Research on Monitoring and Application of Ecological Restoration Engineering in Open Pit Backfilling Mines Based on Satellite Remote Sensing Data

Shuneng Liang [1], Yang Li [2], Ning Zhang [3], Chenchao Xiao [1], Hongyan Wei [1]

[1] Land Satellite Remote Sensing Application Center, Ministry of Natural Resources, Beijing 100048, China；
[2] Key Laboratory of Education Ministry of Precision Opto-mechatromics Technology, School of Instrumentation Science and Opto-electronics ngineering, Beihang University, Beijing 100191, China；
[3] Institute of Earth Sciences and Resources, China University of Geosciences (Beijing), Beijing 100083, China

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Abstract

The restoration and management of mining ecological environment is an important component of China's ecological civilization construction. The implementation of restoration projects is to avoid the serious impact caused by the continuous deterioration of mining ecological structure, and is a key way to maintain regional ecological security and energy and mineral security. Therefore, efficient and rapid monitoring and evaluation of the effectiveness of mining ecological restoration is an essential and important link. With the rapid development of remote sensing technology, remote sensing monitoring has become an important means to objectively, quickly, and accurately obtaining changes in the mining environment. It can provide timely and long-term monitoring of mining and backfilling conditions in mining areas. This article uses the multi temporal stereo images of the Resource 3 satellite over four years to monitor the mining and backfilling situation of the Zhungeer open-pit coal mine area in Inner Mongolia. By reconstructing the Digital Surface Model (DSM) of the open-pit mining area, the changes and thresholds of the multi temporal DSM data are statistically analyzed to extract the mining and backfilling areas, and the earthwork volume is calculated. The results showed that from 2013 to 2016, the main large-scale mining faces in the study area of Zhungeer open-pit mining area had a total mining operation of about 563.5 million cubic meters, and a total backfilling operation of about 604.29 million cubic meters; During the period from 2016 to 2018, the main large-scale mining faces in the region had a total of approximately 721.71 million cubic meters of mining operations and a total of approximately 805.42 million cubic meters of backfilling operations. The overall operational intensity increased from 2016 to 2018. The research results show that based on satellite image data, it is convenient and efficient to obtain DSM and corresponding changes of multiple time periods in mining areas. Monitoring results can provide important support for regional environmental governance and protection, as well as safety production in mining areas.

1.1 Introduction

Open pit coal mines are an important component of China's coal industry, with advantages such as high labor efficiency, large production scale, fast construction speed, and high resource extraction rate. They have played an important role in economic and social development(Zhao et al., 2016). The Zhungeer Coal Mine Area in Inner Mongolia is located in the middle reaches of the Yellow River Basin and is an important coal mining base in Inner Mongolia Autonomous Region(Bi et al., 2022). It is also the largest open-pit coal mine in the Asian region, greatly promoting the economic development of the region. However, years of large-scale coal mining have not only brought economic benefits, but also had a negative impact on the living environment and even people's lives in the mining area and surrounding areas. For this reason, the region has launched a mining ecological restoration and management project(Sun, 2019), which has achieved good results since its implementation. For the restoration and management of open-pit coal mines, backfilling and management of mining pits is a relatively important work, and it is also an important indicator for evaluating and assessing the quality of mining restoration in this type of mining area. Therefore, how to achieve rapid and effective quantitative monitoring of open-pit mining and pit backfilling in the entire coalfield area is an urgent problem to be solved in monitoring the effectiveness of ecological restoration and management in this area and this type of mining area.

Based on this, this article focuses on the monitoring application of satellite image data and its DSM in the open-pit mining situation of coal mines in mining areas. Compared with traditional ground measurements such as GPS measurement, 3D laser scanning technology, and Lidar measurement(Liu et al., 2019; Li et al., 2014; Chaussard E et al., 2016), the method used in this article has the advantages of long monitoring cycle, high cost, and sparse measurement points. It has the advantages of high timeliness, short monitoring cycle, and low cost, The ability to continuously monitor open-pit mining pits through multi temporal data is an important means of revealing changes in regional mining conditions(Yang, 2014).

1.2 General Introduction of the Study Area

The research area of Zhungeer Coal Mine in Inner Mongolia is located in the key mining area of Wuhai Ordos comprehensive energy, heavy chemical and mineral resources. The administrative divisions mainly include the eastern part of Zhungeer Banner in Ordos City, which is one of the areas with the most severe soil erosion in China(Lei, 2005). The research area is a typical semi-arid region with an average annual rainfall of 408mm. Rainwater is mainly concentrated from July to September, accounting for 60% to 70% of the annual rainfall. Among them, Zhungeer Coalfield is a national planned mining area and also one of the main coal mining areas in Inner Mongolia Autonomous Region. The proven coal reserves are 54.4 billion tons, and the prospective reserves are 100 billion

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tons. The geological structure is simple, the burial is shallow, the coal seam is thick, the gas content is low, and the heat generation is above 6000 kcal/kg. It is high-quality thermal coal and chemical coal. In addition, there are a large number of non-metallic minerals distributed in the work area, such as kaolin, dolomite, quartz sand, etc.

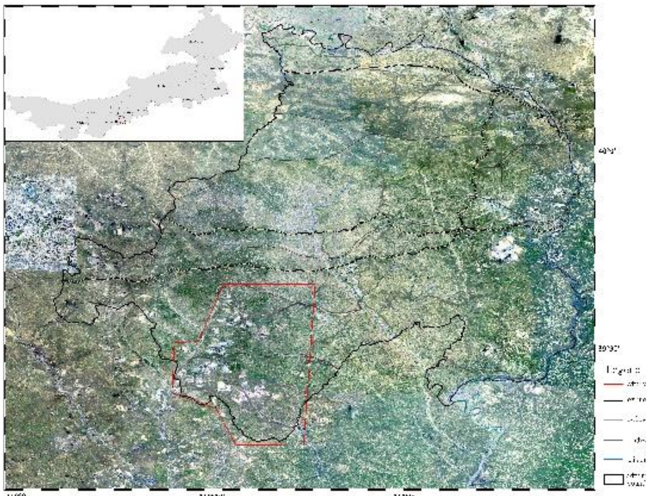


Figure 1. Schematic diagram of the location of the study area

There is a key mining area in the Zhungeer Coalfield area, with main mineral resources including coal, iron, placer gold, and non-metals, involving 10 mining planning areas. In recent years, the excessive exploitation of coal resources in the region has caused damage to the mining environment, and efforts have been made to restore and control the mining environment.

2. Data Processing Methods

2.1 Remote Sensing Data Selection

The remote sensing data in this study is sourced from the TLC standard product of the Resource 3 satellite, which has RPC parameters. The Resource 3 satellite is the first three line array stereo mapping satellite in China, with high geometric positioning accuracy and wide coverage. The resolution of the front view, front view, and back view images of the three line array images is 2.1m, 3.5m, and 3.5m, respectively. The direct positioning accuracy without control points is better than 15m; The plane accuracy with control points is better than 4m, and the elevation accuracy is better than 3m(Li, 2012; Tang et al., 2012).

Spectral range/um	0.5-0.8
Spatial resolution/m	Front view: 2.1m Front view: 3.5m Rear view: 3.5m
Quantization Bits	10
width of cloth/km	52
viewing angle	6

Table 1. Main parameters of three line array cameras

The stereo image pairs of the Resource 3 satellite used in this article have data time periods of 2013, 2016, 2017, and 2018, respectively. The image data covering the study area is not covered by clouds or fog, and the image layers are rich, the texture is clear, and there are no spectral anomalies.

Serial Number	Image data	Image phase
1	ZY3-01a	20130529
2	ZY3-01a	20160307
3	ZY3-01a	20171221
4	ZY3-01a	20180418

Table 2. Column Table of Image Data in the Study Area

Figure 2. The image data diagram of the study area

2.2 DSM Data Extraction

The Digital Surface Model (DSM) includes ground elevation models of surface buildings, trees, and other heights. Compared with Digital Elevation Model (DEM), DEM only contains terrain elevation information, while DSM further covers the elevation of other surface information besides the ground.

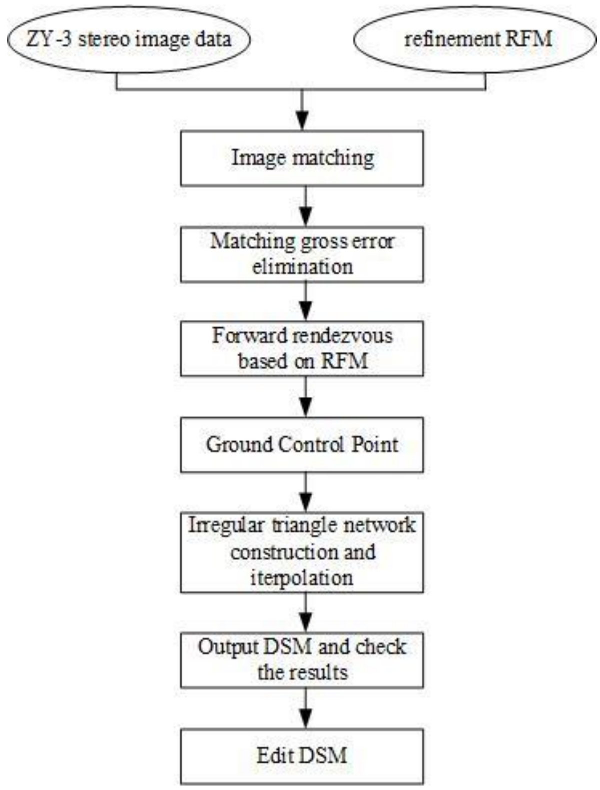
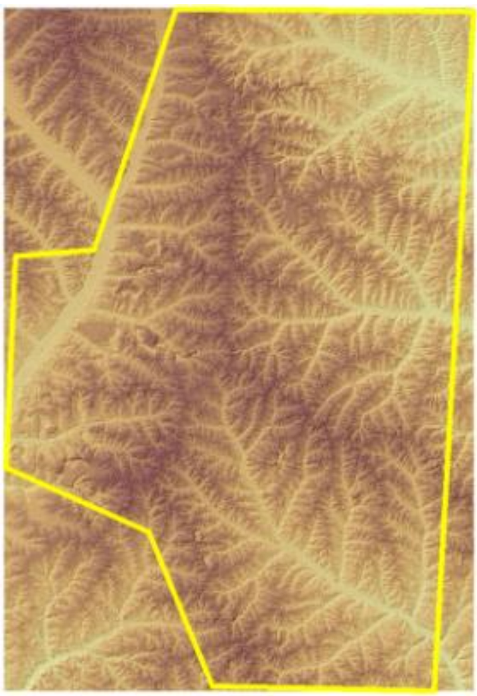
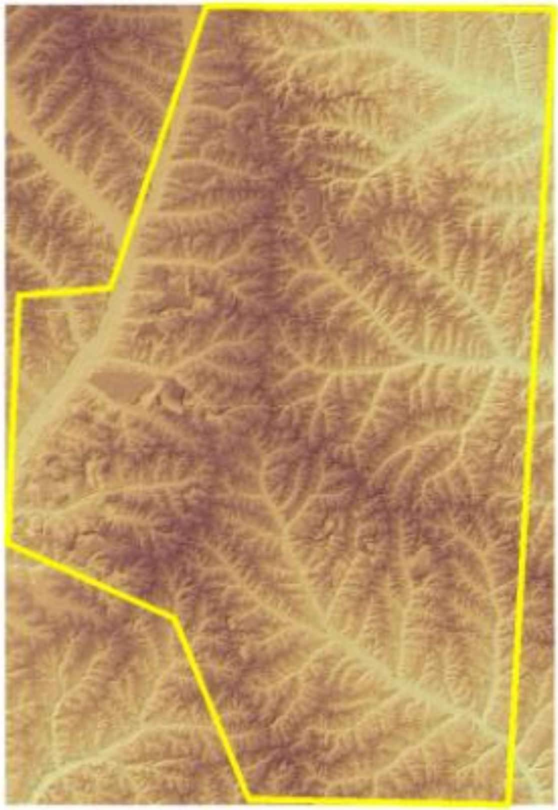


Figure 3. DSM process diagram for extracting data from ZY-3 satellite stereo images

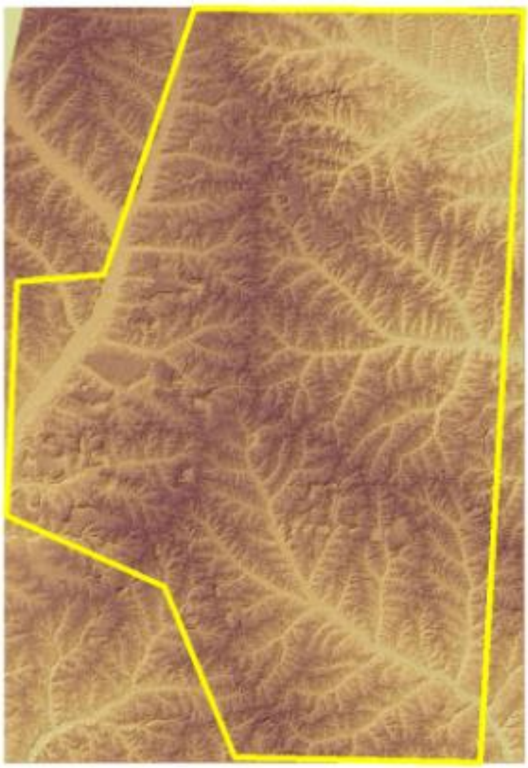
DSM data can truly reflect the terrain undulation situation and play an important role in monitoring the mining and backfilling conditions of open-pit mines. The main steps of using ZY-3 satellite stereo image pair data to extract DSM(Zhang et al., 2017) include: stereo image pair construction, image matching, matching point gross error removal, constructing irregular triangular network TIN, DSM extraction and editing, etc.
The generated DSMs for each phase are shown in Figure 3.



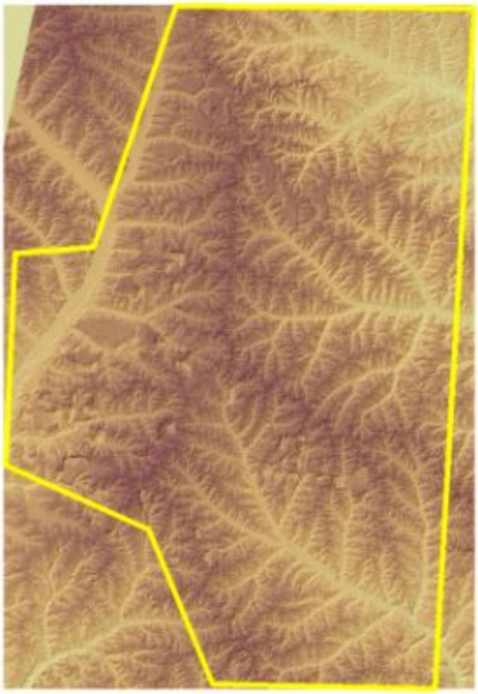
2013



2016



2017



2018

Figure 4. Annual DSM Data Renderings

3. Backfilling and Mining Area Calculation

3.1 Detectionof Surface Changes

Based on registered multi temporal DSM data, obtain the trend of elevation changes in the study area, determine the threshold for terrain change detection, and achieve the determination of the backfill area and mining area range. This article adopts a ground control point based approach for image registration of multi temporal DSM data. Firstly, the 2018 data is used as a reference image to extract features from the images to be registered in 2013, 2016, and 2017. Then, the extracted features are used to establish a matching mapping transformation, which is then applied to affine transformation to obtain the registration results. Secondly, calculate the elevation change and determine the terrain change detection threshold. By performing differential calculations on DSM data from 2013, 2016, 2017, and 2018, elevation change data can be obtained. Considering the impact of DSM data accuracy, other human activities, and soil erosion on elevation change data in addition to the elevation changes caused by backfill and mining areas, it is difficult to accurately extract the backfill and mining areas using only relative elevation changes.

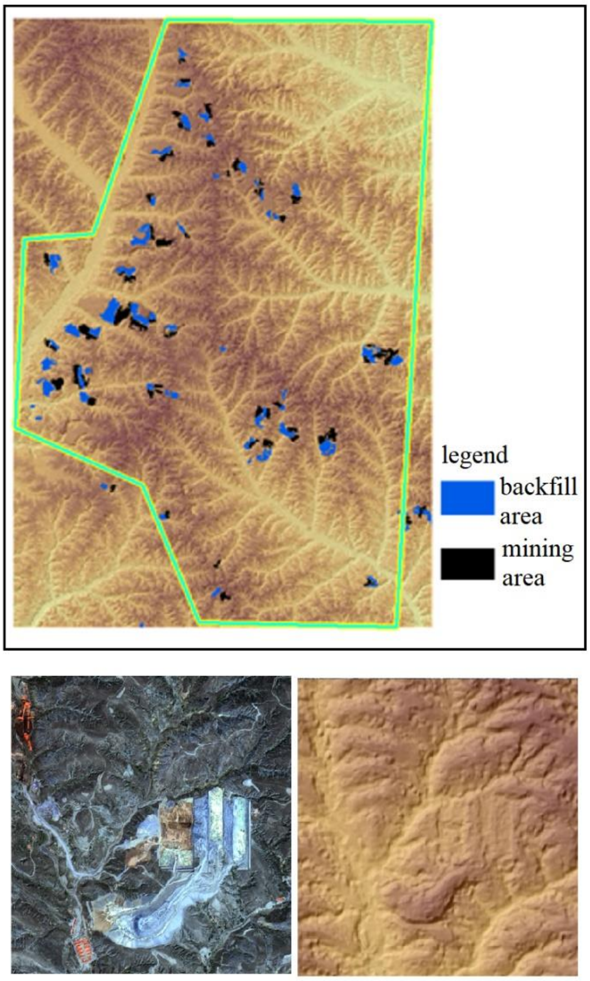


Figure 5. Distribution of Main Mining and Filling Areas from 2013 to 2016 and Partial Enlargement Diagram

Therefore, Determine the terrain change detection threshold through statistical methods, based on 3 σ The criteria screen for areas with significant elevation changes, using areas with significant elevation increases as backfill areas and areas with significant elevation decreases as mining areas. Finally, based on the terrain change detection threshold, extract the mining area and backfill area, as shown in the figure.

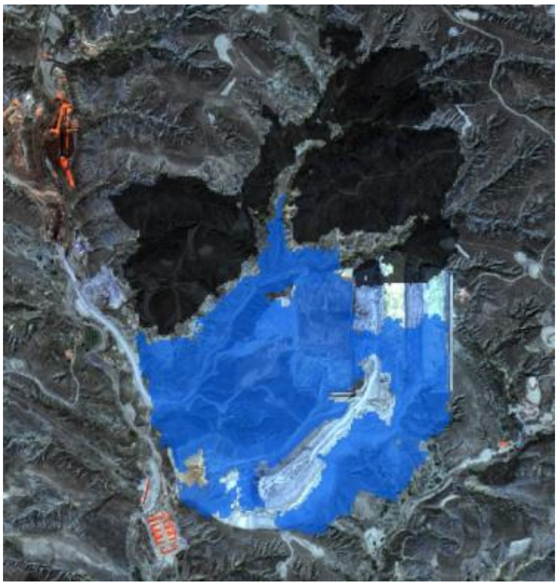


Figure 6. Typical Pit Excavation and Filling Situation (Based on 2013) (Blue represents the treatment and backfilling area, Black represents the mining area)

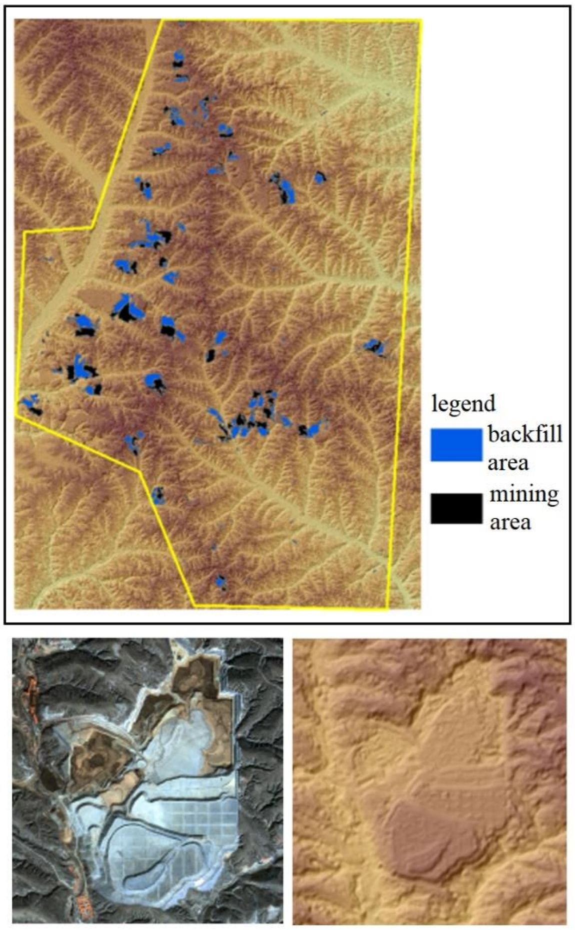


Figure 7. Distribution of Main Mining and Filling Areas from 2016 to 2018 and Partial Enlargement Diagram in 2016

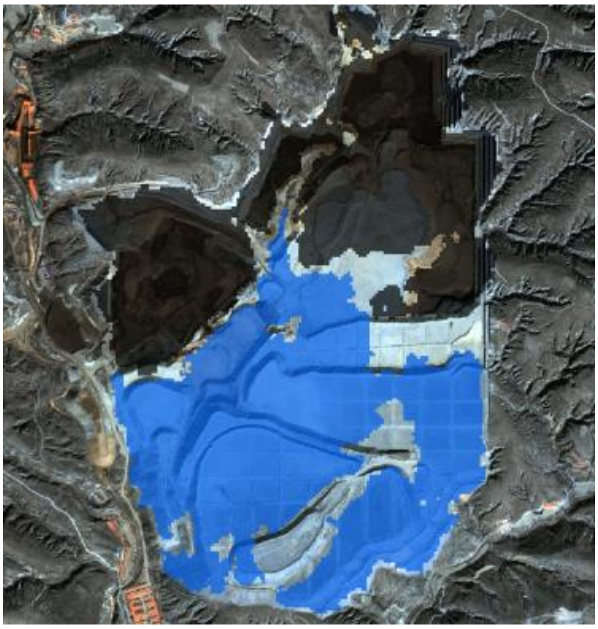


Figure 8. Typical Pit Excavation and Filling Situation (Based on 2016) (Blue represents the treatment and backfilling area, black represents the mining area)

3.2 Calculation of Earthwork Volume

On the basis of elevation change data, based on a regular grid model and DSM pixels as the basic unit for analysis(Gao, 2017; Li et al., 2020; Xiang, 2017), the earthwork volume in the mining and backfilling areas is calculated based on the detection of surface elevation change amount dh in the study area(Xi, 2013). The earthwork volume dV(i,j) of pixels (i, j) in the i-th row and j-th column is S*dh(i,j)). For each mining and backfilling area,he earthwork volume V obtained by accumulating the pixel earthwork volume.

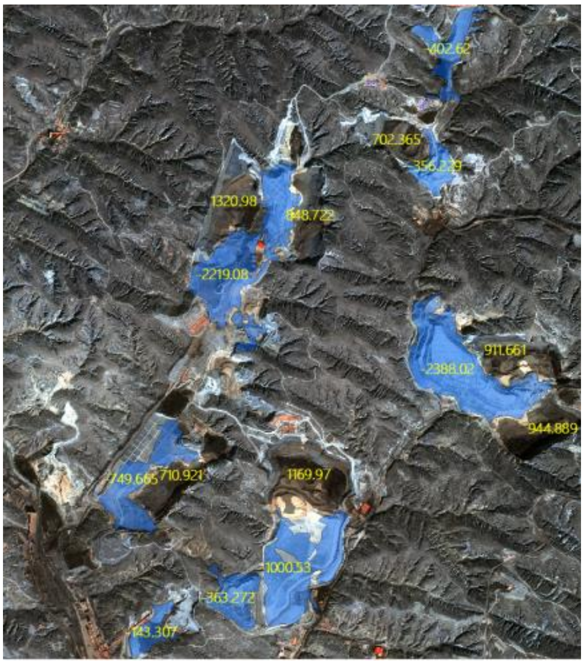


Figure 9. Schematic diagram of the calculation results of earthwork volume in the study area (blue represents the backfill area for treatment, black represents the mining area)

After calculation, from 2013 to 2016, the main large-scale mining faces in the region had a total mining operation of about 563.5 million cubic meters, and a total backfilling operation of about 604.29 million cubic meters. During the period from 2016 to 2018, the main large-scale mining faces in the region had a total mining operation of about 721.71 million cubic meters, and a total backfilling operation of about 805.42 million cubic meters. The overall operational intensity increased from 2016 to 2018.

4. Conclusion

This article is based on the multi temporal stereo images of 2013, 2016, 2017, and 2018 from the Resource 3 satellite to monitor the mining and backfilling situation in the mining area. By reconstructing the surface digital surface model of the open-pit mining area, the mining and backfilling areas are extracted by statistically analyzing the changes and change thresholds of the multi temporal DSM data, and the earthwork volume is calculated based on a regular grid. Draw the following conclusions and understanding:

(1) According to the analysis of the mining and backfilling conditions in the study area, the mining and backfilling operations in Zhungeer Open pit in Inner Mongolia were basically the same from 2013 to 2016, and the backfilling volume was slightly larger than the mining output; From 2016 to 2018, the overall workload increased.

(2) This article is based on the generation of multi temporal DSM data from the resource-3 satellite image, which provides effective data for monitoring surface changes in open-pit mines. It can support the rapid calculation of earthwork volume in the research area and can be widely applied in fields such as mining environmental restoration monitoring. Subsequently, combined with surface measurement information, such as ground control point information, terrain profiles, and other data, the accuracy of surface change detection and earthwork calculation can be improved, further achieving more accurate and automatic monitoring of mining environment.

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