Temporal and spatial changes of land use and landscape in a coal mining area in Xilingol grassland

Chunzhu Guan, Baolin Zhang, Jiannan Li and Junling Zhao

College of Chemistry and Environmental Sciences, Inner Mongolia Normal University, Hohhot 010020, P.R. China

E-mail: nmzhangbaolin@hotmail.com

Abstract. Coal mining, particularly surface mining, inevitably disturbs land. According to Landsat images acquired over Xilingol grassland in 2005, 2009 and 2015, land uses were divided into seven classes, i.e., open stope, stripping area, waste-dump area, mine industrial area, farmland, urban area and the original landscape (grassland), using supervised classification and human-computer interactive interpretation. The overall classification accuracies were 97.72%, 98.43% and 96.73%, respectively; the Kappa coefficients were 0.95, 0.97 and 0.95, respectively. Analysis on LUCC (Land Use and Cover Change) showed that surface coal mining disturbed grassland ecosystem: grassland decreased by 8661.15 hm² in 2005-2015. The area and proportion of mining operation areas (open stope, stripping area, waste-dump area, mine industrial field) increased, but those of grassland decreased continuously. Transfer matrix of land use changes showed that waste-dump had the largest impacts in mining disturbance, and that effective reclamation of waste-dump areas would mitigate eco-environment destruction, as would be of great significance to protect fragile grassland eco-system. Six landscape index showed that landscape fragmentation increased, and the influences of human activity on landscape was mainly reflected in the expansion of mining area and urban area. Remote sensing monitoring of coal surface mining in grassland would accurately demonstrate the dynamics and trend of LUCC, providing scientific supports for ecological reconstruction in surface mining area.

1. Introduction

Coal is a major energy resource in China, and the related industries cause a series of environmental issues in the mining, burning and use of its products. The environmental impacts include problems such as coal mine encroaching on forest, farmland and grassland [1], geological disaster, air and water pollution [2-4], vegetation destruction [5], soil pollution and land degradation [6] and occupation [7], etc. These influences may seriously affect the ecological processes, human health [8] and the coordinated development of social economy. The consequences of terrestrial ecosystem destruction in surface mining are the most obvious and direct. LUCC in surface coal mining areas therefore attracted widely concerns. Studies, such as surface mining monitoring [9], environmental impact indicators [10, 11], vegetation succession [12], relationships between land use change and landscape structure [13], and reclamation of abandoned mines [14], have been carried out in Turkey, Brazil, Australia, Germany, the United States and other countries. In China, extensive studies have also been conducted in surface mining areas, including the extraction of land disturbance features [15], the changes of landscape pattern [16], the evolution of land use pattern [17], the influence of mine subsidence [18], land reclamation and land structure
change [19], etc. Satellite remote sensing has the characteristics of wide coverage and good temporal and spatial continuities, providing us a reliable means for studying large-scale environmental change. Remote sensing technique has been widely applied to mine investigation [20], coal mine monitoring [9], mining supervision [21], mine environment monitoring [22] and ecological recovery [23].

Since the 1990s, LUCC has become the essential component and the primary cause of global environmental change, attracted worldwide concerns [24]. Large-scale exploitation of mineral resources in Xilingol grassland (Inner Mongolia, China) brought great pressure on ecological environment, leaving the local in the dilemma of economic development and ecological protection. Despite of numerous reports on coal mining monitoring and ecological environmental consequences [22, 23], few are about coal mining in Xilingol grassland. Analysis on LUCC and landscape index of coal mining areas in Xilingol grassland will help us to understand the change of land use and landscape patterns, providing a guide for land use planning of surface coal mining in arid and semi-arid grassland, and a scientific basis for land reclamation and ecological compensation.

2. Data and methods

2.1. Study area

Xilingol grassland is on the edge of the east Asian monsoon, located in the northeast China sample belt of IGBP (International Geosphere-Biosphere Program). Coal mines investigated are located in Xilingol grassland (figure 1), the main body of the natural grassland of Inner Mongolia. The study area is located in the mid-latitude temperate monsoon zone of semi-arid and arid continental climate. Soil are mainly chestnut, suffering wind erosion and hydraulic erosion. The grassland vegetation is dominated by *Stipa grandis*, *Leymus chinensis* and *S. krylovii*, etc., with a coverage of 50%.

![Figure 1. Landsat 8 OLI false colour composite image of the study area.](image-url)
2.2. Data and method

Landsat series data used in the study are from the USGS (the United States Geological Survey), acquired on September 2, 2005 (Landsat 5 TM (Thematic Mapper)), August 12, 2009 (Landsat 5 TM) and July 12, 2015 (Landsat 8 OLI (Operational Land Imager)), respectively.

Data processing includes radiometric calibration, atmospheric correction and image enhancement, etc. Using field survey data, supervised classification and man-computer interactive interpretation, land uses were divided into seven categories: open stope, stripping area, waste-dump area, mine industrial area, farmland, urban area and the original landscape (grassland). Post-classification change detection was employed to determine LUCC over the time. Transfer matrix were used to depict the temporal and spatial changes (speed and direction) of land uses. Average annual change rate was used to describe land use changes (in area and speed) and their differences:

\[ K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \]

where K is the average annual change rate of land use; \( U_a \), \( U_b \), the starting and the end of the study period, respectively; \( T \), time (year) [25].

Spatial patterns of LUCC were characterized by landscape metrics calculated using FRAGSTATS. Land use/cover maps derived from classification images were used to quantify the areal extent and spatial configuration of patches within a landscape. We selected Total Area (TA), Percentage of Landscape (PLAND), Number of Patches (NP), Patch Density (PD), Largest Patch Index (LPI) and Euclidean Nearest Neighbor Distance (ENN) to represent the landscape structure and configuration.

3. Results

3.1. Land use change

Table 1. Land use changes in area and proportion in 2005-2015.

| land use/cover      | 2005    | 2009    | 2015    |
|---------------------|---------|---------|---------|
|                     | area (hm\(^2\)) | proportion (%) | area (hm\(^2\)) | proportion (%) | area (hm\(^2\)) | proportion (%) |
| open stope          | 22.32   | 0.03    | 130.50  | 0.17    | 341.73      | 0.45          |
| stripping area      | 187.17  | 0.25    | 756.18  | 1.00    | 1474.29     | 1.95          |
| waste-dump area     | 461.34  | 0.60    | 1860.84 | 2.45    | 3644.82     | 4.82          |
| mine industrial area| 981.00  | 1.29    | 1261.35 | 1.67    |             |               |
| farmland            | 3036.24 | 3.98    | 2060.55 | 2.71    | 1851.48     | 2.45          |
| urban area          | 3904.92 | 5.11    | 4843.89 | 6.37    | 7362.36     | 9.73          |
| original landscape  | 68418.27| 89.59   | 65059.11| 85.57   | 59757.12    | 78.91         |

Table 2. Periodical variations in average annual change index of different land uses.

| land use/cover      | 2005-2009 | annual change gradient (%) | 2009-2015 | annual change gradient (%) | 2005-2015 | annual change gradient (%) |
|---------------------|-----------|-----------------------------|-----------|-----------------------------|-----------|-----------------------------|
| open stope          | 108.18    | 96.94                       | 211.23    | 23.12                       | 319.41    | 130.10                      |
| stripping area      | 569.01    | 60.80                       | 718.11    | 13.57                       | 1287.12   | 62.52                       |
| waste-dump area     | 1399.5    | 60.67                       | 1783.98   | 13.70                       | 3183.48   | 62.73                       |
| mine industrial area| 981.00    | ---                         | 280.35    | 4.08                        | 1261.35   | ---                         |
| farmland            | -975.69   | -6.43                       | -209.07   | -1.45                       | -1184.76  | -3.55                       |
| urban area          | 938.97    | 4.81                        | 2518.47   | 7.43                        | 3457.44   | 8.05                        |
| original landscape  | -3359.16  | -0.98                       | -5301.99  | -1.16                       | -8661.15  | -1.15                       |

With the support from field survey GPS data, supervised classification was used in the study. Land uses were divided into seven types, i.e., open stope, stripping area, waste-dump area, mine industrial area, farmland, urban area and the original landscape (grassland), using supervised classification and human-computer interactive interpretation. The overall classification accuracies were 97.72 %, 98.43 % and 96.73 %, respectively; the Kappa coefficients were 0.95, 0.97 and 0.95, respectively. The areas and proportions of land uses in the mining area, i.e., open stope, stripping area, waste-dump area and mine industrial area, increased in the 11 years (table 1-2, figure 2). Analysis on changes of waste-
dump area showed that the area accounted for 0.60% in 2005, 2.45% in 2009 and 4.82% in 2015, showing a faster increase by 3183.48 hm$^2$. Open stope increased from 0.03% in 2005 to 0.45% in 2015, the growth rate was relatively low. Urban area accounted for 5.11% in 2005, 6.37% in 2009 and 9.73% in 2015. Xilinhot expanded and grew fast, urban area increased by 3457.44 hm$^2$. With the growth of mining and urban areas, farmland and original landscape decreased continuously. Farmland reduced by 1184.76 hm$^2$, dropping from 3.98% in 2005 to 2.45% in 2015. Original landscape decreased by 8661.15 hm$^2$, area ratio decreased from 89.59% in 2005 to 78.95% in 2015. Average annual change rates showed original landscape presented an accelerated decline. In addition, according to patch changes (figure 2) and field survey, agricultural intensification and urban expansion could be found: large irrigation systems appeared and the city grew substantially in the east and the west.

According to land use maps in 2005 and 2015 (figure 2) and land use change matrix (table 3), the conversions of land uses showed that original landscape transformed to urban and waste-dump areas by 3637.89 hm$^2$ and 3479.04 hm$^2$, respectively. Conversions from original landscape to stripping area and mine industrial site were also over 1000 hm$^2$. Therefore, original landscape mainly changed into mining area and urban constructions.

3.2. Changes of landscape metrics
The original landscape dominated the study area, with proportions of over 75%, but the area and proportion appeared to decline (figure 3a and 3b), showing original landscape were destroyed in the 11 years. NP and PD of the mining area increased during 2005-2015 (figure 3c and 3d), demonstrating that fragmentation and ecological risk increased. The effects of mining activity on the landscape patterns can be reflected. LPI of urban and mining operation areas tended to grow (figure 3e), the growth rate of the city was higher. LPI of farmland was decreasing from 2.21% in 2005 to 0.95% in 2009, and then rising to 1.49% in 2015. ENN generally showed a decreasing trend, as showing that the nearest neighbour distance between patches decreased (figure 3f), leading to the increase of the aggregation of patches and the decrease of elongation of various land uses. In the 11 years from 2005 to 2015, landscape changed significantly, the number of patches and patch density increased, and the degree of landscape fragmentation increased. The areas under high fragmentation are located close to coal mines, and the high fragmentation areas increased in areas which were previously under low fragmentation (figure 2).
Figure 2. Land use changes in 2005-2015: a 2005, b 2009 and c 2015.

4. Conclusions and discussion
Surface coal mining is a disturbance to the grassland ecosystem. In 2005-2015, mine areas in the study area increased, while the original grassland landscape showed an accelerated decrease. Damages of surface mining to grassland were obvious and direct. Studies showed that the ecological and environmental loss caused by coal mining was far more than its economic benefits [26], sustainable mining requires continuous monitoring of LUCC to identify the long-term impacts of mining on...
environment and land cover to provide essential safety measures [9]. To understand and predict the status and temporal changes of land uses, studies on land use changes in surface mining area have important significances for rational planning, long-term use and sustainable development of eco-environment.

Table 3. Transfer matrix of land use changes in 2005-2015.

| land use/change (2005) | open stope | stripping area | waste-dump area | industrial area | farmland | original landscape | urban area | total |
|------------------------|------------|----------------|----------------|----------------|----------|--------------------|------------|-------|
| open stope             | ---        | 8.55           | 8.55           | 2.52           | ---      | 2.70               | ---        | 22.32 |
| stripping area         | 4.41       | 75.24          | 37.44          | 22.50          | 0.90     | 39.42              | 6.21       | 186.12|
| waste-dump area        | 3.24       | 94.86          | 83.79          | 18.63          | 2.07     | 189.00             | 69.21      | 460.80|
| farmland                | ---        | 1.35           | 9.09           | 31.95          | 1380.78  | 1268.64            | 341.37     | 3033.18|
| original landscape     | 328.14     | 1280.07        | 3479.04        | 1121.76        | 449.91   | 57662.10           | 3637.89    | 67958.91|
| urban area              | 5.94       | 14.22          | 26.10          | 62.64          | 17.46    | 428.67             | 3307.68    | 3862.71|
| total                  | 341.73     | 1474.29        | 3644.01        | 1260.00        | 1851.12  | 59590.53           | 7362.36    | 75524.04|

Figure 3. Landscape metrics changes in 2005-2015.

Waste-dump had great impacts on land use in surface coal mining area. According to land use dynamics in 2005-2015, the main changes were the conversions of original landscape into artificial features, such as mining and urban areas. Researchers argued that mining and mineral-processing wastes are one of the world’s largest chronic waste concerns [27], environmental monitoring and
assessment should never be neglected. In this study, the influence of waste-dump field on land use was the largest in a surface coal mining area. In European countries, more than 50 % of previously mined lands are reclaimed as forest or grass lands; in China, more than 70 % for agricultural purposes [4]; however, no mined lands in the study area were observed to be reclaimed. Effective reclamation of waste-dump field therefore is very important; this will mitigate eco-environmental degradation, showing great significance to protect grassland ecosystem.

Landscape fragmented in the mining area. The areas under high fragmentation, which were the areas at risk [5], are located close to coal mines. The high fragmentation areas increased in areas which were previously under low fragmentation, but the fragmentation impact on terrestrial environment have been largely overlooked in mining [28]. If eco-environment of grassland was destroyed, ecological restoration would be difficult, high-costed and time-consumed, as is the common issue in the development of coal resources; improper handling will affect the sustainable development of regional economy.

Acknowledgements
The authors gratefully acknowledge financial support from the National Natural Science Foundation of China (Grant Nos. 41261048 and 40961014).

References
[1] Zhai M, Xu X, Jiang D, Jiang X 2012 Remote sensing monitoring of the ecological environment in Wuhai mining area since 1979 (in Chinese with English abstract) Remote Sensing Technology and Application 27(6) 933-940
[2] Lindberg T T, Bernhardt E S, Bier R, Helton A M, Merola R B, A Vengosh, et al. 2011 Cumulative impacts of mountaintop mining on an Appalachian watershed Proceedings of the National Academy of Sciences of the United States of America 108(52) 20929-34
[3] Bernhardt E S, Palmer M A 2011The environmental costs of mountaintop mining valley fill operations for aquatic ecosystems of the Central Appalachians Annals of the New York Academy of Sciences 1223(1) 39-57
[4] Bian Z, Inyang H I, Daniels J L, Otto F, Struthers S 2010 Environmental issues from coal mining and their solutions Mining Science and Technology (China) 20(2) 215-223
[5] Sarma K 2005 Impact of coal mining on vegetation a case study in Jaintia Hills District of Meghalaya, India The International Institute for Geo-information Science and Earth Observation, The Netherlands
[6] Qian T, Bagan H, Kinoshita T, Yamagata Y 2014 Spatial-temporal analyses of surface coal mining dominated land degradation in Hulingol, Inner Mongolia IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 7(5) 1675-87
[7] Bian Z, Miao X, Lei S, Chen S, Wang W, Struthers S 2012 The challenges of reusing mining and mineral-processing wastes Science 337(6095) 702-703
[8] Palmer M A, Bernhardt E S, Schlesinger W H, Eshleman K N, Foufoula-Georgiou E, Hendryx M S, et al. 2010 Mountaintop mining consequences Science 327(5962) 148 -149
[9] Demirel N, Emil M K, Duzgun H S 2011 Surface coal mine area monitoring using multi-temporal high-resolution satellite imagery International Journal of Coal Geology 86(1) 3-11
[10] Santo E, Sánchez L 2002 GIS applied to determine environmental impact indicators made by sand mining in a floodplain in southeastern Brazil Environmental Geology 41(6) 628-637
[11] Kong J L, Xian T, Yang J, Chen L, Yang X T 2016 Monitoring soil moisture in a coal mining area with multi-phase LANDSAT images The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences XLII-B7 537-542
[12] Norman M A, Koch J M, Grant C D, Morald T K, Ward S C 2006 Vegetation succession after bauxite mining in Western Australia Restoration Ecology 14(2) 278-288
[13] Baessler C, Klotz S 2006 Effects of changes in agricultural land-use on landscape structure and arable weed vegetation over the last 50 years Agriculture, Ecosystems & Environment 115(1-4) 43-50
[14] Gorokhovich Y, Reid M, Mignone E, Voros A 2003 Prioritizing abandoned coal mine reclamation projects within the contiguous United States using geographic information system extrapolation
[15] Bi R, Bai Z 2007 Land characteristic information and classification in opencast coal mine based on remote sensing images (in Chinese with English abstract) Transactions of the CSAE 23(2) 77-82, 291

[16] Bian Z, Zhang Y 2006 Land use changes in Xuzhou coal mining area (in Chinese with English abstract) Acta Geographica Sinica 61(4) 349-358

[17] Zhang Q, Bai Z, Hao J, Fan J, Zhao J 2006 Pattern succession analysis of agricultural land converted from large opencast mine in loess areas (in Chinese with English abstract) Transactions of the CSAE 22(11) 98-103

[18] Bai Z, Duan Y, Yang H, Fu H, Lv C, Ma R 2006 Forecast of influence of coal-mining subsidence on soil erosion and land use (in Chinese with English abstract) Transactions of the CSAE 22(6) 67-70

[19] Hu Z, Xie H 2005 Study on land use/cover change of coal mining area based on remote sensing images (in Chinese with English abstract) Journal of China Coal Society 30(1) 44-48

[20] Li C, Sun S, Wang X, Zhang G, Niu J 2010 Application of remote sensing technology in coal resource investigation and evaluation in Zhaotong, Yunnan (in Chinese with English abstract) Coal Geology of China 22(10) 17-21

[21] Kang G, Lu Z, Li S, Jin M 2008 Application of remote sensing technology in coal resource exploitation monitoring and management (in Chinese with English abstract) Coal Geology of China 20(1) 13-16

[22] Quan Z, Cheng H, Yu Y, Zou X 2006 Assessment of subsidence impact on vegetation landscape in coal mining area—a case study of Dongda mine in Jincheng city, Shanxi Province (in Chinese with English abstract) Journal of Plant Ecology 30(3) 414-420

[23] Liu J 2008 Remote sensing dynamic monitoring and landscape ecological reconstruction of mineral resources development in Cangshan County (in Chinese with English abstract) [D] Shandong Normal University

[24] Chen Y, Yang P 2001 Recent progresses of international study on land use and land cover change (LUCC) (in Chinese with English abstract) Economic Geography 21(1) 95-100

[25] Long H, Li X 2001 Land use pattern in transect of the Yangtse River and its influential factors (in Chinese with English abstract) Acta Geographica Sinica 56(4) 417-425

[26] Li F, Liu X, Zhao D, Wang B, Jin J, Hu D 2011 Evaluating and modeling ecosystem service loss of coal mining—a case study of Mentougou district of Beijing, China Ecological Complexity 8(2) 139-143

[27] Bian Z, Miao X, Lei S, Chen S, Wang W, Struthers S 2012 The challenges of reusing mining and mineral-processing wastes Science 337(6095) 702

[28] Wickham J, Wood P B, Nicholson M C, Jenkins W, Druckenbrod D, Suter G W, et al. 2013 The overlooked terrestrial impacts of mountaintop mining BioScience 63(5) 335-348