic belt was the smallest, and the variation range was the largest, at 104.25 ha a$^{-1}$. The variation range between stope and solid waste was nearly 27 times. The change rate was also large, at 20.06 ha a$^{-1}$. The reason is that the metallogenic belt is located in the Taishun-Zhoushan area in the southeast of Zhejiang Province. Except for sporadic outcrops of medium and deep metamorphic complexes on the side of Lishui-Yuyao fault zone, the rest are mostly occupied by a large area of Mesozoic volcanic intrusive complexes. Zhejiang Province is rich in non-metallic mineral resources. Zhoushan is located in a good location of marine sand and gravel in the Yangtze River Delta and has rich resource reserves. With the promotion of the construction of large infrastructure projects, such as the Zhoushan mainland Island connection project, the Shanghai international shipping center, the Yangshan deep-water port area, and the Hangzhou Bay sea crossing bridge, Zhoushan’s economic status in the “Yangtze River Delta” is increasing. The minerals available for development and utilization in Zhoushan are volcanic tuff and granite ordinary building stones. It has made great contributions to Zhoushan’s urban construction, improvement of living conditions, traffic network construction, beach reclamation projects, and support for Shanghai’s infrastructure construction. Island construction requires a large amount of building tuff, which will be used in future economic and social development. It will continue to play an important role in its construction. Therefore, relevant departments can continue to focus on the area to improve the development environment of the mining area.

The area increment of the Kaihua-Huzhou metallogenic belt was the largest, at 39.92 ha a$^{-1}$. The variation amplitude and rate were small, 9.98 ha a$^{-1}$ and 2.49 ha a$^{-1}$, respectively. The metallogenic belt is located in the Kaihua-Lin’an area in the northwest of Zhejiang Province, with the Changhua-Hangzhou fault as the north boundary and the Xiaoshan-qiuchuan fault as the southeast boundary, extending to Anhui Province in the northwest. This belt is rich in mineral resources and is one of the important metallogenic zones in Zhejiang Province. Huzhou is rich in building stone mineral resources and has a wide range of mines. In recent years, with the continuous improvement of China’s urbanization process, the number of land occupied and damaged by mines, such as building materials and other non-metallic minerals, is increasing, and the scale is also expanding. Therefore, it is suggested that further supervision and management should be taken for the mine development and protection of the metallogenic belt.

4.2. Change Trend of Mine Restoration and Management

In recent years, the government has increased investment and stepped up the planning and specific implementation of mine environmental governance. The mine environmental governance in Zhejiang has also achieved certain results.

The figure shows the spatial distribution of the restoration and control of the metallogenic belt from 2018 to 2021. It can be seen from the figure that the spatial distribution of the restoration and control points is uneven, showing a trend of less in the south and more in the north. It is mainly distributed in the economically developed areas of the northern, central, and eastern plains of Zhejiang Province, and the mine covers less land in the economically underdeveloped areas in the south and southeast. It is mainly distributed in the economically developed areas of the northern, central, and eastern plains of Zhejiang Province, and the mine covers less land in the economically underdeveloped areas in the south and southeast. In addition, another obvious feature is that it is distributed along rivers, expressways, national highways, and other important traffic trunk lines, indicating that in carrying out the restoration and treatment project, the natural resource departments and mining units have made great efforts to promote the restoration and treatment of mines and the improvement of ecological environments from the comprehensive treatment of key areas such as “three areas and two lines”, which has made positive achievements in the protection of the mine geological environments (Figure 8).
In order to further analyze the degree of mine environment restoration and governance in each metallogenic belt, the restored governance area was divided by the sum of the abandoned mine area, the mine area under use, and the restored governance area to obtain the percentage of mine environment restoration and governance in the metallogenic belt (hereinafter referred to as governance percentage). According to the statistics of the degree of mine environment restoration (percentage of treatment), the degree of mine environment restoration and treatment in the Taishun-Zhoushan metallogenic belt was the highest, and the percentage of treatment from 2018 to 2021 was 83.01%, 80.07%, 76.91%, and 73.78%, respectively. The Quzhou-Shaoxing metallogenic belt had the second degree of governance, and its governance percentages from 2018 to 2021 were 74.38%, 72.34%, 67.24%, and 64.83%, respectively. The governance percentage of the Kaihua-Huzhou metallogenic belt ranked third, with 70.60%, 70.39%, 66.99%, and 66.21%, respectively, from 2018 to 2021 (Figure 9).
As can be seen from Figure 9, the number of restoration and treatment projects has been increasing for four consecutive years, and the restoration and treatment area has increased significantly. The Taishun-Zhoushan metallogenic belt ranked first in the number of restored mines. From 2018 to 2021, the number of restored mines was 512, 542, 648, and 763, respectively. Because the central government focuses on improving the ecological environment of mines, it was required to start with the comprehensive treatment of key areas such as “three areas and two lines”. Zhoushan is an archipelago city with considerable coastline length. Therefore, the Taishun-Zhoushan metallogenic belt is a key area for comprehensive regulation. Therefore, Zhoushan actively practices the ecological concept of “green water and green mountains are golden mountains and silver mountains” and strengthens the ecological management of abandoned mines. In the design of the treatment scheme, according to the geographical location of the abandoned mine and the availability of the mining area, it is suitable for the scenery, the forest, the reclamation, and the construction, so as to fully improve the comprehensive utilization value of the mining area, which has characteristics and achievements in the protection and treatment of the mine’s ecological environment.

The Lin’an-Huzhou metallogenic belt ranked first in the area of restoration and control. The areas of restoration and control from 2018 to 2021 were 2730.96 ha, 2977.79 ha, 3551.48 ha, and 3610.72 ha, respectively (Figure 10). Hangzhou and Huzhou are both economically developed areas in Zhejiang Province and have played a leading role in the implementation of sustainable development strategies such as mine restoration and management. As the birthplace of the concept of “two mountains”, Huzhou has continued to strengthen mine management, improve the construction level of green mines, protect the natural ecology with beautiful mountains and rivers, and strive to be a model place to practice the concept of “two mountains”. It has also shown a good demonstration and promotion role for other regions. At present, the mine ecological construction in Huzhou has achieved remarkable results and is in the forefront of the country.

Figure 9. Percentage of restoration and control of each metallogenic belt from 2018 to 2021.
5. Restoration Counter Measures of Mines in Metallogenic Belt

According to the geographical location and surrounding environment of the mine, first, the repair shall be carried out year by year according to the identification of the degree of damage of the mine. Second, it should focus on the ecological environment and social impact, followed by economic interests. Third, unified planning should be made and priority given to the treatment of abandoned mines within the scope of “three areas and two lines”. Fourth, ecological measures should be the main measures, supplemented
by engineering measures, with the least being capital investment. Fifth, the waste ore produced by waste restoration should be reused, and illegal mining should be stopped.

Priority should be given to the ecological environment restoration of mines within the scope of “three zones and two lines”, with more biological restoration and less engineering restoration. In areas far away from human habitation, natural restoration shall be carried out using climatic characteristics. In the abandoned mines close to the periphery of the city and closely related to people’s production and life, the characteristics of the periphery of the city are used to carry out land reclamation, land transformation, industrial utilization, mining parks, and other services for the urban ecology.

The key repair scope is “three districts and two lines” within 1 km from both sides of expressways, national roads, provincial roads, and railways; within 1 km outside the banks or embankments of the main stream and primary tributaries of key watersheds; within 1 km of residential concentration areas, landscape areas and nature reserves. A total of 1911 mines are involved within 1 km of the “three zones and two lines”. There are 50 places in the Si’an-Changxing metallogenic belt, 151 in the Lin’an-Huzhou metallogenic belt, 236 in the Kaihua-Hangzhou metallogenic belt, 326 in the Quzhou-Shaoxing metallogenic belt, 513 in the Longquan-Shangyu metallogenic belt, and 635 in the Taishun-Zhoushan metallogenic belt.

Considering the requirements of ecology and tolerance, the selection of plant species should comply with the climatic conditions of Zhejiang, with fast growth, strong regenerative ability, easy reproduction, strong nitrogen fixation ability, and adaptation to local soil conditions (moisture, pH value, soil properties, etc.). It is dominated by zonal vegetation and native tree species, with strong stress resistance (including drought resistance, heat, cold, barren, diseases, pests, etc.), and is configured with shallow rooted plants such as perennial herbs, vines, and small shrubs. The aboveground part is selected from short, deep rooted, and growing blocks with wide coverage. Trees and grasses are mainly perennial. Because the soil structure of the quarry is poor and the content of water and nutrients is low, the plants should be mainly herbs, shrubs, and vines, or some suitable trees. Some plants have a natural adaptability to exposed rocks and facades and can well adapt to the influence of hot weather and strong wind. They are fixed on exposed rocks and facades. Therefore, for lack of water and strong wind, plants suitable for drought should be selected first, climbing plants should be selected first for rock facades, and legumes should be selected for barren abandoned mines.

Zhejiang Province is located in the Yangtze River Delta, where the annual average precipitation is sufficient and the weather conditions are very favorable for plant crop production. Thus, if the damaged area of the mine is small, natural recovery can be adopted because natural recovery is more economical. In the mining area, if the geological environment is good, the rainfall is sufficient, and so on, natural re greening can be considered. During the rainy season, the planting of viable and fast-growing grass seeds enables the mine to repair quickly. In addition, a lot of abandoned mines are formed in the process of mining, which can be used as a disposal site for producing and domestic waste, and can solve the problems of garbage siege, environmental pollution, and resource recovery and reuse. In the light of the fact that 4412 abandoned mines in the metallogenic belt of Zhejiang Province have been found to be in need of treatment, and based on the brief evaluation criteria, a total of 2983 mines can be naturally restored, of which 311 are in the Si’an-Changxing metallogenic belt, there are 325 in the Lin’an-Huzhou metallogenic belt, 387 in the Kaihua-Hangzhou metallogenic belt, 598 in the Quzhou-Shaoxing metallogenic belt, 765 in the Longquan-Shangyu metallogenic belt, and 597 in the Taishun–Zhoushan metallogenic belt.

6. Discussion

Compared with traditional technology, remote sensing technology can carry out comprehensive investigation of regional metallogenic belt mines from different heights and different perspective. In recent years, domestic high-resolution satellite data are more
and more widely used in traditional mine monitoring, but there is less research on mines in metallogenic belts. Because the remote sensing geological survey of a metallogenic belt is a highly professional and comprehensive geological work, researchers are required to be familiar with geology and remote sensing technology at the same time. They must be familiar with the geological principles of remote sensing; use remote sensing images to interpret; be able to interpret the regional tectonic pattern, ore bearing horizon, and other information related to mineralization; skillfully use digital image processing technology and knowledge of geomorphology, geophysics, geochemistry, and other aspects to carry out comprehensive research on the basis of special research.

The research on the mines in the metallogenic belt can better identify, delineate, mark, analyze, and evaluate the evaluation of the mine environment and resource development mode. Because the geotectonic environment of the deposit (point) is the same, the regional crustal evolution is consistent with the metallogenic process, and the ore bearing surrounding rock (sedimentary rock, metamorphic rock, or magmatic rock) is consistent in time and space distribution for the same metallogenic belt. By means of remote sensing and geographic information technology, various spatial information of mines in the metallogenic belt are comprehensively analyzed and processed, which can provide strategic or tactical suggestions for regional geological and mineral surveys. For example, the Taishun-Zhoushan metallogenic belt is rich in mineral resources and mineral-producing areas, which is the most important metallogenic area of non-metallic minerals in Zhejiang Province. In the past four years, the change rate of mine development land occupation in this metallogenic belt was large. Through this study, it was found that the mine development status and mine restoration and management status show different trends in different metallogenic belts. Therefore, it is of great significance to carry out remote sensing monitoring of mines in different metallogenic belts, which can provide a scientific basis and important reference for local mining administration departments to carry out mine ecological environment restorations.

With the development of high-resolution remote sensing technology and low-altitude unmanned aerial vehicle (UAV) technology, remote sensing technology will play a greater role in the field of mine development environmental assessment and land planning in metallogenic belts.

7. Conclusions

Taking the domestic high spatial resolution remote sensing data obtained from 2018 to 2021 as the data source, based on the preprocessed remote sensing data, this paper obtained the distribution information of the development environment of metallogenic belt mines in Zhejiang Province by establishing interpretation marks, a target interpretation, and human-computer interaction information extraction.

(1) Through the statistical analysis of the floor area of each metallogenic belt mine, it was concluded that the floor area of each metallogenic belt mine is dominated by stopes. Among them, the stope area of the Taishun-Zhoushan metallogenic belt was the largest, at 8489.32 ha, 8529.44 ha, 8310.81 ha, and 8072.33 ha from 2018 to 2021, respectively. The area of solid waste was the least. The Quzhou-Shaoxing metallogenic belt, Longquan-Shangyu metallogenic belt, and Taishun-Zhoushan metallogenic belt covered an area of more than 100 ha. Different types of mining development and land occupation in metallogenic belts show different area increments, change ranges, and change rates. The area of each metallogenic belt is decreasing year by year, indicating that under the regulation of the natural resources department, unqualified mining activities in key control areas such as nature reserves, ecological red lines, and the Yangtze River economic belt have stopped in time. Forced closure makes the order of mining development tend to be good gradually.

It is suggested to establish a remote sensing monitoring platform for mines in the metallogenic belt. According to the characteristics of each metallogenic belt, we should participate in the monitoring, early warning, inspection, and evaluation of mine geological environments in the mine development of metallogenic belts through remote sensing.
technology. In addition, it can also improve the frequency of annual monitoring and carry out multi-stage dynamic monitoring. It is possible for the department to strengthen the regulation and supervision of mineral resource development purposefully. It will certainly promote the national mine development supervision.

(2) Based on the remote sensing survey results, the mine environment restoration and treatment of each metallogenic belt was analyzed, and it was concluded that the restoration and treatment points show a trend of less in the south and more in the north, mainly distributed in the economically developed areas of the northern, central, and eastern plains of Zhejiang Province. According to the statistics of the degree of mine environmental restoration and treatment (treatment percentage), the degree of environmental restoration and treatment of the Taishun-Zhoushan metallogenic belt mine was the highest, and the treatment percentages from 2018 to 2021 were 83.01%, 80.07%, 76.91%, and 73.78%, respectively. For four consecutive years, the number of restoration and treatment projects has been on the rise, and the restoration and treatment area has increased significantly. The Taishun-Zhoushan metallogenic belt ranked first in the number of restored mines. From 2018 to 2021, the number of restored mines was 512, 542, 648, and 763, respectively. The Lin’an-Huzhou metallogenic belt ranked first in the area of restoration and control. The areas of restoration and control from 2018 to 2021 were 2730.96 ha, 2977.79 ha, 3551.48 ha, and 3610.72 ha, respectively.

It is suggested to continue to create conditions for the restoration and treatment of mine environments in the metallogenic belts in terms of policy and system. At present, due to the imbalance in the proportion of development and governance, it still needs the joint efforts of the government, society, enterprises, and individuals to truly implement the mine environmental restoration and governance and environmental protection. On the one hand, business owners should be urged to strictly implement the policy of “who develops, who protects; who pollutes, who governs”. On the other hand, for ownerless mines, it is suggested that the government increase financial investment or strive to guide social funds to promote the restoration and treatment of mine environment.

(3) The countermeasures and suggestions for mine environment rehabilitation in metallogenic belts were put forward. In the mining area, if the geological environment is good, the rainfall is sufficient, and so on, it may be considered by the natural restoration to be green primarily. According to the brief evaluation criteria, a total of 2983 mines can be restored naturally, including 311 in the Si’an-Changxing metallogenic belt, 325 in the Lin’an-Huzhou metallogenic belt, 387 in the Kaihua-Hangzhou metallogenic belt, 598 in the Quzhou-Shaoxing metallogenic belt, 765 in the Longquan-Shangyu metallogenic belt and 597 in the Taishun-Zhoushan metallogenic belt. A total of 1911 mines were involved within 1 km of the “three zones and two lines”. There are 50 places in the Si’an-Changxing metallogenic belt, 151 in the Lin’an-Huzhou metallogenic belt, 236 in the Kaihua-Hangzhou metallogenic belt, 326 in the Quzhou-Shaoxing metallogenic belt, 513 in the Longquan-Shangyu metallogenic belt, and 635 in the Taishun-Zhoushan metallogenic belt.

It is suggested to find out the typical situation of environmental restoration and treatment in the metallogenic belts of Zhejiang Province, which can be used as a good reference and popularization for the restoration and treatment of mine geological environments in other metallogenic belts. We should adjust measures to local conditions and pay attention to the effect of governance. According to the different characteristics of each metallogenic belt, different treatment methods are studied and determined.

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