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STUDY ON THE SUBSIDING LAND EXTRACTION FROM LANDSAT TM IMAGE SUPPORTED BY GIS AND DOMAIN KNOWLEDGE

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ABSTRACT: The subsiding land can be extracted from Remote Sensing image based on its spectral and spatial features. The features of subsiding land caused by mining, especially its RS information features and relative knowledge are proposed. Three methods can be used to extract subsiding land from RS image. The first is to categorize the region into different blocks (or layers) according to their features and apply corresponding strategies for each block, the second is to identify the changeable region based on GIS firstly and then to classify those regions, and the third is to post-process the classified image by traditional methods or ANN(Artificial Neural Network) methods based on domain knowledge and GIS. Two direct extraction methods are introduced also. One is the extraction based on the water accumulating property of subsiding land, and the other is based on the dynamic change of land cover in subsiding land.
KEY WORDS: subsiding land; Remote Sensing; Geographic Information System; domain knowledge

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1 INTRODUCTION

Land subsidence caused by underground mining is one of the most important factors that limit regional sustainable development in mining cities and mining areas. Land subsidence leads to damages to land resources, causes a series of ecological and environmental problems, destroys social infrastructure, finally will lead to some socio-economic problems. It is one important aspect of regional sustainable development to monitor, analyze, treat and reuse mining subsiding land. It is well known that Remote Sensing (RS) image can record ground truth and be used to extract mining subsiding land, which is superior to other methods in time, cost, convenience and automation. The extracting methods include ocular interpretation based on visual features, image classification taking subsiding land as a class, identification by multi-source and multi-temporal image fusion, and so on. But all above methods are based on spectral character, and relative Geo-information and knowledge is not used, so the accuracy is not very high. It is necessary to apply GIS to RS image processing and to extract subsiding land by making full use of Geo-information, domain knowledge and the spatial analysis functions of GIS (BOHEAOSIER, 1999; BOLSTAND, 1989; QIN, 2000; SHENG *et al.*, 2001; ZHOU *et al.*, 1999; ZHU and MAO, 1997).

2 USEFUL FEATURES AND KNOWLEDGE OF SUBSIDING LAND

The features of subsiding land can be analyzed from spectral and spatial aspect.

From spectral aspect, because of the land cover change caused by subsidence, the spectral feature of land surface will change and those changes can be recorded by RS sensor. In addition to the changes of gray, the texture feature of land surface will change, and different land covers have different texture feature parameters.

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From the spatial structure, subsiding land is characterized by: 1) it is in pit shape, both moving basin and subsiding pit are lower in middle than in edge; 2) it is continuous in large scale but discrete in small scale, 3) water is accumulated in subsiding pit, especially in summer and autumn, the water accumulating is very serious; and 4) its cover is un-uniform, including water, vegetation, waste land and others, and different cover types are intersected irregularly in space. So the following knowledge can be used to extract subsiding land according to its feature:

(1) The dynamic water accumulation field changes with time, and this knowledge can be expressed by:

IF $W_2(i, j) = 1$ THEN subsiding land 0.9

where W_2 is got from the algorithm $W_2 = W_1 - W_0$ based on raster computation. W_0 is the natural water captured from map, W_1 is the water extracted from RS image.

(2) The areas with water accumulation are located in the buffers of mining coal seam. Firstly buffer analysis is applied to underground working space and region *Buf* is got, then W_1, the water in the classified image, is conducted "and" algorithm with *Buf* and region *W-Buf* will form, finally every pixel in *W-Buf* is judged by the rule as follows:

IF $W\text{-}Buf(i, j) = 1$ THEN subsiding land 0.9

(3) The dynamic change of land use. Supposed that I_1 represents the classification result on one time and I_2 is on another time, so I_1 will be compared with I_2 and the changeable pixels are found, and then the subsiding land can be extracted according to the forming rules of subsiding land and above knowledge. That can be illustrated by the following formula:

IF $I_1(i, j) = I_2(i, j)$ THEN $R(i, j) = I_1(i, j)$

ELSE $R(i, j) = F(I_1(i, j), I_2(i, j))$

where F is a function to analyze the type of the two periods, aiming at extracting the subsiding land according to the changing type and process.

3 SUBSIDING LAND EXTRACTION FROM LANDSAT TM IMAGES

3.1 Subsiding Land Extraction Based on Layered Classification with the Support of GIS

The method of layered classification supported by GIS is to categorize land cover into different layers according to specific criteria reflecting the characteristics of each object firstly, and then to apply relative classified methods to each layer according to its properties. The specific classified criteria are: 1) to categorize land cover into different layers according to their sensitivities to change of field investigation and prior knowledge; 2) if land cover in one layer is hardly to change, the pixels in this layer are not processed and the class in GIS is given; and 3) if land cover in one layer is easy to change, the possible change forms are determined firstly and then effective bands and methods are used to classify this layer. The sampling area is divided into the following layers:

L_1: Mountain and natural water layer.

L_2: Traffic layer.

L_3: Mining area layer. For each mine, buffer analysis is used for mining coal boundary in order to form mining area layer, and subsidence occurs frequently in this layer.

L_4: Vegetation layer.

L_5: Construction land layer.

Each layer is represented by binary image, that is, 1 is used for those pixels within this layer and 0 to pixels out of this layer.

G is used to represent the class in GIS database, and T_1, T_2, T_3, T_4, T_5, T_6 represent the matrix formed by Band1, 2, 3, 4, 5, 7 of Landsat TM image, O is used to represented the output classified image. Each pixel is processed by different strategies according to its value in every layer, and that can be expressed as follows:

```
FOR I = 1 TO M
  FOR J = 1 TO N
    IF L1 = 1 or L2 = 1 THEN O = G;
    IF L3 = 1 THEN CLASSFIED BY C1
    IF L4 = 1 THEN CLASSFIED BY C2
    IF L5 = 1 THEN CLASSFIED BY C3
  END
END
```

That means that L_1 and L_2 are not processed and the class in GIS database is assigned directly, and L_3, L_4 and L_5 (those represent mining area land, vegetation, construction land) should be classified as follows:

C_1: BPNN (Back Propagation Neural Network) is used to classify L_3 because land cover is complex and diverse in mining area.

C_2: Vegetation can be identified from Vegetation Index (VI) and Normalized Difference Vegetation Index ($NDVI$). Firstly vegetation set L_{41} is got by G_{TM4}/G_{TM3} and the class in L_{41} is same to G. After that region L_{42} is formed by $L_{42} = L_4 - L_{41}$, which represents the land that change from vegetation to other land covers and should be classified further. According to the features in studying area, vegetation can change to three types, including wasteland, construction land and water, so the bands sensitive to those three classes are selected to the classification of L_{42}.

C_3: For layer L_5, construction land is not seldom changed to other land, except for some special situations such as housebreaking, village moving to other place because of underground mining. The possible shapes of construction land evolving are vegetation land and water. So G_{TM4}/G_{TM3} is firstly used to extract vegetation from L_5 and the class is vegetation, then water is extracted from L_5, and the water is certainly in subsiding land formed by mining.

According to above classified strategies, practical knowledge, information in GIS database and RS image can be used for classification at the same time, and the computation burden is low, so it is an effective method to classify and extract subsiding land from RS image.

3.2 Subsiding Land Extraction Based on Changeable Area Identifying

This method is similar to the former method in thoughts and rules, but different in detail classified strategy. Land use map in GIS is transformed to an image G_1 firstly, and then G_1 is converted to a simulated RS image G_2. The gray of each pixel in G_2 is assigned by the statistical mean gray of responding class in Band 5 of TM image. The changeable area is then determined by $R = G_{TM5}/G_{G2}$, and the rule can be expressed as follows.

```
FOR I = 1 TO M
  FOR J = 1 TO N
     IF 0.9 < R < 1.1 THEN O = G1
          ELSE CLASSIFIED BY C2
  END
END
```

In The same region, O_1 is not processed and only the changeable area O_2 should be classified. The classifier can use Maximum Possibility, Minimum Distance rule or ANN(Artificial Neural Network), and here BPNN is also adopted. The training area is selected from region O_1. The trained BPNN is used to classify region O_2, and the result is output to O_2, finally O_1 is combined with O_2 and the classification is completed.

3.3 Subsiding Land Extraction by Post-processing to Classified Image Supported by GIS

It is one of the main methods of RS image classification to process the classified image by conventional method according to the rules and knowledge derived from the features of each class such as elevation, slope, adjacent relation and so on, and this processing is under GIS environment usually. That is so called post-processing to classified image in GIS. In this strategy, the maximum likelihood method (MLM) is firstly used to primary classification, and then knowledge and rules are collected, finally the former classified image is processed with the support of GIS and the ultimate class of each pixel is determined.

Supposed that the land use map in GIS database is digitized and G is used to express the digitized image, and the value of each pixel represent differents class: 1 is water, 2 is green land, 3 is construction land, 4 is wasteland (mainly subsiding land). C_1 is the primary classified image, and the image derived from the processing by rules and knowledge in GIS is expressed by C_2. In addition, one binary image, M is formed by the buffer analysis to mining area.

The knowledge is expressed with the following formats:

IF condition THEN conclusion CF

Here CF is the confidence factor of the conclusion.

The main rules include:

* Rules about elevation and slope

IF slope > 5° THEN construction land 0.1

IF slope > 5° THEN water 0.1

IF m > 60m THEN mountain 1.0

IF m > 50m THEN construction land 0.1

* Rules about dynamic change

IF $G = C_1$ THEN $C_2 = G = C_1$

IF $G = 2$ & $C_1 = 1$ THEN subsiding land 0.9

IF $G = 1$ & $C_1 = 4$ THEN water 0.9

IF $G = 2$ & $C_1 = 3$ THEN construction land 0.9

IF $G = 2$ & $C_1 = 4$ THEN subsiding land 0.9

IF $G = 2$ & $C_1 = 1$ THEN subsiding land 0.9

IF $G = 3$ THEN mountain 0.9

IF $G = 3$ & $C_1 = 1$ THEN subsiding land 0.9

IF $G = 3$ & $C_1 = 4$ THEN subsiding land 0.9

IF $G = 4$ & $C_1 = 1$ THEN subsiding land 0.9

IF $G = 5$ & $C_1 = 2$ THEN green land 0.9

IF $G = 2$ & $C_1 = 3$ THEN construction land 0.9

* Rules about spatial relation (here W is the 5 × 5 window centered with the given pixel)

IF $M = 1$ & $C_1 = 1$ & $G \neq 1$ THEN subsiding land 0.9

FOR W in M IF $G = 2$ & $C_1 = 1$ or $G \neq 5$ THEN subsiding land 0.9

The post-processing is realized by comparison to the class of each pixel in GIS database and in primary classified image and the application of relative rules. The advantages of this method is to give synthetic process to each pixel by making full use of spectral knowledge, spatial relation, statistical knowledge and object rules, and it is more precise and reliable than former methods, but every pixel should be processed several times and the computing burden is large.

4 SUBSIDING LAND EXTRACTION BASED ON GIS AND DOMAIN KNOWLEDGE

Because image classification and post-processing is high working burden, it is more convenient to extract subsiding land directly from RS image according to the typical features and knowledge.

4.1 Extraction Model Based on Water Accumulation in Subsiding Land

It is easy to extract water from Landsat TM image, and two methods can be used, one is extracting water based on a given threshold, and another is extracting water according to the relation in different bands. Here the relation in different bands is used to set up a water extraction model (ZHOU *et al.*, 1999), that is:

IF $(G_{TM2} + G_{TM3}) - (G_{TM4} + G_{TM5}) > 0$ THEN water 1

The subsiding land can be determined by extending the water accumulation area with a statistical radius. That can be described as follows:

(1) Buffer analysis is applied to the center (or border) of mining area and region R_1 is got. The buffer radius r_1 is determined according to subsiding parameters.

(2) Logical "and" algorithm is used to R_1 and W_1, the water area extracted from RS image, and then R_2, water locating in the buffer is got.

(3) The natural water W_2 determined by map is extracted from R_2, and R_3 is formed, that is, $R_3 = R_2 - W_2$, and then every pixel and patch in R_3 is filled.

(4) The extending radius r_2 is derived from the relation between border of subsiding basin and accumulated water. The subsiding land can be extracted by extending from the border of R_3 by the radius r_2.

4.2 Extraction Model Based on Land Cover Change

The un-accumulated water subsiding land must be extracted according to the dynamic change of land cover. The detail method can be described as follows:

(1) Buffer analysis is applied to the center (or the border) of mining area and region R_1 is got. The buffer radius r_1 is determined according to subsiding parameters.

(2) The land use change region, R_2, is determined, and the changing types are decided by multi-temporal RS image or GIS information, finally the region coinciding with the features of subsiding land is extracted.

(3) The subsiding land set R_3 is determined by R_2 and reasoning rules.

(4) The subsiding land is extracted by buffer analysis to the border of R_3 with radius r_2 at last.

We have experimented all above methods in a mining area, and it proved that RS image could be used to extract subsiding land in a large region from medium or large scale.

5 CONCLUSIONS

In this paper, the subsiding land extraction and classification methods from Landsat TM image with the support of GIS are discussed, and the following conclusions can be drawn from the studies in this paper:

(1) The RS image classification and information extraction with the support of GIS can make full use of RS image, spectral feature, Geo-information, domain knowledge and spatial analysis synthetically, and it is superior to other methods.

(2) The algorithms and methods proposed in this paper are tested and satisfied results were achieved.

The natural conditions must be taken into account when extracting subsiding land. Because the features in different areas are varied, it is necessary to give further study to the methods oriented to different regions.

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