REMOTE SENSING DETECTION FOR SUBSIDENCE-RESULTED WATER BODY AND SOLID-WASTE DUMP IN COAL MINE: YANZHOU BEING A CASE

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KEY WORDS: Land Cover, Change Detection, Coal mining, Satellite Image, NDWI, Infrared

ABSTRACT:

Taking LandSat TM/ETM+ images as information source, this paper used the Normalized Difference Water Index (NDWI) to extract mining subsidence-resulted surface water body information in Yanzhou coal mining area. It was found that the extracted water body information would be mixed with solid-waste dumps. Taking DN 40 in band 5 as threshold value, the water bodies and solid-waste dumps were identified accurately. In addition, DN 80 in band 3 could be used as threshold value to identify shallow water and deep water. Furthermore, the results based on NDWI-threshold method were cross validated by IR band, and the changing trend of water bodies and solid-waste dumps was detected in Yanzhou coal mining area in the past 15 years.

1. INTRODUCTION

Satellite remote sensing plays an important role in environmental monitoring for mining area. It has the following advantages: 1) images cover large areas on the ground; 2) it is not time consuming but has sufficient temporal frequency; 3) prices per square kilometer are generally lower than in-situ investigation and monitoring.

A number of papers focus on monitoring the environment of mining area by using of various remote sensing data. Mine wastes and lands affected by selenium-rich water runoff, in southeast Idaho, were mapped and analyzed by AVIRIS imagery and digital elevation data (John et al., 2003). With the help of remote sensing technology, in the St. Austell China clay (kaolin) region, Cornwall, UK, the waste tips were identified and classified and its spatial distributions were mapped (Richard et al., 2004). In Kailuan coal mining area, north China, multi-temporal ERS1/2 SLC SAR data were used for the monitoring and the dynamical analysis of surface subsidence (WU Li-xin et al., 2005). In the Raniganj Coalbelt, India, temperature anomalies caused by coal-fires were identified (R.S. Chatterjee, 2006). The numerous studies indicate that remote sensing is an effective method for environmental investigation and monitoring in mining area.

2. SELECTED MINING AREA AND SATELLITE DATA

Yanzhou coal mining area, which lies in the southwest plain of Shandong province (Fig.1), has an annual yield of more than 3 000×10^4 tons raw coal. It includes Xinglongzhuang, Dongtan, Baodian, Nantun, Beisu, Yangcun, Jierkuang coal mine, etc. Around the mining area, there is large area of fertile farmland. The massive coal mining is making a strong environmental and ecological impact on surface environment. Mining subsidence-resulted surface water bodies and solid-waste dumps, which take a large area of farmland and become the two main aspects of the mining impact.

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LandSat TM/ETM+ images may be the most frequently used data for monitoring land cover change. The spatial resolution of the visible and reflected IR bands is 30 m, and that of the thermal IR band 6 is 120 m for TM and 60 m for ETM+. This paper selected a group of multi-temporal LandSat TM/ETM+ images, acquired in September 19, 1987 and May 31, 2002 respectively (http://glcfapp.umiacs.umd.edu), as the information source to detect the environment changes during the past 15 years.

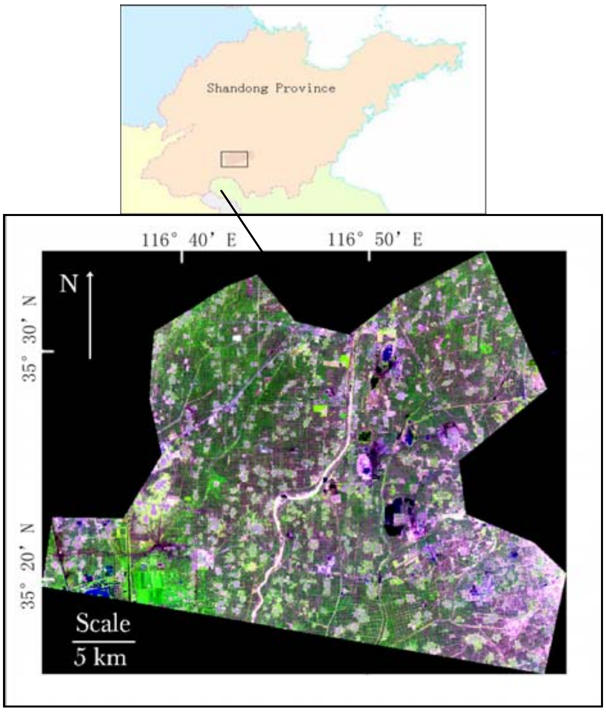

Figure.1. Location of the study area (ETM+ images)

3. NDWI THRESHOLD-BASED METHOD

3.1 Identification of mining subsidence-resulted surface water bodies and solid-waste dumps

Reflectance ratio of water body in NIR band is much lower than that in visible band. So Normalized Difference Water Index (NDWI) is used to extract water body. NDWI is described as follows (McFeeters S K, 1996; XU Han-qiu, 2005):

$$NDWI = (Green - NIR)/(Green + NIR) \qquad (1)$$

Here, *Green* means reflectance value in green visible band; *NIR* means reflectance value in NIR band. As to TM/ETM+ images, *Green* and *NIR* are band 2 and band 4 respectively.

The images acquired in 2002 were taken as an example. The water information could be extracted with appropriate threshold value according to NDWI. It was found that the results from NDWI were in accordance with that from the false-color image composed from band 5, 4 and 3 (RGB), while the results from NDWI were not in accordance with that from false-color image composed from band 7, 5 and 4 (RGB) (Fig. 2). The investigation revealed that there was fuzzy specification between water bodies and solid-waste dumps. Here, solid-waste dumps included coal, coal gangue, fly ash and so on. By analyzing the spectral characteristics (Fig. 3), it was found that the reflection ration (DN) of water and solid-waste in band 2, 3 and 4 was not significant enough to distinguish solid-waste from water, while the DN in band 5 and 7 was significant enough to distinguish waste solid from water (Table 1). Hence, DN value 40 in band 5 was selected as threshold value to make detection between water bodies and solid-waste dumps.

a) Results from NDWI b) Results in RGB543 c) Results in RGB754

Figure.2. Water body information extracted by NDWI in Xinglongzhuang coal mine

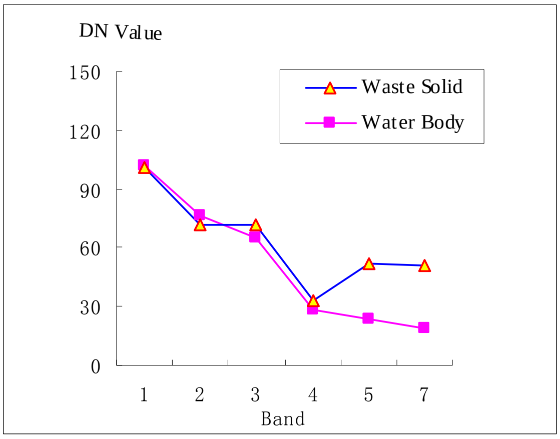

Figure. 3 The spectral curve of water body and waste solid

Feature\Band	1	2	3	4	5	7
Water body-1	108	90	84	29	26	13
Water body-2	98	75	65	27	23	19
Water body-3	102	76	65	28	24	19
Water body-4	115	102	101	43	25	22
Waste solid-1	112	83	83	40	58	58
Waste solid-2	105	83	82	44	73	61
Waste solid-3	115	92	98	47	74	57
Waste solid-4	101	73	67	33	52	51

Table 1 DN of water body and waste solid in the bands

3.1 Identification of water body with different depth

In the false-color image composed from band 5, 4 and 3 (RGB), the color of mining subsidence-resulted water bodies was different, which may be blue (Fig. 4) or black (Fig. 5). By analyzing the spectral characteristics of two kinds of water, it was found that the DN value of both kinds of water in band 4, 5 and 7 was approximately equivalent, but it was different in band 1, 2 and 3 (Fig.6, Table 2). There are two possible causes for the difference, being different impurities in water, or different depth of water. In-situ investigations revealed that different depth of water in subsidence basin was the main cause for the spectral characteristics in band 1, 2 and 3 and the black-color water was deeper than the blue-color water. Hence, the blue color meant shallow water while the black color meant deep water. In visible bands, DN value became smaller with the increase of the depth of water. The research reached that DN value 80 in band 3 should be selected as threshold to identify shallow water and deep water qualitatively in mining subsidence basin.

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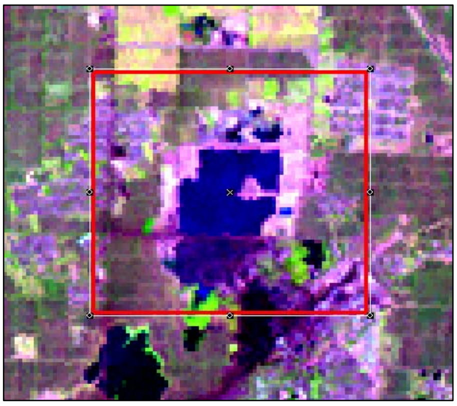

Figure. 4 Water in RGB 543 image near Xinglongzhuang

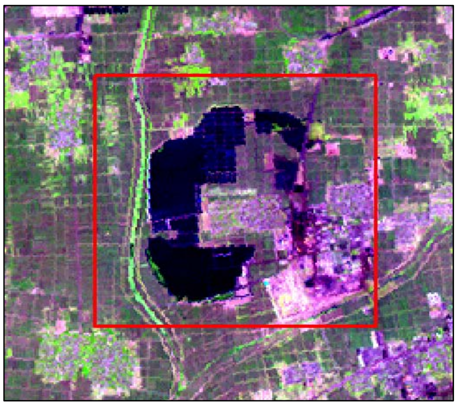

Figure. 5 Water in RGB 543 near Nantun image

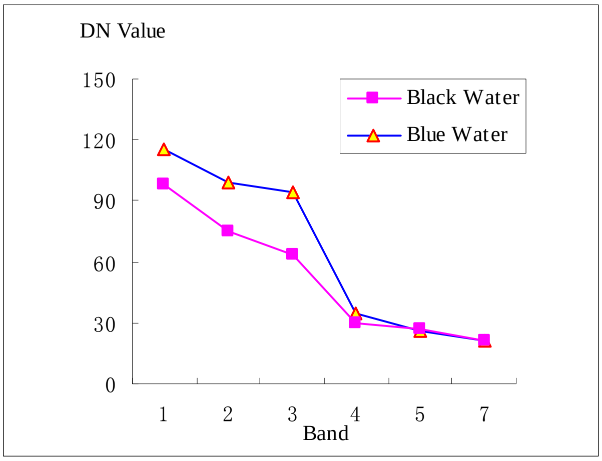

Figure. 6 The spectral curve of blue water and black water

Feature\Band	1	2	3	4	5	7
Blue water-1	115	99	94	40	23	19
Blue water -2	108	90	87	29	26	20
Blue water -3	112	92	90	37	32	23
Black water-1	94	71	61	30	23	18
Black water-2	98	75	63	28	26	21
Black water-3	103	79	62	28	25	17

Table 2 DN value of blue water and black water in the bands

3.1 Cross validation by thermal IR band

Mining subsidence-resulted water body and solid-waste dump are of different characteristics in temperature change and heat radiation features. In daytime, because of great specific heat ratio, the temperature of water rises slowly and the water body becomes cold body as compared to environment objects. Oppositely, because of small specific heat ratio, the temperature of solid-waste rises promptly and solid-waste becomes hot body. Therefore, thermal infrared band could be used to cross validate the dependability of the mining subsidence-resulted water bodies and solid-waste dumps. By the use of some formula-transformation, the ground brightness temperature was retrieved from DN in thermal infrared band (band 6 of TM/ETM+ images) which could reveal the difference of thermal field of land surface. The formula is described as follows (Dai Changda et al., 2004):

$$L_b = L_{\min} + \left(L_{\max} - L_{\min}\right)/255 \bullet DN \quad (2)$$

$$T_b = K_2 / \left[ln\left(K_1 / L_b + 1\right)\right] \quad (3)$$

Here, L_{max} means the maximal radiation value that the detector could detect; L_{min} means the minimal radiation value that the detector could detect; L_b means spectral radiance; T_b means radiation temperature; K_1 and K_2 are constant.

The results shows that because of great temperature difference (more than 10 K), the mixed information of water bodies and solid-waste dumps could easily be specified (Fig. 7).

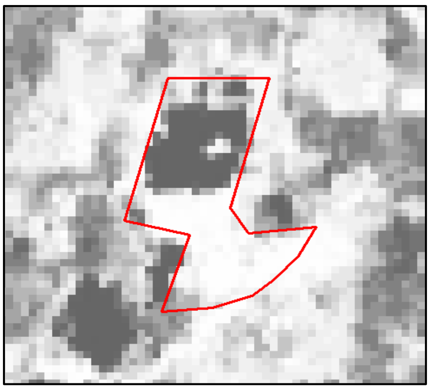

Figure. 7 Land surface temperature image in Xing longzhuang

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4. METHOD APPLICATION IN YANZHOU MINING AREA

The methods were also applied for the satellite remote sensing images of Yanzhou coal mining area acquired in 1987. It was 1revealed that, in Yanzhou mining area, the area of solid-waste dumps and mining subsidence-resulted water bodies in 2002 was 0.90 times and 2.87 times greater than that in 1987 respectively. The main changed areas of mining subsidence-resulted water bodies were located nearby Nantun, Xinglongzhuang and Dongtan coal mines, which began coal production in 1971, 1981 and 1989 respectively. The details show that, from 1987 to 2002, the area of mining subsidence-resulted water bodies located nearby Nantun coal mine rose to 253.67 hm^2 from 38.26 hm^2, the area of mining subsidence-resulted water bodies located nearby Xinglongzhuang coal mine rose to 98.61 hm^2 from 23.96 hm^2, and the area of mining subsidence-resulted water bodies located nearby Dongtan coal mine rose to 49.87 hm^2. The basic cause for the above changes was high-intensity mining for many years. For example, the annual yield of raw coal of the coal mines had risen to 3 000×10^4 t in 2000 from 700×10^4 t in 1986.

5. CONCLUSIONS AND DISCUSSIONS

Based on TM/ETM+ images, it was unable to distinguish solid-waste dumps from water bodies in coal mine by NDWI. However, with the help of the threshold, DN 40 in band 5, it was effective to identify water bodies and solid-waste dumps. In addition, according to the spectral characteristics of water bodies with different depth, DN 80 in band 3 was selected as the threshold to identify shallow water and deep water. The NDWI-based investigation could be cross validated by IR band.

To verify its universality, this method was also applied in Kailuan and Huainan coal mining area. The results were satisfying. Anyway, for different temporal satellite images, how to get a common threshold is a remaining problem. It is demanded to consider the differences of illumination and atmosphere among the various satellite images to determine the common threshold in the next research.

ACKNOWLEDGEMENTS

This research is jointly supported by the Natural Science Fund of China for Distinguished Young Scholars (No. 50525414), the Natural Science Fund of China (No. 50774017).

REFERENCES

Dai Changda, Jiang Xiaoguang, Tang Lingli. 2004. *Processing and Analysis for Applications to remote sensing image*. Tsinghua University Press, Beijing, China.

John C. Mars, James K. Crowley, 2003. Mapping mine wastes and analyzing areas affected by selenium-rich water runoff in southeast Idaho using AVIRIS imagery and digital elevation data. *Remote Sensing of Environment,* 84(3): 422-436

McFeeters S K, 1996. The use of Normalized Difference Water Index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing*, 17(7): 1425-1432.

Richard J. Ellis, Peter W. Scott, 2004. Evaluation of hyperspectral remote sensing as a means of environmental monitoring in the St. Austell China clay (kaolin) region, Cornwall, UK. *Remote Sensing of Environment,* 93(1-2):118-130

R.S. Chatterjee, 2006. Coal fire mapping from satellite thermal IR data - A case example in Jharia Coalfield, Jharkhand, India. *ISPRS Journal of Photogrammetry and Remote Sensing,* 60(2): 113-128

WU Li-xin, GAO Jun-hai, GE Da-qing, LIAO Ming-sheng, 2005. Experimental study on surface subsidence monitoring with D-InSAR in mining area. *Journal of Northeastern University (Natural Science),* 26(8):778-781

XU Han-qiu, 2005. A study on information extraction of water body with the modified Normalized Difference Water Index (MNDWI). *Journal of Remote Sensing,* 9(5)：589-595

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