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Short communication

Vegetation coverage change and stability in large open-pit coal mine dumps in China during 1990–2015

Xiaoyang Liu[a], Wei Zhou[a,b,*], Zhongke Bai[a,b]

[a] School of Land Science and Technology, China University of Geosciences (Beijing), 29 Xue Yuan Road, Handian District, 100083 Beijing, People's Republic of China

[b] Key Laboratory of Land Consolidation and Rehabilitation, Ministry of Land and Resources, 100035 Beijing, People's Republic of China

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ABSTRACT

Ecosystem reconstruction via vegetation restoration is key to comprehensive renewal of the fragile ecological environment of an open-pit mine dump. To investigate vegetation coverage change and stability after mine dump land reclamation, three dumps in the Antaibao open-pit coal mine, northern Shanxi province, China, were used. This region has a typical temperate arid to semi-arid continental monsoon climate. Vegetation coverage was calculated from 11 Landsat remote images taken 1990–2015. Methods included calculation of the Normalized Difference Vegetation Index (NDVI), decomposition of mixed pixels, calculation of variation trends, and a transition matrix. The results show that vegetation coverage in the dumps increased dramatically from 1990 to 2015 (with NDVI rising from −0.02 to 0.02 in 1990 to 0.24 to 0.31 in 2015). The change in NDVI was classified mainly as significantly improved, to mostly moderately high coverage, by 2015. Water is a restrictive factor that greatly influenced the growth and development of vegetation. There was greater vegetation coverage and rate of improvement in coverage at higher elevations, and less coverage on steep slopes. Stability analysis of vegetation coverage succession and its recovery after a fire indicate that post-reclamation vegetation coverage in the dumps is relatively stable.

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1. Introduction

Vegetation is an important direct or indirect driver of ecosystem change. It acts as an indicator in global change research (Sun et al., 1998). Vegetation coverage change is a direct result of ecological environment change. As one of the most sensitive and important environmental factors in the ecosystem, it not only reflects the general state of ecological environment (Xin et al., 2007), but also has an influence on other environmental factors (Hu and Chen, 2008).

The severe disturbance caused by coal mining disrupts the original morphology and stratum structure of open-pit coal mines, and hence biotic communities therein (Bai et al., 2000), particularly the local vegetation coverage (Brom et al., 2012; Zhang et al., 2014; Lei et al., 2016). It is important to acquire information about vegetation coverage accurately and quickly during ecosystem reconstruction within a mining area (Hu and Chen, 2008). Waste dumps are an unstable factor in mining areas and vegetation restoration and treatment are particularly difficult in the arid and semi-arid Loess Plateau of China. Researching vegetation coverage in dumps using remote sensing techniques can be both efficient and important. Information about the dynamic ecological environment can be quickly acquired, allowing evaluation of the eco-environmental quality and ecosystem stability of dumps.

Studies on the microscale of dumps and stabilities of different degrees of vegetation coverage in the ecological restoration process are scarce. Therefore, in the present study, using 11 Landsat remote images taken from 1990 to 2015, we analyzed the vegetation coverage change and stability of three dumps of the Antaibao open-pit coal mine in Shanxi province, China. We sought to reveal the following: (1) vegetation coverage change in time and space under reclamation; (2) stabilities of different degrees of vegetation coverage during ecological restoration; and (3) the main factors influencing vegetation coverage in the mining area.

* Corresponding author at: School of Land Science and Technology, China University of Geosciences (Beijing), 29 Xue Yuan Road, Handian District, 100083 Beijing, People's Republic of China.

E-mail address: zhouw@cugb.edu.cn (W. Zhou).

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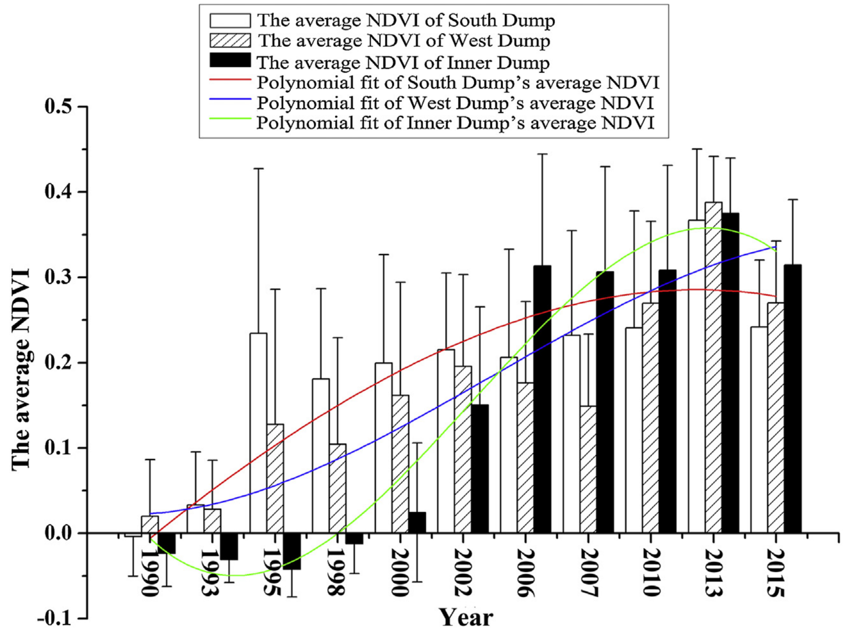

Fig. 1. Average NDVI of dumps in 1990–2015 and its variation trend imitated by Cubic Curve-fitting lines.

2. Materials and methods

2.1. Study area

The Pingshuo mining area is located in Shuozhou, northern Shanxi province, China. This region has a typical temperate arid to semi-arid continental monsoon climate. The average annual temperature is 4.8–7.8 °C and average annual precipitation is 428.2–449.0 mm. The geomorphic type of the mining area is loess low hill area. The zonal vegetation is steppe. The zonal soil is chestnut soil and loessial soil (Zhou et al., 2007). Ecosystem resistance ability here is poor and belongs to a typical fragile eco-environmental zone in the Loess Plateau. The Pingshuo mining area includes three large open-pit mines (Anjialing, Antaibao, and Donglutian). The total area is approximately 160 km^2.

The Antaibao coal mine is the largest open-pit coal mine in China. The original geomorphologic profile has changed greatly since mining began in 1986 and has become the typical artificial stepped dump landform, which has strong influences on the landscape. We took three dumps, specifically the Inner Dump, South Dump and West Dump as the basic objects of analysis. Location, soil properties, and other basic information about the dumps are provided in Supplementary Table 1, Supplementary Figs. 1 and 2.

2.2. Data sources and processing

We used 11 remote sensing images (Landsat TM or Landsat ETM+) taken from 1990 to 2015 (Supplementary Table 2). All remote images were obtained from Geospatial Data Cloud (http://www.gscloud.cn/). To improve the accuracy and reduce the effects of terrain and atmosphere, the images were preprocessed by geometric correction, radiometric calibration, and atmospheric correction using ENVI 5.1 (Exelis Visual Information Solutions, USA).

Meteorological data were obtained from the China Meteorological Administration data network (http://data.cma.gov.cn/). Owing to the absence of meteorological data for Shuozhou, we used Pingyuan, a city 70 km from the study area, as the reference point. Terrain data of the mining area were measured using RTK (Real Time Kinematic) in 2013. Data from the mine was generated into a 5 m spatial resolution digital elevation model (DEM). First-order terrain factors, including elevation, slope, aspect, plan curvature, and profile curvature, were extracted from the DEM.

2.3. Methods

2.3.1. Calculation of the Normalized Difference Vegetation Index (NDVI)

NDVI reflects the proportion of photosynthetically active radiation that is absorbed by vegetation. It can describe the growth condition of vegetation (Yang et al., 2009), and is one of the most frequently used indices for quantitatively evaluating vegetation cover (Tucker et al., 1991; Detsch et al., 2016).

2.3.2. Decomposition of mixed pixels

We used the dimidiate pixel model (Li et al., 2010) to relate vegetation cover to NDVI by classifying each pixel as either pure vegetation or bare soil. The percentage of pure vegetation is called fractional coverage (fc) (Li et al., 2015).

2.3.3. Trend of variation in vegetation coverage

A trend line can describe the trend of changes to a group of variable quantities over time (Ma et al., 2006; Kim et al., 2015). It can reflect the trend for each pixel and so reflect the trend for the whole region (Stow et al., 2003). We used cubic curve fitting to approximate vegetation change trends.

2.3.4. Transition matrix

A transition matrix can depict the structure and trend in variation of different elements both comprehensively and specifically. It is frequently used in studies of land use change (Qiao et al., 2013). We used a transition matrix to track the transitions of NDVI over time.

2.3.5. Other statistical analysis methods

Correlation analysis method was applied to identify the relationship between vegetation coverage or variation trend of vegetation and terrain factors.

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