Analysis Method of Surface Changes Due to Open-Pit Mining Activities: A Case Study of Pingshuo East Open-Pit Mine in China

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Abstract: The open-pit mining activity has caused the surface to be in an unstable state of change, causing problems such as slope instability, geological hazard, and damage to the ecological environment. The analysis of open-pit mine surface changes is of positive significance to the sustainable development of the mining area and the improvement of the ecological environment. Based on the spatial-temporal process, the open-pit surface changes area can be divided into three dynamic surface units due to the open-pit mining activities, that is, the progressing mining area, the continuing mining area and the discontinued mining area. Taking the East open-pit mine of Pingshuo Mining Area in China as an example, this paper uses the multi-sequential Digital Elevation Models (DEMS) for calculation to extract the dynamic surface units. The geometric changes and vertical changes of the open-pit surface were analyzed and evaluated quantitatively. The analysis method of surface changes due to open-pit mining activities quantitatively in the GIS environment, is of practical value for the investigation and evaluation of artificial surface changes in open-pit mines.

1 INTRODUCTION

Human activities are leaving a significant signature on the Earth via altering its morphology, evolution, and ecosystem (Foley et al., 2005; Ellis, 2011; Brown et al., 2013; Tarolli, 2014). Open-pit mines cause important and anthropogenic topographic signatureson the Earth (Tarolli and Sofia, 2016; Chen et al., 2015). Open pit mining is a typical anthropogenic activity for stripping and cutting the earth's surface. This activity can cause drastic geomorphic changes of the mine's landscape, affecting the surface evolution of the Earth (Tarolli and Sofia, 2016). During the mining process, the earth's surface is in an unstable state over a long period, this leads to the damage and/or deterioration of natural environment, as a result of forming a terrain environment with negative depths and steep slopes on a large-scale and causing a series of geological hazards, soil erosion and land reclamation etc.

Currently, the methods used for land cover changes of open-pit mine are high-resolution remote sensing technologies, including UAV, TLS, LIDAR and so on. The high-resolution topographic data combined with the image data were used to extract the data variation of surface information such as soil erosion, land cover and geological hazard in open-pit mines, investigating and analyzing characteristic changes and dynamic monitoring of natural environments caused by mining activities. Neugirg (Neugirg et al., 2015) analyzed the soil erosion patterns on the steep slopes and Haas (Haas et al., 2016) quantified and analyzed the geomorphic processes using the long-term data of LIDAR and UAV photogrammetry in five and a half years of Italian open-pit iron mine; Martín-Duque (Martín et al., 2010) discussed the reclamation problems of open-pit mining during 13-year monitoring using TLS technology; Tong (Tong et al., 2015) researched the three-dimensional modeling and monitoring method through the UAV and TLS for classifying the land covers in the open-pit mine; Yucel (Yucel and Turan, 2016) created 3D terrain models to quantify areal changes linked to anthropogenic and meteorological effects over the

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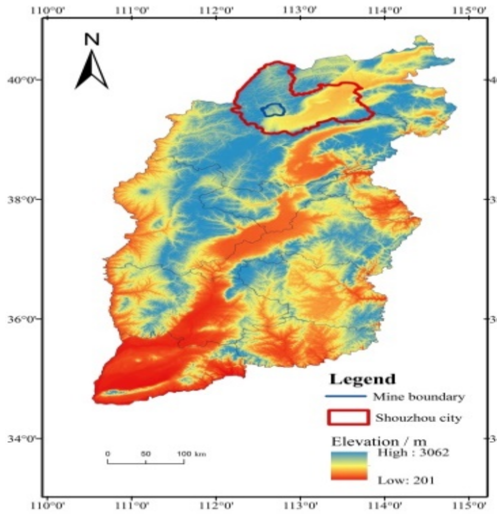
study period of open-pit mine lakes using UAV photogrammetry.

The technique for Geomorphic Change Detection (GCD), which is based on gridded models, can be applied by ground-based topographic survey data to measure the process-based changing information to geomorphologists (James et al., 2012; Carley et al., 2012; Schaffrath et al., 2015; Hu and Wu, 2016). The use of multi-sequential DEM(Digital Elevation Model) calculations to extract areas of change is an effective method for surface change monitoring. James (James et al., 2012) considered that differentiating two or more sequential DEMs is a rudimentary form of spatially distributed and dynamic geomorphological analysis; the time-discrete DEMs in the static mode can also be used to identify the location of geomorphic stability/instability, past trends, processes, and change rate; Carley (Carley et al., 2012) used the subtraction of DEMs between different points in time as a method to determine temporal scour patterns and fill of the channel change detection between contour maps and point cloud models; Schaffrath (Schaffrath et al., 2015) estimated geomorphic change of an extreme flood on a landscape scale in 2010; Hu (Hu and Wu, 2016) researched the method for extracting ground deformation and analyzed the link between regional ground deformation and local deformation for the West Open-Pit Mine in Fushun, Liaoning province, China.

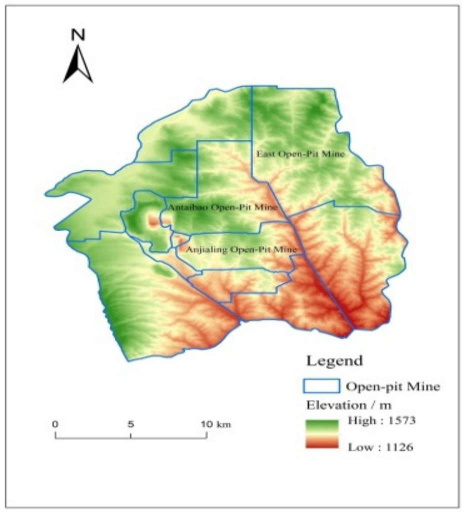
In this paper, an analysis method that is using dynamic topographic data was proposed to evaluate open-pit mining surface changes. By analyzing the spatio-temporal relationship of the open-pit mining activities, three dynamic surface units were defined in the mining process, and the calculation models between elevation deformation information and dynamic surface units were established to simulate the spatial evolution of surface mining. A case study was focused on investigating the dynamic changes of the ground surface information of Pingshuo East open-pit mine, which is located in the loess plateau region, China, using the DEM date collected five periods (6 months for one period) from Jan 2015 to Jan 2017. The vertical deformation information and mining area were extracted through differential calculating the DEM data obtained in the different periods, and dynamic surface units in each time period are obtained by using spatial sets operations; dynamic simulation of the mining process and visualization change of the surface space were carried out chronologically; and surface damage intensity of the dynamic region were evaluated using the geometric and vertical variation parameters.

2 MATERIALS AND METHODS

2.1 Study Area



(a) Location of Pingshuo mine



(b) Open-pit mine in Pingshuo mine

Figure 1: Location of the study area.

East Open-Pit Mine (39° 23′ -39° 37′ N,112° 10′ -113° 30′ E) is located in Shuozhou City, Shanxi Province, China, and one of three open-pit mines (Anjialing open-pit mine, Antaibao open-pit mine and East open-pit mine in PingShuo coal mine(as shown in Figure 1). The Pingshuo coal mine covers an area of 176.3 km^{2}with a geological reserve of 5 billion tons, having 3 layers of coal seam with an average thickness of 26 meters. This mine is located in the Loess Plateau and a region of bare hills, and its soil and ecosystem are easy to be eroded and damaged, having an altitude between 1200m and 1600m and elevation difference within 500m. This area has a typical arid and semi-arid continental monsoon climate and its average annual temperature is in the range of 4.8 -7.8°C and annual precipitation is about 428.2-449.0 mm. The mining direction is heading towards west direction. The west side of the slope is a stripping working slope and a coal mining working slope, while the south and north sides are end slopes; the east side is an internal dump.

2.2 Data Sources

The research area of the East open-pit mine is 5.01km^2. The collecting time period for the measured data (as listed in Table 1) is every 6 months from January 2015 to January 2017 (as shown in Table 1). The surveying data included the elevation data of discrete points on the ground, the bench crest line, and the bench toe line. Based on these discrete points data during five periods, five DEM data, with a spatial resolution of 2m, are generated from the discrete-points data over the five time periods by taking bench crest and bench toe as topographically characteristic lines using the constraint TIN method (Zhu and Zhang, 2017), which are denoted as E_1, E_2, E_3, E_4 and E_5, respectively, as shown in Figure 2. The terrain information of those five time periods is summarized in Table 1.

2.3 Analysis of the Open-Pit Mining Activity

The mining activities on the rock strata directly cause the damage of the earth's surface. The earth's surface is stripped and mined by the mining activities. Stripping activity is that the soil and rock, which cover the top and surrounding of ore body, are peeled off to make the ore easy to be dug. After stripping, the mining activity is followed to excavate the loose ore rock on the bench and put it into the transportation equipment. In this paper, the mining activity can be subdivided into four stages according to the temporal-spatial mining sequence (Figure 3): unexploited stage, progressive mining stage, continuous mining stage and ending stage. The latter three stages are the surface change process.

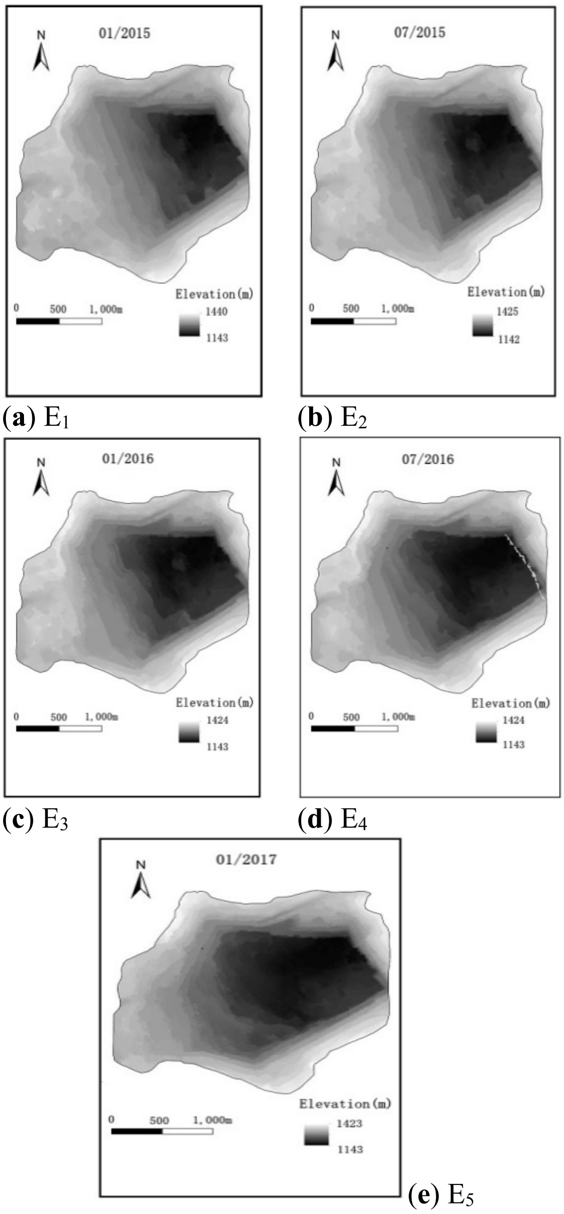


Figure 2: Five Period DEM data set of East Open-pit Mine. (a) DEM in January 2015; (b) DEM in July 2015; (c) DEM in January 2016; (d) DEM in July 2016;(e) DEM in January 2017.

Table 1: The terrain information of five period DEM.

Serial number	Elevation (m)	Average elevation(m)	Standard deviation of elevation	Slope(°)	Average slope (°)
E_1	1143-1440	1292	85.75	0-86.56	17.93
E_2	1142-1425	1284	80.83	0-86.48	16.16
E_3	1143-1424	1284	81.12	0-86.77	17.58
E_4	1143-1424	1283.5	81.7	0-88.97	16.2
E_5	1143-1423	1283.5	85.75	0-86	18.31

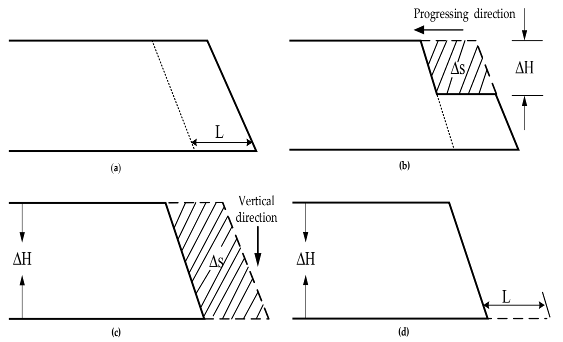


Figure 3: Four stages of the open pit mining activity. (a) Unexploitation stage; (b) Progressing mining stage (Shaded areas for the mining area); (c) Continuous mining stage; (d) Ending stage.

Unexploited stage (Figure 3-a). This stage refers to the mining activities are not carried out yet.

Progressing mining stage (Figure 3-b). In this stage, the topsoil is removed and the ore body isstripped , being divided in each mining section. The stripping area is extended to the direction of excavation after the rock and soil are stripped. The progressing direction is westward, "ΔS" indicates the progressing stripping area," ΔH" indicates the progressing stripping depth. During this stage, the surface is changed in both horizontal and vertical directions.

Continuous mining stage (Figure 3-c). This is the deep cutting process, based on the stripping workspace, in the vertical direction, terminating when the working surface is completely exploited. As a result, a large amount of ore is excavated from the coal seam and the surface is significantly destroyed. The stripping slope is vertically cut, until the elevation changes to a maximum value. During this stage, the horizontal area of the surface keeps unchanged, but the vertical area is obviously changed.

Ending stage (Figure 3-d). No further mining activities will take place in this area after the mining process.

2.4 Dynamic Surface Units

Based on the analysis of the mining activity, the surface can be divided into three dynamic units: progressing mining area, continuing mining area, and discontinued mining area, respectively. The progressing mining area includes both horizontal and vertical changes in the area, which correspond to the progressing mining stage; the continuing mining area is only along the vertical direction, which corresponds to the continuous mining stage; the discontinued mining area corresponds to the ending stage, which has not any changes along the horizontal and vertical directions.

For an example (Figure 4): The mining direction is westward. The progressing mining area, the continuing mining area and the discontinued mining area is showed along the mining direction.

S_1, S_2, S_3 represent the mining areas of the T_1, T_2, and T_3 periods, respectively.

From the T_1 period to the T_2 period, the mining area changed from the S_1 to the S_2. In the range of S_1, the dynamic units of the discontinued mining area and the continuing mining area are formed; within the range of S_2, the dynamic units of the progressing mining area and the continuing mining area are formed. The continuing mining area is the intersection of S_1 and S_2.

Similarly, from the T_2 period to the T_3 period, the mining area can also be divided into three surface dynamic units.

Therefore, the surface change process is the alternating process of dynamic units due to the mining activities.

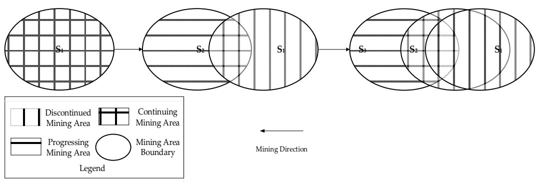


Figure 4: Dynamic surface units.

2.5 Method

Taking three time terrain data as an example (Figure 5), the dynamic topographic data E_1, E_2, and E_3 are the DEM data which are corresponding to the time of t_1, t_2 and t_3, respectively. The calculation method is as follows：

Through the DEM differential calculation , it can be obtained:

$$M_1=E_2-E_1;\ M_2=E_3-E_2;$$

Regroup the raster data to filter out the raster dataset with M<0; and then extracts the corresponding vector data S_1 and S_2; They are mining areas stripped in the period of T_1 and T_2 ;

The intersection of S_1 and S_2 is performed to obtain the continuing mining area C_1 which is stripped in the period between T1 period and T_2:

$$S_1\cap S_2=\{C_1 \mid C_1\in S_1, \text{and } C_1\in S_2\}$$

Differential calculation of S_1 and C_1 to obtain discontinued mining area D_1 which is stripped in the period between T_1 and T_2;

$$S_1-C_1=\{D1 \mid D_1\in S_1,\text{and } D_1\notin S_2\}$$

Differential calculation of S_2 and C_1 to obtain progressing mining area P_1 obtained in the period between T_1 and T_2;

$$S_2-C_1=\{P_1 \mid P_1\in S_2,\text{且 } P_1\notin S_1\}$$

After the calculation process described above, the mining change areas of D_1 and P_1 in the period of T_1 and T_2 are obtained, respectively, and the continuing area is C_1.

Based on this method, the mining surface area change in specific mining time is obtained through DEM differential computation and the calculation of vector data of the space set. The surface changing is simulated through the combination of the time series and topographic data.

3.1 Results

The elevation changing datasets are calculated by differential calculation of DEM data in five times (t_1,t_2,t_3,t_4,t_5), which are M_1, M_2, M_3 and M_4 respectively. Then, the mining area datasets, which is S_1, S_2, S_3, and S_4, can be extracted as the value of M_1, M_2, M_3 and M_4 are less than zero, it means the decreasing elevation datasets among the elevation changing datasets. According to the raster calculation, the calculation relationship between the dynamic surface units and the elevation changing datasets are listed in Table 2. Therefore, the elevation changing datasets of the dynamic surface units can be extracted to simulating the open-cast mining process chronologically.

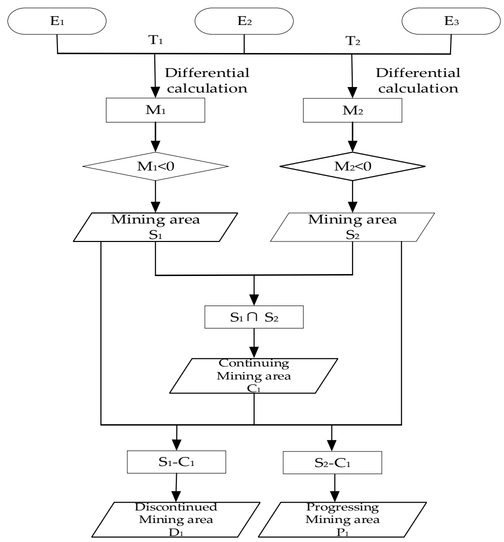


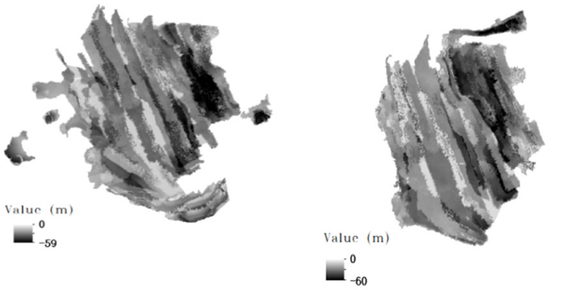
Figure 5: Dynamic terrain data calculation method.

3 RESULTS AND ANALYSIS

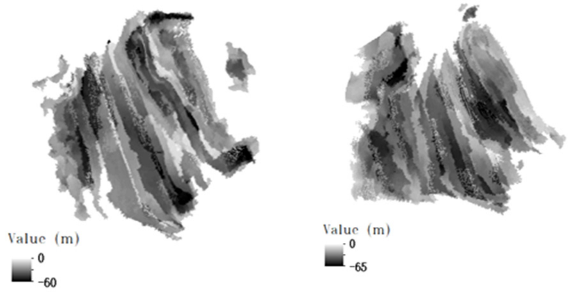
Table 2: Elevation changing datasets calculation relationship.

Time	Change area	Mining area	Promoting mining area	Continuing mining area	Discontinued mining area
T_1	$M_1=E_2-E_1$	$S_1=M_1<0$	/	$C_1=C_1\cap S_1$	/
T_2	$M_2= E_3-E_2$	$S_2=M_2<0$	$P_1=P_1\cap S_2$	$C_2=C_1\cap S_2$	$D_1=D_1\cap S_1$
T_3	$M_3= E_4-E_3$	$S_3=M_3<0$	$P_2=P_2\cap S_3$	$C_3=C_3\cap S_3$	$D_2=D_2\cap S_2$
T_4	$M_4= E_5-E_4$	$S_4=M_4<0$	$P_3=P_3\cap S_4$	$C_4=C_4\cap S_4$	$D_3=D_3\cap S_3$

The spatial distribution of the mining area, during different time intervals of the East open pit mine, is extracted from the five-phase DEM data and shown in Figure 6, and the dynamic surface units area in different stages are shown in Figure 7-9.



(a) S_1 (201507-201501)   (b) S_2 (201601-201507)



(c) S_3 (201607-201601)   (d) S_4 (201701-201607)

Figure 6: Open-pit mining area.

(a) P_1 (201601-201507) (b) P_2 (201607-201601) (c) P_3 (201701-201607)

Figure 7: Progressing mining area (the red region).

(a) C_1 (201601-201507) (b) C_2 (201607-201601) (c) C_3 (201701-201607)

Figure 8: Continuing mining area (the red region).

(a) D_1 (201507-201501) (b) D_2(201601-201507) (c) D_3 (201607-201601)

Figure 9: Discontinued mining area (the green region).

3.2 Analysis

In this paper, the variation parameters of mining area are grouped into geometric changes parameters and vertical changes parameters in horizontal and vertical directions, respectively. Geometric changes parameters are mining area, mining perimeter and the proportion of total mining area in each region. The vertical parameters include maximum mining depth, the average mining depth and standard mining depth deviation. The change parameters of the mining area are calculated in Table 3-6. The statistical analysis of the mining area in each period are summarized in Figure 10.

Mining area. S_1 has the largest mining area and perimeter, and the smallest mining depth and average mining depth; and S_4 has the largest mining depth, average mining depth and mining depth standard deviation.

Table 3: Mining area parameters.

	Geometric changes parameters			Vertical changes parameters		
Mining area	Area(km^2)	Perimeter(km)	Proportion(%)	Maximum(m)	Average(m)	Standard deviation
S_1	2.13	13.57	42.52	59	32	9.58
S_2	1.75	9.22	34.93	60	32.5	9.63
S_3	1.72	12.65	34.33	60	32	10.7
S_4	1.79	13.05	35.73	65	35	11.62

Table 4: Promoting mining area parameters.

	Geometric changes parameters			Vertical changes parameters		
Mining area	Area(km^2)	Perimeter(km)	Proportion(%)	Maximum(m)	Average(m)	Standard deviation
P_1	0.17	7.38	3.39	60	32	18.18
P_2	0.33	7.62	6.59	57	29	16.45
P_3	0.49	9.01	9.78	65	33	18.76

Table 5: Continuing mining area parameters.

	Geometric changes parameters			Vertical changes parameters		
Mining area	Area(km^2)	Perimeter(km)	Proportion(%)	Maximum(m)	Average(m)	Standard deviation
C_1	1.58	7.84	31.54	54	27.5	15.59
C_2	1.39	9.02	27.74	60	31.6	18.06
C_3	1.3	11.18	25.95	63	32	18.18

Table 6: Discontinued mining area parameters.

	Geometric changes parameters			Vertical changes parameters		
Mining area	Area(km^2)	Perimeter(km)	Proportion(%)	Maximum(m)	Average(m)	Standard deviation
D_1	0.55	14.7	10.98	59	29.5	16.74
D_2	0.36	8.96	7.19	60	32.5	16.16
D_3	0.42	11.89	8.38	64	32.08	18.31

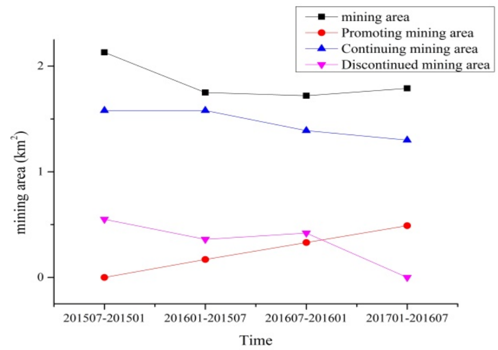


Figure 10: Analysis of mining area and dynamic surface units.

Progressing mining area. In T_4 period (as P_3), the mining area and perimeter are largest, the value of mining depth, the average mining depth and mining depth standard deviation are the largest.

Continuing mining area. C_1 is the largest in the continuing mining areas, the largest mining circumference is C_3, and C_3 has the maximum mining depth, and the lagest average mining depth and mining depth standard deviation.

Discontinued mining area. D_1 is the area with the largest circumference and the area has the shortest circumference is D_2. In addition, D_2 has the largest average mining depth, and D_3 has the largest standard deviation of the maximum mining depth.

The area composition of each dynamic unit and mining area is shown in Figure 11. Due to the relationship model between mining activity and dynamic data, the mining area is decomposed into dynamic units, which is specifically expressed as follows:

The mining area S_1 corresponding to the initial time interval can be decomposed into combination of continuing mining area C_1 and discontinued mining area D_1;

The mining area S_2 corresponding to the second period of time interval and the mining area S_3 corresponding to the third period of time interval can be decomposed into two combinations of dynamic units; one is combination of continuing mining area and promoting mining area, and the other is the combination of continuing mining area and discontinued mining area;

The mining area S_4 corresponding to the last period of time can be decomposed into acombination of continuing mining area and promoting mining area.

In each dynamic change units, the continuing mining area is the largest region, the area range is [1.3, 1.58]; the promoting mining area is the smallest, and the area range is [0.17, 0.49]. The results show the mining surface change is affected by continuous mining more than the promoting mining within the mining period.

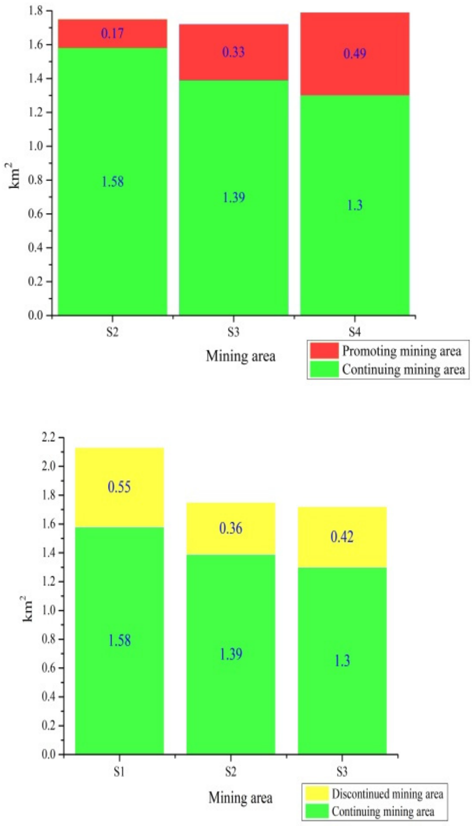


Figure 11: Dynamic surface units statistical histogram.

4 CONCLUSIONS

In this study, a fast, effective and low-cost data calculation method was proposed to simulate surface mining process through analyzing the temporal and spatial variation characteristics of open-pit mining process. Using the spatio-temporal data model, DEM calculation method and spatial datasets operation, the surface dynamic process evaluation in the open-pit mine can be numerical simulated and analyzed practically.

The conclusions are as below:

According to the correlation between"vertical dynamics" and "horizontal dynamics" of the mining engineering activities, the regular pattern between "vertical deformation" and "surface change" is excavated, and the spatial-temporal calculation model of open-pit mining is established;

The key point of this method is that the mining changing area is divided into three dynamic surface units. According to the dynamic process of mining, the mining surface is decomposed into three dynamic surface units to simulate the dynamic surface processes coupled with the mining engineering activities;

Through the differential calculation of multi-period DEM data and the spatial relationship calculating of dynamic region, the spatio-temporal process of the open-pit mining surface is simulated effectively. The method can not only analysis the dynamic change and realize three-dimensional visualization, but also quantitatively evaluate the surface mining change.

REFERENCES

Brown A G, Tooth S and Chiverrell R C, et al. 2013 The Anthropocene: is there a geomorphological case? *Earth Surface Processes & Landforms* **38(4)** 431-434

Carley J K, Pasternack G B and Wyrick J R, et al. 2012 Significant decadal channel change 58–67 years post-dam accounting for uncertainty in topographic change detection between contour maps and point cloud models *Geomorphology* **179** 71-88

Chen J, Li K and Chang K J, et al. 2015 Open-pit mining geomorphic feature characterisation *International Journal of Applied Earth Observation & Geoinformation* **42** 76-86

Ellis E C 2011 Anthropogenic transformation of the terrestrial biosphere *Philosophical Transactions* **369**(1938) 1010-1035

Foley J A, Defries R and Asner G P, et al. 2005 Global Consequences of Land Use *Science* **309(5734)** 570-574

Haas F, Hilger L and Neugirg F, et al. 2016 Quantification and analysis of geomorphic processes on a recultivated iron ore mine on the Italian island Elba using long-time ground-based LIDAR and photogrammetric data by an UAV *Natural Hazards & Earth System Sciences* **3(10)** 6271-6319

Hu W and Wu L 2016 Ground Deformation Extraction Using Visible Images and LIDAR Data in Mining Area ISPRS - International Archives of the Photogrammetry *Remote Sensing and Spatial Information Sciences* **XLI-B7** 505-512

James L A, Hodgson M E and Ghoshal S, et al. 2012 Geomorphic change detection using historic maps and DEM differencing: The temporal dimension of geospatial analysis *Geomorphology* **137(1)** 181-198

Martín ‐ Duque J F, Sanz M A and Bodoque J M, et al. 2010 Restoring earth surface processes through landform design. A 13 ‐ year monitoring of a geomorphic reclamation model for quarries on slopes *Earth Surface Processes & Landforms* **35(5)** 531-548

Neugirg F, Kaiser A and Schmidt J, et al. 2015 Quantification, analysis and modelling of soil erosion on steep slopes using LiDAR and UAV photographs *Proceedings of the International Association of Hydrological Sciences* **367** 51-58

Schaffrath K R, Belmont P and Wheaton J M 2015 Landscape-scale geomorphic change detection: Quantifying spatially variable uncertainty and circumventing legacy data issues *Geomorphology* **250** 334-348

Tarolli P 2014 High-resolution topography for understanding Earth surface processes: Opportunities and challenges *Geomorphology* **216** 295-312

Tarolli P and Sofia G 2016 Human topographic signatures and derived geomorphic processes across landscapes *Geomorphology* **255(4)** 40-161

Tong X, Liu X and Chen P, et al. 2015 Integration of UAV-Based Photogrammetry and Terrestrial Laser Scanning for the Three-Dimensional Mapping and Monitoring of Open-Pit Mine Areas *Remote Sensing* **7(6)** 6635-6662

Yucel M A and Turan R Y 2016 Areal Change Detection and 3D Modeling of Mine Lakes Using High-Resolution Unmanned Aerial Vehicle Images *Arabian Journal for Science & Engineering* **41(12)** 1-12

Zhu W B and Zhang J 2017 A method of building the Open-pit mine DEM based on hierarchical constraint TIN *Science of Surveying and Mapping* **42(7)** 160-164(in Chinese)