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ScienceDirect
Trans. Nonferrous Met. Soc. China 21(2011) s583−s588
Transactions of Nonferrous Metals Society of China
www.tnmsc.cn

Annual integral changes of time serial NDVI in mining subsidence area

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Received 19 June 2011; accepted 10 November 2011

Abstract: By means of MORTRAN4 model of FLASSH module, an atmospheric correction of the SPOT II/IV data of four-year period for eight experimental coal faces of Lu'an mine area was done. The mining-affected zones were obtained with probability integral method. The normalized difference vegetation index (NDVI) and its mean were obtained by band ratio calculation at the mining subsidence area. Using FOURIER4 model of the fast Fourier transform (FFT) of discrete Fourier analysis theory, the mean NDVI time series data set was reconstructed. With the mean of NDVI transformed into amplitude and the phonological information transformed into phase, the law of NDVI variation by monthly, quarterly, annual were obtained. The annual integral of the time series of NDVI Fourier function (ANDVI) was obtained. The results show that an experience formula of ANDVI variation accompanies with mining time; A fast estimation formula of NPP by means of a coefficient of mining disturbance such as γ.

Key words: Lu'an mine area; annual integral of NDVI; net primary productivity; coefficient of mining disturbance

1 Introduction

Based on NDVI, the net primary productivity (NPP) spatial-temporal variation has many research results [1−4]. A study shows that the integral values of NDVI curve can comprehensively reflect the overall growth status of vegetation [5]. ANDVI of each pixel in one year is the whole organics manufactured by green vegetation assimilation CO_2 with the help of solar energy within a year. The formula is as follows:

$$ANDVI = \int_0^T NDVI(t)\mathrm{d}t \tag{1}$$

where T is the integration time, and its values range from 0 to 36 calculated by ten days (10 d), and range from 0 to 12 calculated by thirty days (30 d). Each pixel NDVI for a given period can be accumulated and the value can be used as green vegetation primary productivity of the pixel in this period [6].

XIAO et al [7] use remote sensing data of NOAA satellite and estimate NPP in that year in China through the statistical relationship between cumulative sum of NDVI and NPP for various vegetation types within a year. NPP model obtained is as follows:

$$NPP = a[-\ln(1-b\cdot YNDVI)] \tag{2}$$

where a and b are fitting constants related to vegetation type. It can be seen that NPP can be expressed by ANDVI of NDVI integral, and ANDVI and NPP has positive relationship. Therefore, ANDVI changes can incarnate NPP changes.

2 Experimental

2.1 Experimental area

Eight experimental coal faces are selected from Wuyang, Zhangcun, Wangzhuang and Changcun mining areas belonging to Lu'an mining group. Probability integration method (PIM) is used to obtain mining influence areas in mining subsidence prediction. Then NDVI change study of four years, seven phases and 20 m×20 m space resolution is carried on experimental coal faces (see Fig. 1).

2.2 Experimental data

Seven SPOT II/IV images are selected to study, and the date of acquisition on them are respectively 2004−07−08, 2004−11−01, 2005−02−01, 2005−08−26, 2006−05−22, 2007−04−09, 2007−06−01 [8].

Foundation item: Project (50525414) supported by the National Outstanding Youth Fund; Project (2009CB226107) supported by the National Basic Research Program of China
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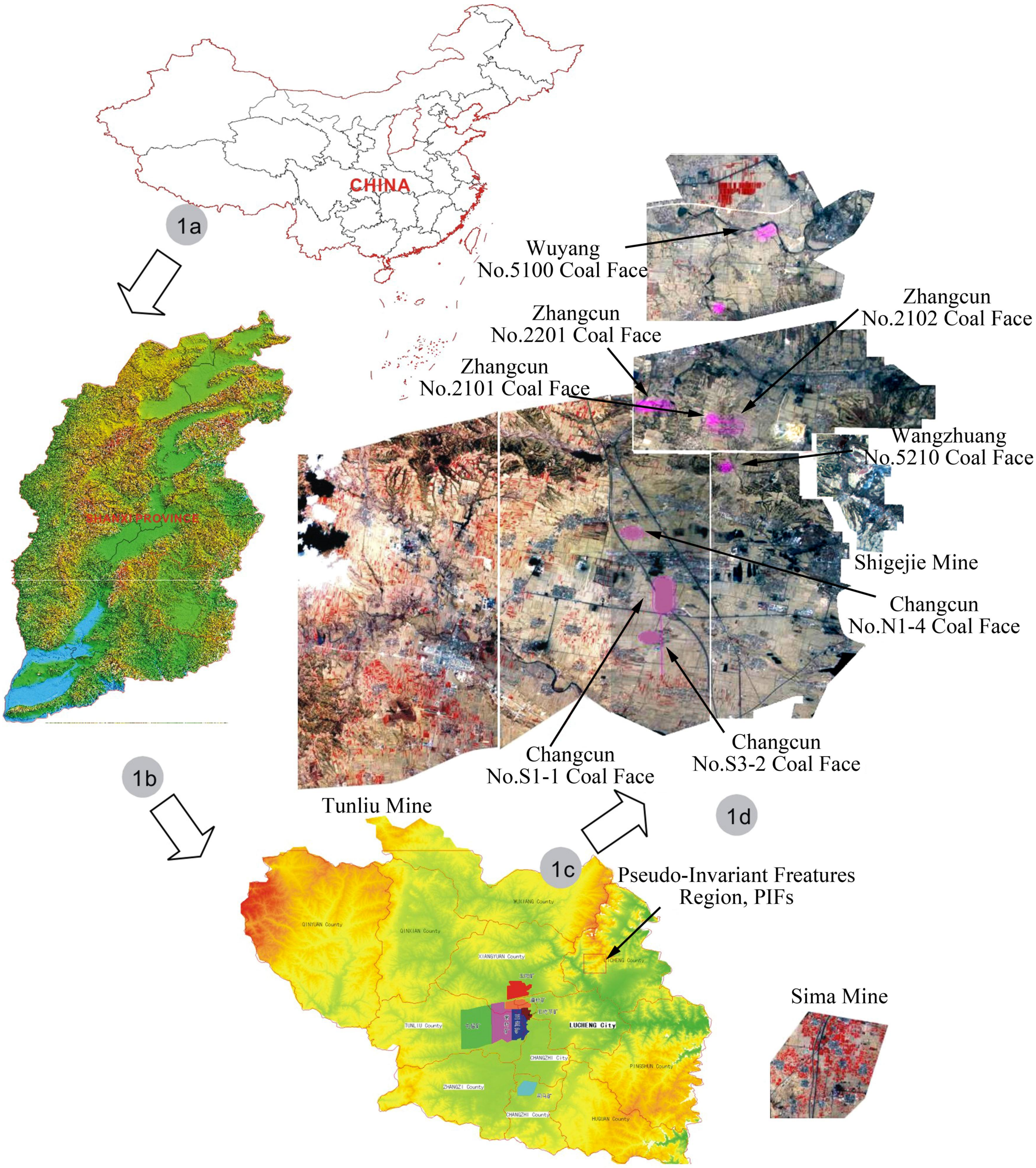

Fig. 1 SPOT images and subsidence regions of experimental coal faces

2.3 Data reprocessing

2.3.1 Radiometric calibration

Radiometric calibration is a process to determine the gray value *DN* and radiance value *L* (see Fig. 2). Gain and Bias are gain parameters and offset parameters that can be obtained from the header files of images [9].

2.3.2 Atmospheric correction model

Fast line-of-sight atmospheric analysis of spectral hyper cubes (FLAASH) are improved by MORTRAN4 model (see Fig. 2). Atmospheric correction can be carried out by way of FLAASH for SPOT images [9].

2.3.3 Band math

According to spectral reflectance characteristics of vegetation, normalized difference vegetation index (NDVI) uses reflectivity of red band and near-infrared band and other factors and their combination to extract vegetation information. These bands often contain more than 90% vegetation information [9].

2.3.4 Mining subsidence prediction with probability integration method

Mining subsidence areas are obtained by subsidence prediction in according with probability integral method. The algorithm is the main method of mining damage prediction at present, which bases on normal distribution function as influence function and expresses rock and surface subsidence basin with integral form [10]. Mountain ground movement and deformation prediction method, land slip overlap method or slip effect function

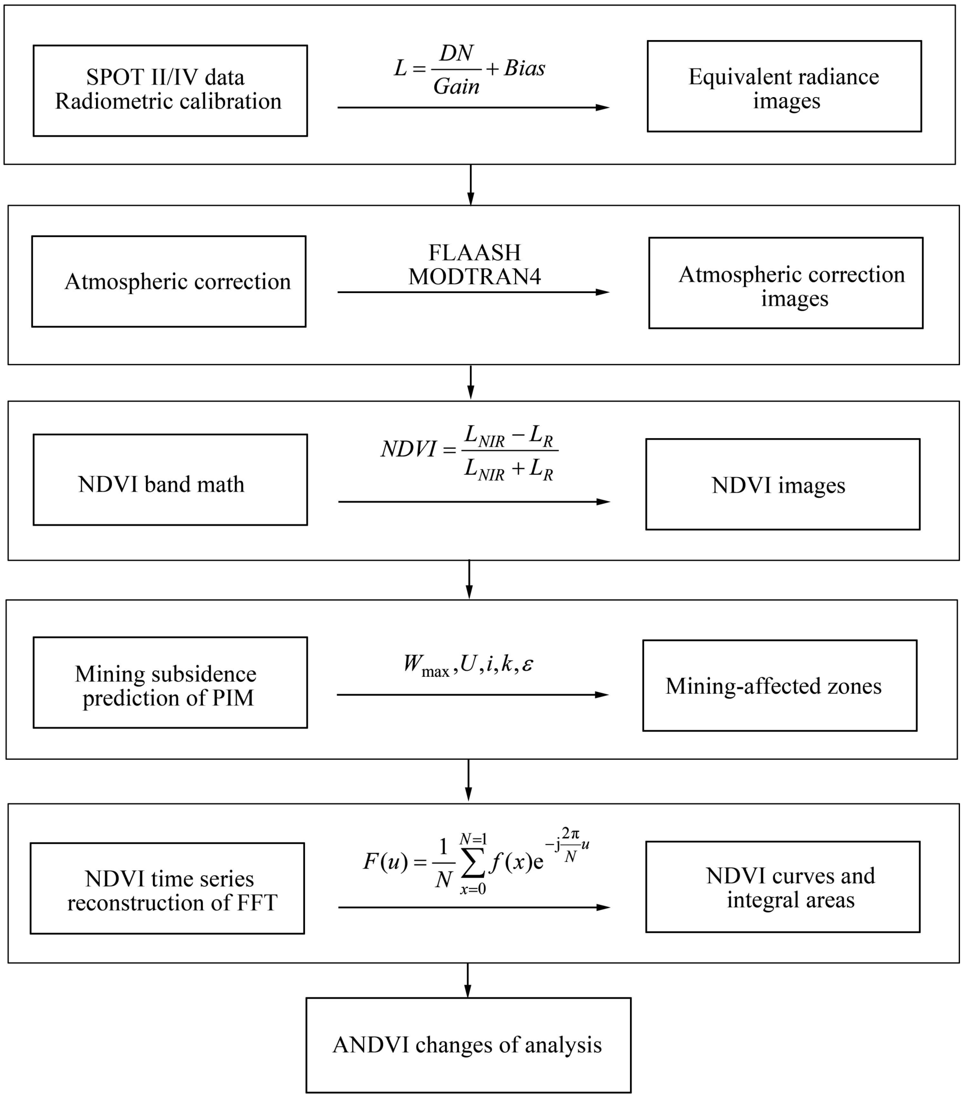

Fig. 2 Flow chart of data processing

method which is recommended by coal mining regulations on coal pillar and mining under buildings, water, rail and major tunnel [10].

2.3.5 Time series reconstruction

Fourier analysis as a superior method of time series analysis can be used to analyse data for vegetation time series, remove noise, identify crop, extract phenology information and so on. Fast Fourier transform (FFT) is used in the study. It can convert NDVI into amplitude and convert phenological information into phase. $F_{amplitude}=(F^2_{real}+F^2_{imaginary})^{1/2}$ is amplitude component of NDVI sinusoidal function; $F_{phase}=\text{atan}(F^2_{imaginary}/F^2_{real})$ is phase component of corresponding NDVI sinusoidal function [11−12].

According to reconstruction of NDVI time series, NDVI envelopes and integral area charts of experimental coal faces can be drawn (see Fig. 3).

NDVI time-series curve in non-subsidence area is a curve closing to annual variation. NDVI maximum values show a decreasing trend year by year. While NDVI maximum values of time-series curves in subsidence area show a decreasing trend due to impact of mining subsidence.

3 Study methods

ANDVI values are obtained by integrating of NDVI time series fitting function in experimental coal faces.

$$ANDVI=\int_0^{12} F(t)\mathrm{d}t \tag{3}$$

Annual integral of NDVI time series in experimental faces is realized by MATLAB scientific computing module. Annual integral values obtained are listed in Table 1. Core integral code is as follows: syms *x*; int (NDVI (*t*), *x*, *a*, *b*).

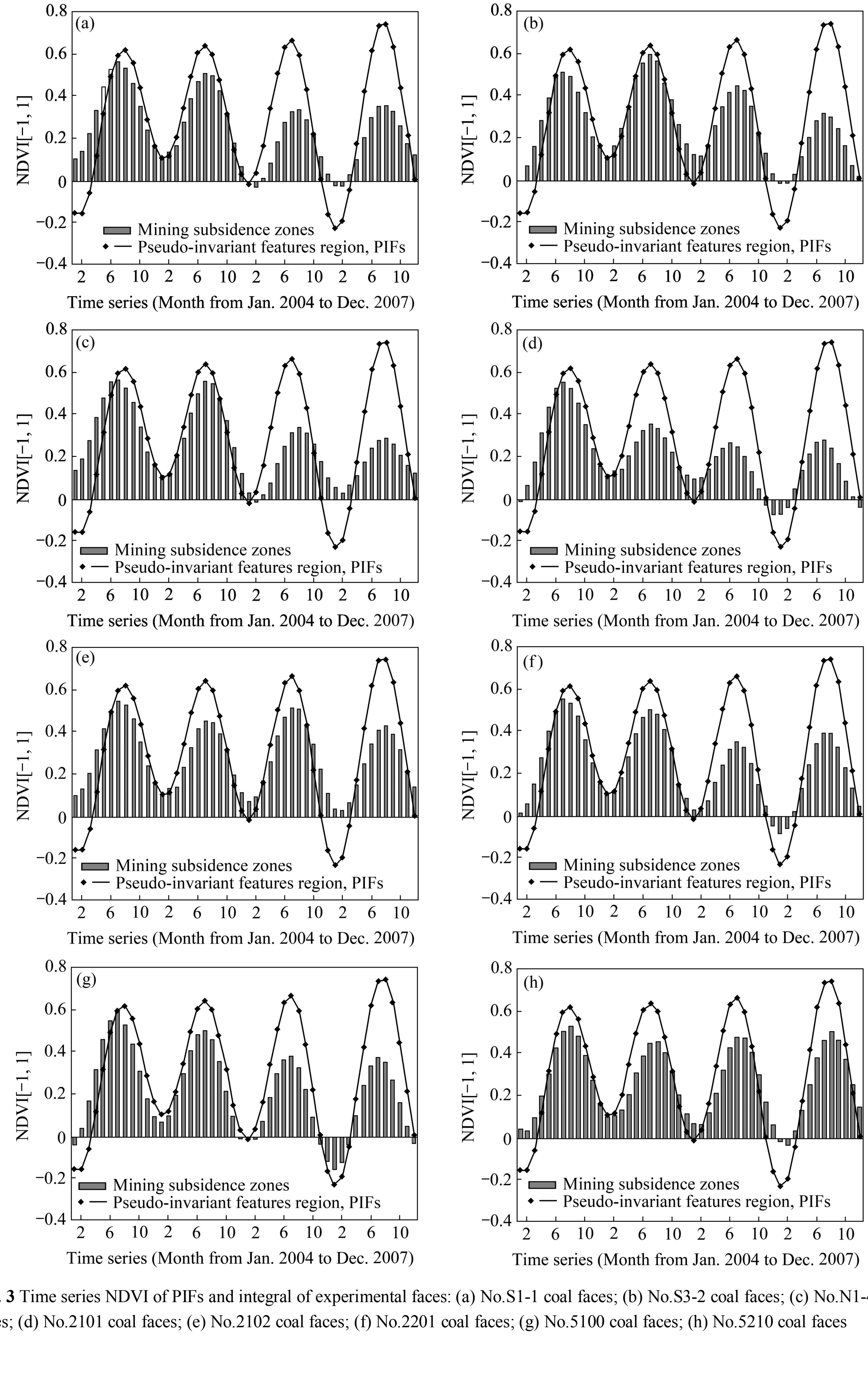

Fig. 3 Time series NDVI of PIFs and integral of experimental faces: (a) No.S1-1 coal faces; (b) No.S3-2 coal faces; (c) No.N1-4 coal faces; (d) No.2101 coal faces; (e) No.2102 coal faces; (f) No.2201 coal faces; (g) No.5100 coal faces; (h) No.5210 coal faces

Table 1 ANDVI of experimental faces (Unit: 1 000 kg C/hm^2·a or t WD/hm^2·a)

Mining areas/ ANDVI	Changcun mine			Zhangcun mine			Wuyang mine	Wang-zhuang mine	Annual sum of NDVI	Annual mean of NDVI (ANDVI)
	No.S1-1	No.S3-2	No.N1-4	No.2101	No.2102	No.2201	No.5100	No.5210	Σ*ANDVI*	⅛or¼
2004	4.008 4	3.321 9	4.207 2	3.637 4	3.877 6	3.600 1	3.504 1	3.383 0	29.666 7	3.708 3
2005	3.482 1	4.295 2	3.857 4	2.557 0	3.149 7	3.483 4	3.124 3	3.134 7	21.080 1	2.635 0
2006	1.777 1	3.055 8	2.005 3	1.613 1	3.539 4	1.942 9	1.752 6	3.058 0	16.987 1	2.123 3
2007	2.079 0	1.632 2	1.931 2	1.220 3	2.676 3	1.997 9	1.438 2	2.797 8	8.773 4	2.193 3
Mining time	04.2−05.1	05.10−06.9	05.6−06.12	04.2−05.2	03.1	05.1	05.11−06.2	04.1	−	−

It can be shown from Table 1.

1) Eight experimental coal faces in mining subsidence area are continuous monitored four years. Monitoring results show that Σ*ANDVI* of eight coal faces in the first mining year (red background) is 29.666 7, ANDVI mean value is 3.708 3, Σ*ANDVI* of four faces not exploitation is 14.633 3, ANDVI mean value is 3.658 3, and the change rate is 1.34%. So it can be considered that ANDVI of coal faces in the first year after mining has no significant change;

2) In the second year after mining, Σ*ANDVI* of eight coal faces (yellow background) is 21.080 1, and ANDVI mean is 2.635 0, falling 28.94% compared with the first year after mining;

3) In the third year after mining, Σ*ANDVI* of eight coal faces (blue background) is 16.987 1, and ANDVI mean is 2.123 3, falling 16.76% compared with the second year after mining and 42.74% compared with the first year after mining;

4) In the forth year after mining, Σ*ANDVI* of eight coal faces (green background) is 8.773 4, and ANDVI mean is 2.193 3, increasing 3.29% compared with the third year after mining and falling 40.85% compared with the first year after mining;

5) ANDVI is a parabola quadratic function according to initial judgment, set $Y = aX^2 + bX + c$ (Y is ANDVI, X is the mining year), the empirical formula of ANDVI changing along with exploitation time can be obtained:

$$ANDVI = 0.2858X^2 - 1.9348X + 5.3582$$

Due to ANDVI and net primary productivity (NPP) of vegetation, the total accumulation of carbon shows a positive relationship [5−7], so the biomass or productivity of vegetation in subsidence area shows quadratic function trends during mining time (shown in Fig. 4). The biomass in mining area is the lowest in the third year after mining. If the artificial reclamation is not carried out, it forecasts that ANDVI (or biomass) in the seventh year after mining can spontaneous recovery to the initial level.

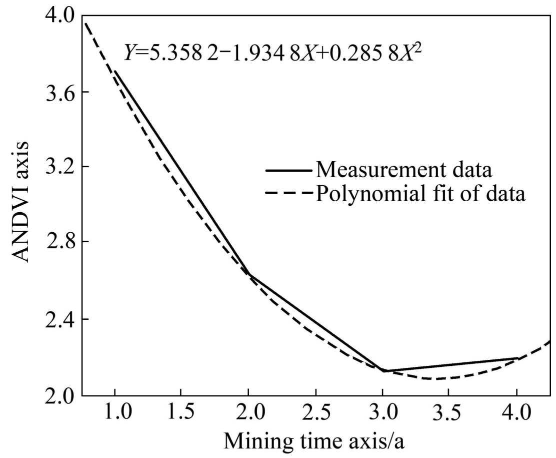

Fig. 4 Fitting curves of ANDVI vs mining time at mining subsidence area

4 Results

1) An experience formula of ANDVI variation with mining time is obtained through monitored four years:

$$ANDVI = 0.2858X^2 - 1.9348X + 5.3582$$

"ANDVI-mining time" curves indicate that the vegetation productivity or biomass trends show a quadratic function within subsidence area during mining time. After three years of surface mining area biomass is the lowest value. Without artificial reclamation, about 7 or 8 years the ANDVI (or biomass) will return to the initial state in subsidence area.

2) For mining disturbed areas, NPP computing model can be used to estimate NPP by adding "Coefficient of mining disturbance" γ at the same geological and mining conditions in mining subsidence areas. The coefficients of before mining, the first year after mining, the second year after mining and the third year after mining in experimental area are 1.000 0,

0.710 6, 0.572 6 and 0.591 5, respectively.

$$NPP = a[-\ln(1 - b \cdot ANDVI \cdot \gamma)]$$

Acknowledgement

Thanks the following fund support: Doctor Fund of Henan Polytechnic University (B2009-46); Graduate Student Thesis Innovation Fund of Henan Polytechnic University (2010-4-20)

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(Edited by HE Xue-feng)