Extraction of soil salinization information from the Manas river basin based on TM Images

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Abstract

Remote sensing technology is widely used in real-time observations. In this study, therefore, salinization information was extracted from Thematic Mapper (TM) images. In particular, remote sensing information regarding saline soil was obtained to analyse its dynamic changes. This soil collected from the Manas River Basin in Xinjiang Province China was selected as the research area. Data from Landsat TM remote sensing images with seven bands were obtained in August 2010 as inputs, and salinization information was extracted using the e-Cognition system. As per this information, high-salinity soil is mainly distributed outside the oasis. The data were analysed further through the normalized differential vegetation, normalized difference water, and remote sensing image indices. Analysis results show that overall classification accuracy can reach 83.7%, thus demonstrating that the automatic extraction of information regarding saline soil is highly accurate. Furthermore, this information can be automatically and precisely extracted using an object-oriented method.

Keywords: Manas river, river basin, soil salinization, NDVI

1 Introduction

Soil salinization predominantly limits sustainable agricultural development. The estimated salinization level is 9.55 × 108 hm2, which accounts for 7.26% of the land surface on the Earth. Hence, salinization has become an international problem. Specifically, salinization is severe in the Manas River and has stilted the utilization efficiency of its water resources. As a result, sustainable agricultural development is restricted in this region. All aspects of saline alkali soil (properties, range, geographical distribution, and saline degree) must therefore be effectively determined. These factors may help facilitate the monitoring and control of soil salinization in the Manas River Basin.

Soil salinization was first monitored through satellite remote sensing in the 1970s. In the early 1980s, multi-band and temporal remote sensing were widely used to assess saline soil [1, 2]. In the 1990s, however, visual interpretation was developed as an important method of monitoring soil salinity [3], and it has remained significant since then. Researchers report that comprehensive analysis and image feature analysis methods can eliminate the interference of objects with foreign bodies in a single spectrum [4-7]. Zeng first presented the concept of a “geographical control system”, which considered the soil and the landscape area as a whole [8]. Zhang obtained meteorological data from the National Oceanic and Atmospheric Administration to establish a regression model between soil salinization and daily minimum and maximum temperatures [9-11].

In the current study, processing technology for remote sensing images was adopted to determine soil salinity in the Manas River. This technology may clarify the distribution of soil salinization consistently and can guide the dynamic monitoring of this salinization in the Manas River Basin. We also develop a reasonable salinity control solution by analysing the progression of salinization. The results of this study promote the development of agricultural production in the Manas River Basin.

2 Research area

The Manas River Basin (longitude 85°00’ – 86°30’, north latitude 43°30’ – 45°40’) is located at the northern foot of Tianshan Mountain in Xinjiang, China. Administratively, this basin covers Manaxin County, Shawan County, and the reclaimed Shi He-zi area for a total area of 26500 km^2. The research area also includes six rivers, namely, the Taxi River, Manas River, Ning River, Gold River, South River, and Bayin River. upstream to downstream, and the constitution of soil salinity has shifted from sulfate to chloride salt accordingly [12].

3 Data sources and methods

3.1 DATA SOURCES

A Landsat Thematic Mapper (TM) remote sensing image was obtained for this research. The image contains seven bands (Table 1) and has a spatial resolution of 30m×30m upon resampling. The research area was pinpointed according to its coordinates, and the pixel array was 7904 (row)×11479 (line). This study also utilized land use, stream, and meteorological data.

TABLE 1 Bands of the remote sensing image (TM)

Band NO.	Range (μm)	Main function
TM1	Blue waveband (0.45–0.52)	The blue waveband is used to Distinguish soil and vegetation, as well as artificial objects
TM2	Green waveband (0.52–0.60)	The red waveband is used to detect the healthy of the plants and reflect the reflectivity of the plant.
TM3	Red waveband (0.62–0.69)	The red waveband is used to measure the pigments of vegetation and distinguish the artificial surface feature.
TM4	Near-infrared waveband (0.76–0.90)	The near-infrared waveband is used to determine the condition of the crop, drawing water boundary and detect the soil humidity.
TM5	Middle-infrared waveband (1.55–1.75)	The middle-infrared waveband is used to detect the soil moisture and the water content, distinguish the cloud and snow.
TM6	Infrared waveband (1.04–1.25)	The infrared waveband is used to detect the thermal radiation of the earth surface's object.
TM7	Middle-infrared waveband (2.08–2.35)	The middle-infrared waveband is used to monitor the radiation source.

3.2 EXTRACTION OF SOIL SALINIZATION INFORMATION

Soil salinization information can be extracted by classifying the remote sensing images. This method is based on various combinations of spectral data [13] and is object-oriented. Since the 1970s, it has been widely integrated into the classification of the remote sensing images at the interpretation stage [14, 15]. Object-oriented image analysis mainly involves two procedures: image segmentation and information extraction. Both processes are interactional and cyclic. We can then extract class information according to the dimensions of the image object [16].

4 Spectral analysis of salinized soil, variable selection, and establishment of a taxonomy system

4.1 SPECTRAL ANALYSIS OF SALINIZED SOIL

During the dry season of universal salt, a salt crust is formed on the surface of salinized soil, and the spectral reflectance of this soil is greater than those of other soil types. Furthermore, the colour of the salinized soil image is thinnest relative to those of the images of other soil types regardless of the visibility of the spectrum or of the near-infrared band. Soil salinity is mainly induced by white crystal; thus, we can determine the extent of soil salinization according to the white marks in the image during spectral analysis.

4.2 VARIABLE SELECTION

The *NDWI* is the normalized ratio of the green waveband and the near-infrared band. Its formula can be described as follows:

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

where Green represents the green waves and *NIR* signifies the infrared waves. Green and *NIR* denote the second and fourth bands, respectively, in the Landsat TM remote sensing image.

The NDSI is a quantitative index used to observe ice. It is the core of SNOMAP arithmetic. In remote optical sensing, this index is the universal method of extracting accumulated snow. It can not only recognize accumulated snow as its primary function, but it can also accurately determine snow-clouds. Thus, it may enhance the sensitivity of soil monitoring.

The NDVI is a remote sensing indicator that can reflect on remote sensing data regarding the research area, as displayed in Table 2.

4.3 CLASSIFICATION SYSTEM OF LAND USE

We established a classification system of land use based the land cover conditions. This index can be defined as follows:

$$NDVI = NIR - R \ / \ NIR + R \ , \qquad (2)$$

where *NIR* is the reflected value of the near-infrared band and R is the reflected value of the red wave band. The *NDVI* can detect vegetation progression and coverage; hence, it effectively extracts vegetation information [17].

TABLE 2 Classification system of land use

No.	Land use	Definition
1	Tillage	Crop land
2	Forestry	Forest land (arbor, bush, bamboo)
3	Grassland	Herbaceous plants (covers the degree below 5% of the entire area)
4	Stream	Natural or artificial stream
5	Lake	Natural ponds
6	Reservoir	Artificial ponds
7	Glacier	Lands covered with glaciers and snow
8	Residential land	Urban settlements, traffic paths
9	Severe salinization	Salinity of the surface soil ≥ 75 g kg–1; Vegetation coverage is 0%—1%
10	Moderate salinization	Salinity of the surface soil is 45 g kg–1—75 g kg–1; Vegetation coverage is 5%
11	Mild salinization	Salinity of the surface soil is 15 g kg–1—45 g kg–1; Vegetation coverage is 15%
12	Bare soil	Soil texture cover; < 5% of the ground is covered with vegetation
13	Bare rock	Rock covers the ground; > 5% of the ground is covered with rocks

5 Extraction and analysis of remote sensing information on soil salinization

In this research, e-Cognition image processing software was adopted to extract non-salinization information. Prior to classification, the image was pre-processed to facilitate image segmentation and information extraction.

5.1 MULTI-SCALE IMAGE SEGMENTATION

The multi-scale partition method used in this study is the most commonly used partition approach. It defines a specific scale for the polygon of the target image and highly optimizes image segmentation. In multi-scale segmentation, we first identified the compiled layers. We then measured each compiled layer under different weights. We considered every band to be coverage, and the compiled layers correspond to the band number. Therefore, we can determine the weights of all compiled layers. The multi-scale data were segmented based on different characteristics and classifications. In this study, the segment dimensions were set at 600 and 15 to divide the remote sensing images and to generate differently scaled images, as shown in Figure 1.

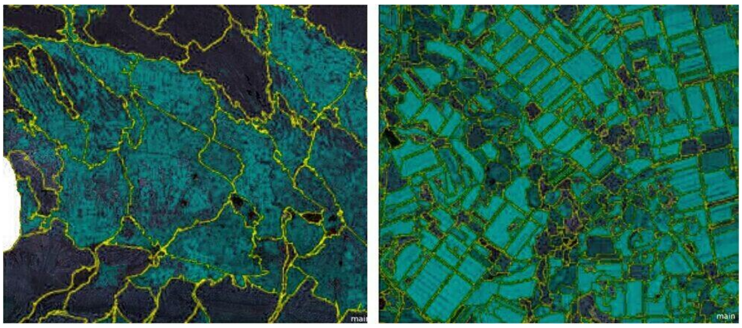

FIGURE 1 Image split at scales of 600 and 15

When the parameters of the segmented image are high in value, the image is actually poorly split. The image split at a scale of 15 may accurately segment the various ground features of soil into different polygons. By contrast, the image segmented at a scale set of 600 displays a low segmentation accuracy. Hence, we selected the image split at a scale of 15 as the base map of soil salinization in this study.

5.2 POLYGON CONSTRUCTION

Polygons may be constructed within the split image. Prior to this procedure, however, we must verify the image features (e.g., boundary, shape, area, length, and width) and the mean values and standard deviations of these features to classify image treatment. If image segmentation is poor, the scale parameter of the image must be readjusted. As per an analysis of the feature of the image divided at a set scale of 15, the studied image meets the requirements of the research.

5.3 HIERARCHY OF LOADING CLASS

We segmented the remote sensing image of the research area into the following categories based on surface feature type: Tillage, forest land, meadow, stream, lake, reservoir, glacier, residential land, severe salinization, moderate salinization, mild salinization, bare soil, and bare rock. The different surface features are presented in different colours.

5.4 IMAGE CLASSIFICATION

5.4.1 Classification of non-salinized land according to land type

In this study, the two characteristic variables NDWI and NDSI were regarded as the base map. We obtained different interval values by trial and error. The wave and the glacier were extracted using optimum threshold value methods, whereas vegetation was detected by the eCognition processing system for remote sensing images. Briefly, the Classification step is as follows: Feature view → Object features → Customized → NDVI. Once we generated the NDVI, the values of this index could be adjusted to validate the optimal ranges of the categories tillage, forest land, and grassland. The land type between the bare rock and bare soil could be identified by adopting the interval value of NDVI obtained from a reiteration of the test.

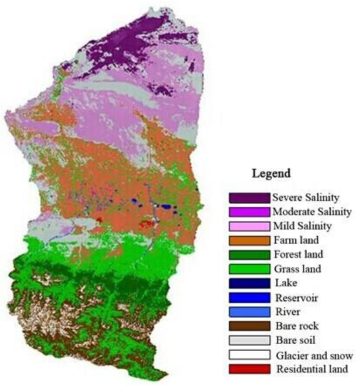

FIGURE 2 Classification of degrees of salinity at the Manas Basin

5.4.2 Classification of the extent of salinization

Based on brightness and the NDVI values of the bands, computers can automatically derive the extent of salinization. As the degree of salinity in an area increases, land cover decreases. We therefore set an appropriate NDVI threshold value to distinguish saline soil from non-saline soil. The brightness values of the severely saline soil and the sandy soil from TM1 are close, and the brightness values of the clay and the sandy soils are maximized. Hence, we can determine severe salinity by setting threshold values for both TM1 and TM7.

In this study, visual interpretation methods were used to determine the NDVI values at various extents of salinity (moderate and mild salinization alone were considered). Consequently, the e-Cognition system extracted these values through logical calculus.

5.5 ANALYSIS OF SALINIZATION INFORMATION

As illustrated in Figure 2, the soil of the research area displays different degrees of salinity. The distribution of salt concentration is presented in different areas and shapes. Moreover, the moderately saline soil is spread across the surrounding tillage and grassland. The mildly saline soil is distributed across the phases of tillage. The degree of salinization of the soil in the Manas River Basin is accentuated from upstream to downstream and from south to north. Furthermore, soil salinization is concentrated and distributed in the upstream of the alluvial plain and around the reservoir. Land is fertile and water resources are abundant within the oasis, and this region is not salinized because of the lack of ground water. The distribution of saline soil within the tillage portion is generally slight. In addition, the mildly saline soil is widely distributed outside the oasis. We calculated the proportion of saline soil according to the attributes of salinization classification (Table 3).

Table 3 reveals that the minimum and maximum proportions of the Manas River Basin are composed of areas with moderately and mildly salinized soils, respectively. The salinized areas accounts for 23.09% of the entire research region.

TABLE 3 Proportion of salinized areas in the research region

Salinity degree	**Mild**	**Moderate**	**Severe**	**Non-salinized**
Area (m^2)	6390855	168259	2028581	28608394
Proportion (%)	17.18	0.46	5.45	76.91

5.6 EVALUATION OF SALINIZATION CLASSIFICATION ACCURACY

Once the shadowgraph of this study was sorted, we validated its accuracy based on the four classification results of the e-Cognition processing system for remote sensing images. Moreover, sample accuracy was verified using the confusion and error matrices. The result of the accuracy test is 0.837. However, soil salinization was difficult to distinguish in the remote sensing image obtained in August 2010. Table 4 and Figure 3 presents the evaluation results.

TABLE 4 Accuracy of soil salinity classification

Type	Producer accuracy (%)	User accuracy (%)	Mean (%)
Mild salinity	80	83.72	81.85
Moderate salinity	71.11	100	85.55
Severe salinity	100	100	100
Total: 83.7%			

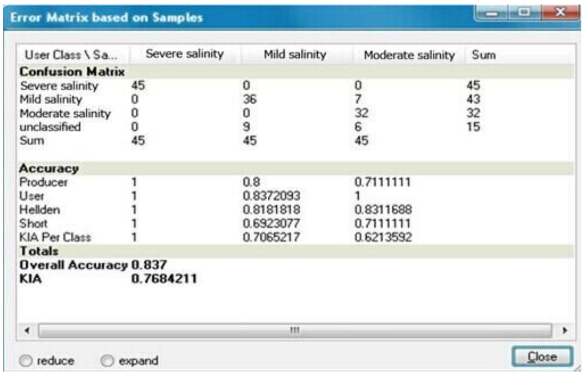

FIGURE 3 e-Cognition system results

6 Results and conclusions

1) The extracted information revealed that severely saline soil is mainly distributed outside the oasis. Moderately saline soil is highly distributed around the central tillage portion of the Manas River, whereas the mildly saline soil is distributed in the bare soil area.

2) According to the proportion of the degree of salinization, the areas with mildly and moderately saline soil account for 17.18% and 0.46% of the total area, respectively.

3) In this study, NDVI, NDWI, and NDSI were used to analyze soil salinity. The analysis results show that overall classification accuracy can reach 83.7% and that the automatic extraction of soil salinity information is highly accurate.

4) The remote sensing image, which was obtained during a period of active vegetation, influenced classification accuracy slightly.

5) The remote sensing image was classified using object-oriented methods. The results suggest that these methods may extract actual geographies automatically. Hence, this research may promote the development of both remote sensing and geographic information systems.

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