

Extraction of palaeochannel information from remote sensing imagery in the east of Chaohu Lake, China

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Abstract Palaeochannels are deposits of unconsolidated sediments or semi-consolidated sedimentary rocks deposited in ancient, currently inactive river and stream channel systems. It is distinct from the overbank deposits of currently active river channels, including ephemeral water courses which do not regularly flow. We have introduced a spectral characteristics-based palaeochannel information extraction model from SPOT-5 imagery with special time phase, which has been built by virtue of an analysis of remote sensing mechanism and spectral characteristics of the palaeochannel, combined with its distinction from the spatial distribution and spectral features of currently active river channels, also with the establishment of remote sensing judging features of the palaeochannel in remote sensing image. This model follows the process of supervised classification → farmland masking and primary component analysis → underground palaeochannel information extraction → information combination → palaeochannel system image. The Zhegao River Valley in the east of Chaohu Lake was selected as a study area, and SPOT-5 imagery was used as a source of data. The result was satisfactory when this method has been successfully applied to extract the palaeochannel information, which can provide good reference for regional remote sensing archeology and neotectonic research. However, the applicability of this method needs to be tested further in other areas as the spatial characteristics and spectral response of palaeochannel might be different.

Keywords palaeochannel, remote sensing, information extraction, spectral characteristic, Chaohu Lake

1 Introduction

The palaeochannel, which was formed by the natural or anthropogenic factors, is a geological-geomorphologic body of the abandoned channel resulting from its changes (Wu, 2008). Many studies about the palaeochannel have been done, combined with practice, by scientists including domestic and foreign scholars (Bridge, 1985; Kalickl, 1987; Khan, 1987; Wu et al., 1996; Xu et al., 1996; Wu, 2002; Brown et al., 2010; Kemp and Rhodes, 2010; Smith et al., 2010). However, traditional methods of investigation into palaeochannels and changes of drainage pattern need more investment of manpower, material and financial resources, and a longer time must be consumed. The use of remote sensing technology solves this problem. The extraction of remote sensing information, such as the information extraction of water, residential areas, roads, geological structure, etc., has been extensively studied in recent years, and various methods about the information extraction have been proposed (Du et al., 2001; Yin et al., 2005; Rathore et al., 2010; Smedt et al., 2011). Remote sensing application for extracting information of palaeochannels not only serves the comprehensive management of watershed systems, territorial planning within the catchment and regional sustainable development, but is also important for the regional remote sensing archeology and revealing how much palaeochannels' changes affect human activities.

Since 1950s, extracting information about palaeochannels and analyzing the changes of drainage pattern by use of remote sensing technology have been carried out extensively. The best representative is the discovery of paleodrainages in the Eastern Sahara (McCauley et al., 1986). The Columbia Space Shuttle carried SIR-A flight through the Sahara in November 1981. Study of the radar echo by the bedrock under the sand layer from SIR-A images brought out the palaeochannels several meters

under the sand, which indicated that there used to be a river system larger than the Nile River in the north of Africa, and negated the argument that there was not a main water system in this area. The palaeochannels provided oases for Paleolithic human in the desert, showing the Sahara's environmental conditions at that time. Many similar studies have been conducted in China. Bai (1994) extracted the change information of the Tarim River after the enhancement of MSS image, and found that the modern Tarim River was the merger of two major river systems from the north and south, proposing that the main reason of the changes was the atmospheric circulation adjustments and neotectonic movements. An application of satellite remote sensing was also used to explore the mystery of Loulan's disappearance, which found that two landslides in the upstream of Peacock River blocked the channel and cut off the water supply that led to the abandonment and dying out of ancient Loulan City (He and Sun, 2001). It was the first time that the riddle of Loulan's disappearance has been answered by use of satellite remote sensing images. With a broad research on historical documents, historical maps, large scale topographic maps, satellite images and other data, Zhang et al. (2004) revealed the channel changes of Santun River and Hutubi River in the past 300 years, finding out a close relationship between the spatial distribution of river system and the historical changes of Manas Lake. He then analyzed the main factors of drainage changes in different time stages. Radar remote sensing technique has also been widely used in the extraction of palaeochannel information. By use of the remote sensing archeological method, Wang et al. (2006) researched the ancient Tongji Grand Canal in Sui and Tang Dynasties and explored the reasons for its traffic function transformation from a narrow ScanSAR image (300 km × 300 km) that was obtained by Canadian Radar Satellite 1 in 1997. A number of old river valley and lake basins buried by wind-blown sand were recognized based on analyses of SIR-A, SIR-B, SIR-C, Radarsat ScanSAR, Landsat MSS and Landsat TM images acquired on different dates and the investigations made in several field trips in Alxa Plateau of Inner Mongolia (Guo et al., 2000a, b; Wang et al., 2002; Wang et al., 2004). This study also establishes a preliminary drainage evolution model in this area since the Tertiary, and finds that the Alxa Plateau was once an area with many rivers and lakes amid a warm and humid climate. According to the results of previous studies, this study explored the palaeochannels within the Zhegao River Basin in the east of Chaohu Lake using the SPOT-5 images, and produced an effective method for remote sensing information extraction of palaeochannels.

2 Study area and data sources

The Zhegao River, located in Chaohu City, is one of the

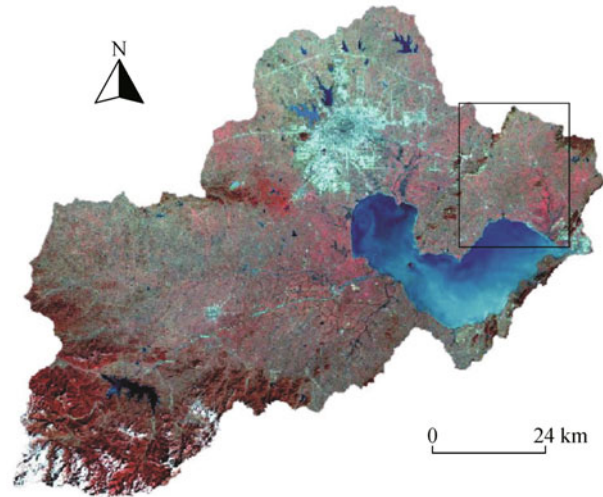


Fig. 1 Location map of the study area

main eastern rivers flowing into the Chaohu Lake (Fig. 1). With the total length of 35 km, the Zhegao River originates in the eastern foot of Fucha Mountain, and flows from the north-west to the south-east, and turns south at Zhegao Town. At last, it passes by Qingtai Mountain to the west. It crosses the Wudu Bridge of the Heyu Road and the Zhonghan Bridge of the Huainan Railway, then flows into the Chaohu Lake at the Hekou Village to the north-west of the Guishan Mountain, which is one of the four major bays (Chorography Compiling Commission of Chaohu City, 1992). The Zhegao River Basin is located in 117°34'–117°52'E, 31°38'–31°55'N, covering an area of about 507 km², including 46 km² of massif area and 41 km² of polders. The branches present trellis drainage going from north-east to south-west or from south-west to north-east. The whole basin is surrounded by hills and mountains from three sides, with one side facing the lake that consists of piedmonts alluvial and lacustrine plains. The well-developed river system of this basin, as well as the dense vegetation and fertile lands, are suitable for human activity. Within the basin, there are a large number of relics from the Neolithic Age to the Shang and Zhou Dynasties (Gao et al., 2008).

The data used is the multi-band image obtained by SPOT-5 on January 4, 2004 (K/J: 288-286/3), with 10 m spatial resolution (the short-wave infrared band is 20 m), including five wavebands (Table 1). To facilitate the

Table 1 Spectral wavelength and resolution of SPOT-5

Sensor	Spectral waveband	Ground resolution/m	Wavelength range/ μ m
SPOT-5	Panchromatic	10	0.48–0.71
	B1: green	10	0.50–0.59
	B2: red	10	0.61–0.68
	B3: near infrared	10	0.78–0.89
	B4: short-wave infrared (SWIR)	20	1.58–1.75

research, data formed in winter is selected to reduce the influence of vegetation cover. Thus, it is convenient to investigate the palaeochannels and exhibit the small beaded lakes, swamps and micro-geomorphologic structure, etc. Besides, there are other data: 1:50000 topographic maps and the land use maps of the study area. To improve the geometric precision of the image, the first step is to make the image registration with multi-band and panchromatic image by use of the cubical polynomial transform model in the software of ERDAS IMAGING 8.4. Then, 50 control points with the same name were selected from two images, and got resampled using the nearest-interpolation method. At last, corrected multi-band images were merged to get the images at 10 m spatial resolution.

3 Rationale and methods

3.1 Principles of spectral information extraction for palaeochannels

Multispectral satellite images recorded the information of electromagnetic waves reflected from the surface feature and its own thermal radiation. Due to the difference of ground objects' structure, composition and physical-chemical properties, their reflection information and their own thermal radiation are different (Du and Zhou, 1998). In terms of the extraction of spectral information, the geological characteristics of palaeochannels in the study area are very important; whether they are different from others' is the crucial theoretical basis for the successful extraction of palaeochannels information. According to the structure and composition of palaeochannels, some underground parts appeared as dark stripped trace in the images, and others remaining on the ground showed beaded lakes or discontinuous dead rivers. Therefore, it is possible to extract the information from the images. The reasons are as follows. 1) What the palaeochannels left on the ground are mainly water body of which the spectral signature in infrared band is strongly absorbed, the digital number (DN) value is much smaller than other features, and diminishes with the increase of the wavelength. So, water body can be easily distinguished and extracted. 2) The underground parts of palaeochannel are full of groundwater, so the vegetation on the surface ground grows well. Through analyzing the soil moisture content and vegetation water status in near-infrared and SWIR bands, the underground palaeochannels can be distinguished. 3) Although the underground palaeochannels are covered by soil, the rich groundwater and well growing vegetation form linear objects in the images, which stand out from the background. Hence they can be obviously reflected in the images. According to the three points above, by selecting optical remote sensing data with appropriate spatial and radiometric resolutions, studies on the spectral

characteristics of palaeochannels formed in the images can establish appropriate information extraction model for palaeochannels research.

3.2 Establishment of interpretation keys for palaeochannels

In regard to the interpretation of palaeochannels in the study area, the visual interpretation method is mainly used to interpret the SPOT-5 B3-B2-B1 false color composite image. Then, according to the historical geographic data and field GPS information, some interpretation keys can be established as follows.

1) The shape feature of palaeochannels in the image. The shape of palaeochannel reflected in the image is the same to its own shape, which is complicated in a linear feature. However, due to their different shapes, which sometimes even get interweaved with ponds and lakes, the marks of palaeochannels' shapes are not very clear. In this case, the interpretation of palaeochannel should mainly depend on other features, with the shape feature thought about as one of the factors.

2) The tonal feature of palaeochannels in the image. Because most of the ancient river channels were buried below the ground level, their reactions in the image are presented by the radiation characteristic of electromagnetic spectrum on the surface feature above palaeochannels. Therefore, we should pay more attention to the interpretation of indirect signs. Indirect interpretation signs of palaeochannels included both soil marks and vegetation marks, for which the reason is that the existence of underground palaeochannels influences some physical properties of surrounding soil and vegetation growth, causing their different radiation characteristics (Chen et al., 2002; Wu et al., 2002; Parcak, 2009). Though palaeochannels are buried by later deposits, the shallow fresh water have been enriched with the underground palaeochannels, and the soil moisture content is higher than that of other regions. Accordingly, in the distribution area of palaeochannels with high level groundwater, the permeability of soil is very good, and the soil is also rich in organic matter, leading to an excellent growth of vegetation. As for the Zhegao River Valley, since the time of the image was in January 2004, when the vegetation is not yet turning green, the interpretation signs of palaeochannels should consist of mainly soil marks. In SPOT-5 B4-B3-B2 false color composite image, compared with the normal regions, the soil surface color in the distribution area of palaeochannels was dark gray, representing a thick zonal distribution.

3.3 Extraction method of thematic information for palaeochannels

As for the collection of object features, one should figure out the images first, and then extract the information in a proper way. The objects of our research are

palaeochannels. In the Zhegao River Valley, most of the palaeochannels lie underground. According to the phase feature of this image with less vegetation, in combination with the above mentioned judging criterion and the information of soil moisture content, a spectral signature-based information extraction model could be established, which follow the process of supervised classification → farmland masking and primary component analysis → underground palaeochannel information extraction → information combination → palaeochannel system image.

3.3.1 Supervised classification and precision evaluation

For SPOT-5 B3-B2-B1 false color composite image, we interpreted the image with use of visual judgment in terms of the image grayscale, color, texture, shape, size and other features. Land types in this area were divided into four major types: water body, residential area, mountain forest and arable land. The water body was further divided into modern river system and palaeochannels remained on the earth's surface, in such forms as the beaded lakes, discontinuous dead rivers etc. In addition, the training plots were chosen along with field investigation data and land use classification maps. When people compile the grader in the ERDAS, about 30 samples or more were selected for each land use type in the determination of feature classification to improve classification accuracy. To achieve better classification results for arable land and water body, about one hundred of samples were selected for both types. Thus, the supervised classification image of Zhegao River Valley was obtained (Fig. 2).

By accuracy evaluation we mean to compare two images, one of which is a classified remote sensing image to be evaluated, while the other is a reference image assumed to be accurate. A good practice is comparing the consistency between every pixel in two images. But in most cases, as it is hard to get a complete accurate reference image, people choose to evaluate parts of pixels in image samples and their reference classification can be achieved by field investigation, more detailed aviation photographs or other classified pictures. As usual, the training samples are divided into two parts: some are used to classify, and others are used for accuracy evaluation. To meet the research need, the method of group sampling is used for accuracy evaluation, including error matrix and

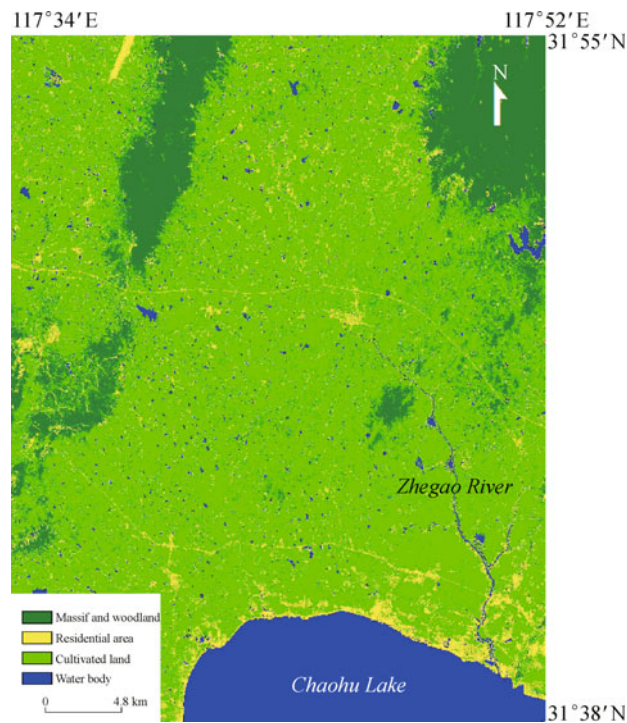


Fig. 2 Supervised classification map of the Zhegao River Valley

kappa analysis.

Error matrix is a kind of standard format for the expression of accuracy evaluation. It is a matrix of “ n ” by “ n ,” and “ n ” represents the number of types. Normally it can be expressed as follows

$$P_{+j} = \sum_{i=1}^n P_{ij}, \quad (1)$$

$$P_{i+} = \sum_{j=1}^n P_{ij}, \quad (2)$$

where P_{ij} is the component of the i -class of categorical data type and the j -class of measured data. The following tables are the classification error matrices obtained after the precision evaluation from the supervised classification image according to different land use types with layer random sampling (Table 2) and the basic precision index calculated from the error matrix (Table 3).

Table 2 Classification error matrices

Reference image	Land use type	Evaluated image				Total
		Water body	Residential area	Massif and woodland	Cultivated land	
Water body		1709	0	0	0	1709
Residential area		72	1890	363	91	2416
Massif and woodland		0	4	1665	2	1671
Cultivated land		185	204	173	2674	3236
Total		1966	2098	2201	2767	9032

Table 3 Basic accuracy index

Land use type	Mapping accuracy	Omission error	User accuracy	Misclassification error
Water body	1709/1709 = 100%	0	1709/1966 = 86.93%	13.07%
Residential area	1890/2416 = 78.23%	21.77%	1890/2098 = 90.09%	9.91%
Massif and woodland	1665/1671 = 99.64%	0.36%	1665/2201 = 75.65%	24.35%
Cultivated land	2674/3236 = 82.63%	3.36%	2674/2767 = 96.64%	17.37%

Note: Total accuracy = (1709 + 1890 + 1665 + 2674)/ 9032 = 87.89%

Kappa analysis adopts another dispersed multiplex technology and considers all the factors in a matrix to get over the defects of overall accuracy, customer and drafting accuracy. The produced assessment index is called K_{hat} statistics. K_{hat} is an index to measure the precision and fitness between two pictures. The formula is as follows:

$$K_{\text{hat}} = \frac{N \sum_{i=1}^r \chi_{ii} - \sum_{i=1}^r (\chi_{i+} \chi_{+i})}{N^2 - \sum_{i=1}^r (\chi_{i+} \chi_{+i})}, \quad (3)$$

where r refers to the total number of types in the error matrix; χ_{ii} represents the number of pixels located on the row i and column i in the error matrix (that is the number of correct classification); χ_{i+} and χ_{+i} represent respectively the total number of pixels on the row i and column i ; N represents the total quantity used for precision evaluation.

According to the calculation and analysis above, the overall accuracy of supervised classification is 87.89%; K_{hat} statistic is 83.67%, which indicates a high precision of supervised classification. The user precision and mapping accuracy for arable land type are 82.63% and 96.64% respectively, which meet the requirements for farmland masking.

3.3.2 Farmland masking and principal components analysis (PCA) transformation

According to the characteristics of time phase in the study area, the vegetation coverage rate is low in January. The information of buried palaeochannels is mainly reflected by soil moisture. Therefore, the mask-processing can be done through the result of supervised classification of the information of farmland, so as to remove the interference and affection from other surface features. The concrete method is to select cultivated land types by using the region of interest (ROI) tool under the support of ENVI 4.0, and then apply the masking tool to calculate the multiband image. In this way, only the information of cultivated land was left in the multiband image.

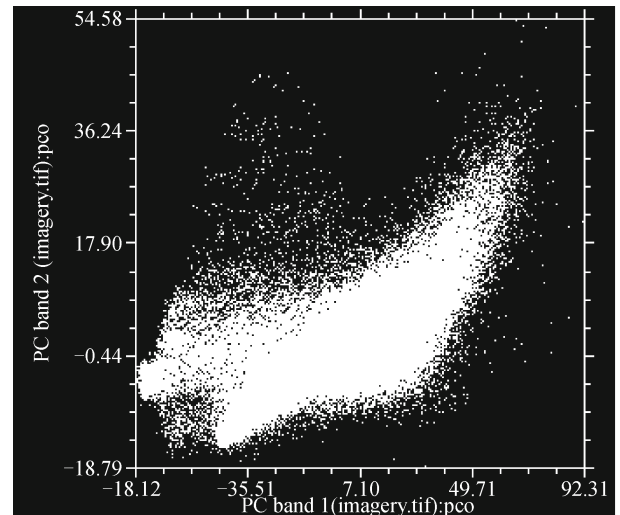
To verify whether it is efficient to remove the interference from other surface features to the buried palaeochannels, or determine the final proposal of information extraction, principal components analysis was used in the original multiband image and the image

Table 4 Characteristic values from principal components analysis

PCA of original image		PCA of farmland masking	
No.	Eigenvalue	No.	Eigenvalue
PC1	0.839091	PC1	0.839091
PC2	0.134602	PC2	0.134602
PC3	0.019263	PC3	0.019263
PC4	0.007044	PC4	0.007044

after farmland masking. From the eigenvalue of principal components in Table 4, it can be concluded that the information of the original multiband image and the image after farmland masking was mainly concentrated by the first two principal components. 97.39% of the variance information can be understood.

The two-dimensional spectral scatter plots were generated by the combination of PC1 and PC2 principal components (Fig. 3), showing that the shape of plots is irregular, and the spectral variability of the components makes the selection very difficult. However, after the farmland masking, the two-dimensional spectral scatter plots generated by the combination of PC1 and PC2 principal components are of rule shape (Fig. 4), showing a simple ribbon pattern.

**Fig. 3** Planar scatter plot of original image

The endmember selected from the images and further analysis show that (Fig. 5) the long axis of the strip reflects

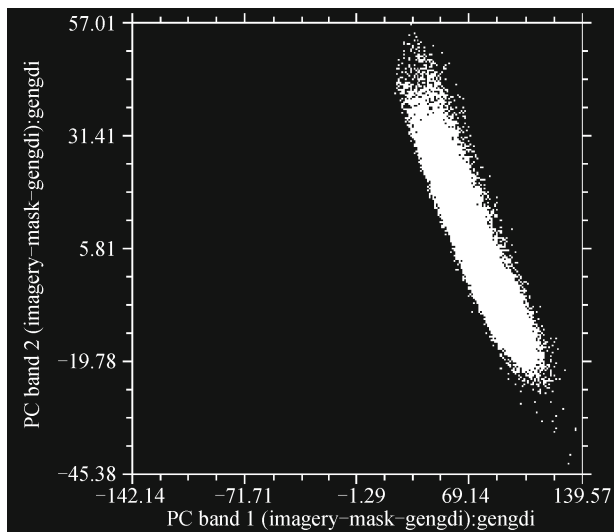


Fig. 4 Planar scatter plot of masking image

changes in soil moisture content with simple and clear endmember. This indicates that farmland masking image can well reject information interference of other surface features. Therefore, threshold segmentation method can be used to extract information of the palaeochannels.

3.3.3 Extraction of palaeochannels information using threshold method

The above analysis of farmland masking and PCA transformation indicate that PC1 made by farmland masking image is sensitive to soil moisture content,

while the impact of vegetation can be neglected. Thus, the threshold segmentation method of PC1 can be adopted to extract the information of underground palaeochannels. Then cursor-inquiring function in ENVI 4.0 was used to analyze the DN value of PC1. Through repeated tests, we learnt that when the threshold is 54 the information of palaeochannels can be extracted efficiently. The extraction model established by the threshold method is as follows. If $PC1 < K$ Then Palaeochannel ($K = 54$).

There are many isolated pixel points amidst mixed pixels, which perform as noise in the extraction of images, and this hampers the extraction. However, smoothing effort is an appropriate way to eliminate these noises. In view of the specific conditions of the Zhegao River Valley, we have used the function of clump classes in ENVI 4.0 to perform image filtering so as to eliminate the figure spot. Finally, after integrating the extracted information of underground palaeochannels to the surface ones from supervised classification, the final extracted image of palaeochannels was got (Fig. 6). Comparing the extracted image with the B3-B2-B1-band false color composite image, we have found out that the extraction of palaeochannels information has achieved success.

4 Results and discussion

Studies show that for the areas with dense vegetation in East China, the characteristics of spatial distribution and spectrum for palaeochannels are different from that of the current river channels. Through analyzing the palaeochan-

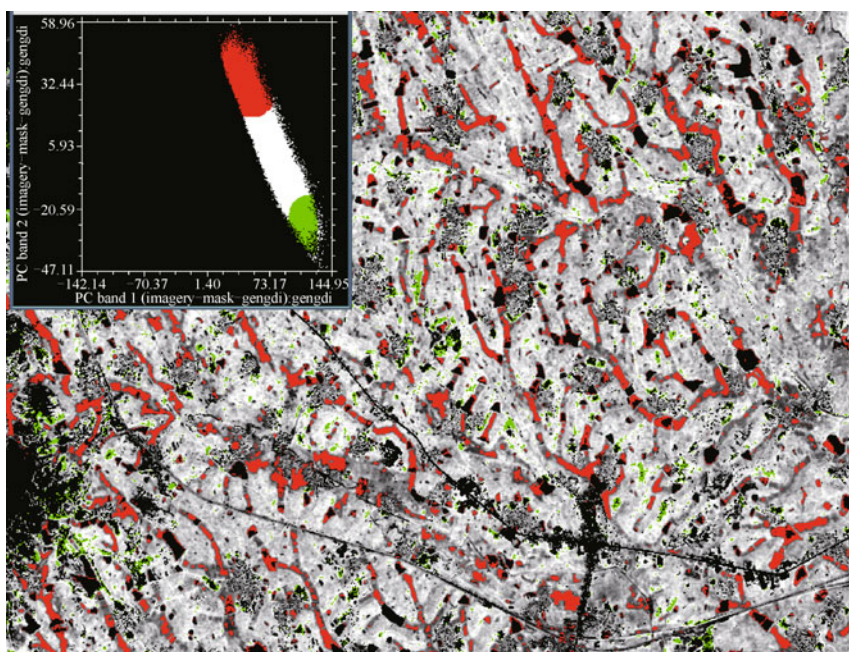


Fig. 5 Endmember selection of masking image

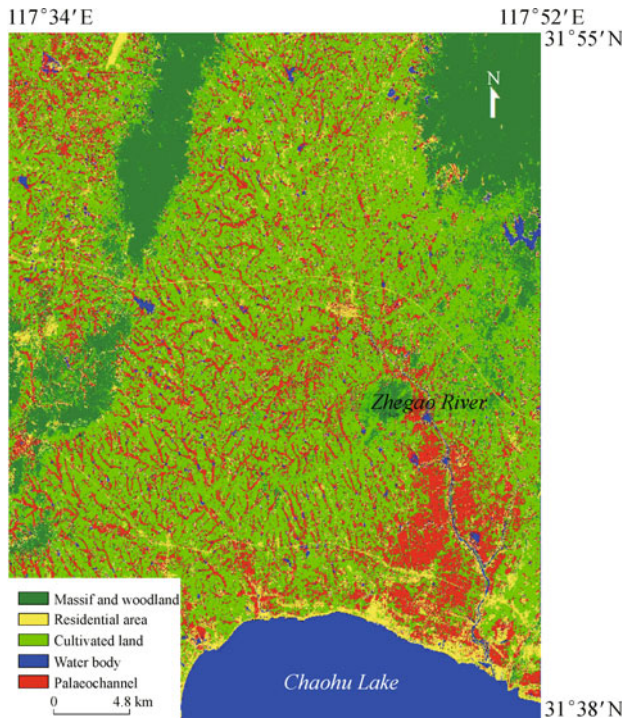


Fig. 6 Distribution of palaeochannels in the Zhegao River Valley

nels' spectral signature of different types, selecting the SPOT-5 image with special time phase in study areas, as well as removing other interferential information, the information extraction model based on spectral signature was built on farmland masking image, which follow the process of supervised classification → farmland masking and primary component analysis → underground palaeochannel information extraction → information combination → palaeochannel system image. In this way the information of palaeochannels could be extracted efficiently and more accurately.

The general applicability of the extraction method proposed in this study and whether it can be used in other regions needs further test, especially for the method which is restricted to the time phase of the images. Therefore, further study on the spectral signature of palaeochannels is necessary. However, as long as the characteristics of palaeochannels are alike with those in this study, our method should be applicable for an efficient extraction of palaeochannels information, and will be able to provide fundamental data for the regional remote sensing archeology.

From the image of palaeochannel distribution, we can see that there used to be a huge ancient water system in the west of the Zhegao River Valley during the geological period. The palaeochannels' traces have shown that the water moved from west to east as might be related to a tectonic tilting movement. This finding needs further discussion with reference to the results of archeological and historical data.

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