
Evaluating the use of SPOT satellite imagery for extracting small-sized archaeological sites along palaeochannels: Zhegao River Valley in the northeast of Chaohu area, China a case study

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Abstract: Because of the flourishing vegetation and developed agriculture in East China, it is difficult to extract information of small-sized archaeological sites from remote sensing image only based on spectral analysis of features. This article presents an evaluation of the viability of SPOT satellite imagery in detecting mound-shaped archaeological sites in Zhegao River Valley in the northeast of Chaohu area. Initial studies have shown evidence of a prominent palaeochannel river system, which has become buried under land cover of western Zhegao River Valley sometime during late Holocene. 1: 50000 digital topographic maps could be highly effective in determining mound-shaped sites and their elevation in study zones. These mound-shaped sites include known and unknown small-sized archaeological sites of the Neolithic and Pre-Qin periods. Database of seven known small-sized archaeological sites compiled from various published sources, prepared in GIS environment could be utilized to understand their relationship with identified courses of palaeochannels. Through this study and multi-source data integration, 3 likely archaeological sites were identified from many mound-shaped sites and tested by field investigations with the Administration Place of Culture Relic of Chaohu City. This new method strengthens the use of multispectral images in archaeological survey of subtropical agricultural area. It was found that there is a close relationship between small-sized archaeological sites and palaeochannels, and suggested that

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other raised mounds adjoining the identified palaeochannel courses may be taken up for further archaeological exploration.

Key words: palaeochannel, archaeological sites, information extraction, spatial analysis, Zhegao River

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1 INTRODUCTION

The Chinese civilization of thousands of years of has left a substantial number of ancient cultural sites (i.e. historical remains of human production, livelihood and other activities in the ancient times) for mankind (Nie & Yang, 2009; Deng, *et al.*, 2010). Surveys and analyses of various sites could reveal the conditions of China's history, society, economy and culture with a view to understanding the development of human activities, the laws of environmental evolution and the man-land relations. How to timely discover ancient cultural sites has always been the archaeologists' concern. Since the mid 20th century, space science and information technology have been developing at a high speed, so the archaeological field work under the support of new technologies has made rapid progresses, and its means and methods are also being gradually improved and perfected (Schiffer, 1984; Garrison, *et al.*, 2008; Lertlum & Mamoru, 2009; Rua, 2009; Rajani & Rajawat, 2011). By analyzing the aerial remote sensing images of the Burgundy crop region in France, archaeologists once discovered the ancient Roman roads and villages hidden under the crops, and they also discovered Syria historical remains that buried in the sand in the ancient Roman period by virtue of the geophysical prospecting method (Fowler, 1995). In 1987, China Aero Geophysical Survey & Remote Sensing Center for Land and Resources started a remote sensing investigation over the Great Wall in Beijing (Zeng, *et al.*, 1987); by interpreting aerial remote sensing data, Chen, *et al.* (2002) made forecasts according to the differences between the ground objects in shape, size, hue and shadow in the images and discovered about 200 relatively large sites with the

characteristics of archaeological sites in Shanghai; by using the remote sensing images and ground penetrating radars, Zhou, *et al.* (2007) successfully plumbed the contour of the Mausoleum of the First Qin Emperor and the underground circumstances of the unexcavated areas; and Wang, *et al.* (2005) discovered the underwater old city in the Chaohu Lake by virtue of the remote sensing images and underwater television.

Most of the past studies on the information extraction of archaeological sites focus on large and medium-sized archaeological sites like the ancient building relics and town sites, etc.; investigations into some small-sized archaeological sites (which cover an area of less than 100 thousand square meters) mainly relied on manual work. Because of their structure and composition of highly-reflective materials, or their location in bare and level terrains which present great contextual differences from the surrounding environment, large-sized archaeological sites or relics may leave significantly-contrasted spectral information between the ground objects and their backgrounds in the images, which may be interpreted directly and visually or extracted through simple image processing. As regards small-sized archaeological sites situated in complicated environment (especially the areas with intense vegetation in Eastern China) composed of special parts and severely destructed by human activities, the same spectrum corresponds to different objects and the same object with different spectrums are commonly seen in the images. Such comprehensive ground objects are unlikely to distinguish and identify according to the spectral characteristics. With regard to the general surveys of such kind of archaeological sites, the archaeologists, after defining the archaeological area, conduct a blanket search in the entire archaeological area

by reference to the relief map. It's quite tough because the work cycle is long and the investigation route often runs through some regions with harsh environment.

Recently, as the third national archaeological survey has been fully launched, it's required to introduce information technologies to generally survey all archaeological remains within the Chinese territory. By selecting Zhegao River Valley in northeast Chaohu in Anhui as an experimental area and utilizing SPOT-5 satellite images, topographic map and other data, this study realizes the extraction and identification of information on small-sized archaeological sites based on the knowledge of the spatial relations between ground objects, thus providing rapid and precise methods for general archaeological surveys.

2 STUDY AREA AND DATA

The Zhegao River Valley, located in the northeast Chaohu Lake area with well-developed river systems and intense vegetation, is level in the middle and covered by low mountains and hills nearby, and suitable for ancient human activities. The analyses of archaeological surveys and historical data concerned have indicated the existence of a considerable number of archaeological sites of Shang and Zhou Dynasties (Gao, et al., 2008). As the demand for social and economic development and the aggravated influence of human activities, bulk of remains on the ground surface have been or will be undermined. According to the survey records of extant archaeological sites, there are 14 archaeological sites of Shang and Zhou Dynasties have been discovered. Under the guidance of staff members from Chaohu Center for Administration of Cultural Relics, we conducted a field survey over 7 known archaeological sites and 5 unconfirmed places that don't belong to archaeological sites, and precisely measured the shapes, positions and areas of the archaeological sites using the mobile GIS-ArcPad software-equipped PDA (Personal Digital Assistant) in combination with the GPS module. The extant archaeological sites which are conserved

intact have following characteristics: the archaeological sites are mostly mesas or gentle slope mounds which overtop the surrounding ground surface; the difference in elevation is 1-6 meters; their surroundings are cultivated land, their top is level, and many small rivers go through or surround them; their flat configuration is oval or approximately circular; and they cover areas of 3000 m² to 10000 m². Imprinted ceramic relics of the Shang and Zhou Dynasties that were routed up for farming can be found on them, and some crops that were planted on the surface are the same as those surrounding ones, so they are small-sized archaeological sites.

The image selected, which was got in January 2004, is the multi-spectral image data on northeast Chaohu Lake area got with French SPOT earth survey satellite series SPOT-5. SPOT-5 satellite imagery data are technically advantaged because of their high resolution and large-area acceptance. The resolution capacity for the red, green and near infrared waveband is 10 meters and the resolution capacity for shortwave infrared is 20 meters, making it suitable for the overall observation of ground objects (Table 1).

Table 1 Parameters of SPOT-5 satellite data

Spectral wavebands	Wavelength range / μm	Ground resolution /m
B1 (Green)	0.50—0.59	10
B2 (Red)	0.61—0.68	10
B3 (Near infrared)	0.78—0.89	10
B4 (Short-wave infrared)	1.58—1.75	20

3 SPECTRAL ANALYSES OF FEATURES

The ERDAS IMAGINE 8.5 software was adopted to geometrically correct the SPOT-5 image according to the field gathering by reference to the topographic map, and the parametric method was utilized to universally convert it into the UTM-WGS84 coordinated system. Their positions were marked according to the GPS information on known archaeological sites which were got through field measurements. Though visually interpreting the

images, we found that the known archaeological sites and the ground objects in the background were mixed, and their shapes, sizes and hues were difficult to distinguish. As the image was captured in winter when there was little vegetation, except the rape flower; but large areas of rape flowers were planted on the surface of archaeological sites, hence making it difficult to distinguish the hues reflected by the image and the surrounding environment. The relative altitudes of these archaeological sites are only several meters, showing no significant shadows, so it is difficult to distinguish them simply according to image features.

Since the ground objects have different structures, compositions and physicochemical properties, they reflect different electromagnetic energies, which are registered by different pixel luminance in the image. To concretely analyze the characteristics of the spectral luminosity of archaeological sites and the ground objects on SPOT-5, ground objects of 5 typical kinds were selected in the image by virtue of the spectral profile tool in the ERDAS 8.5 image processing software, and the average spectral curves (Fig.1) of ground objects were drawn by selecting a specific number of spots on the archaeological sites, vegetation, river system surrounding the archaeological sites, residential areas and roads.

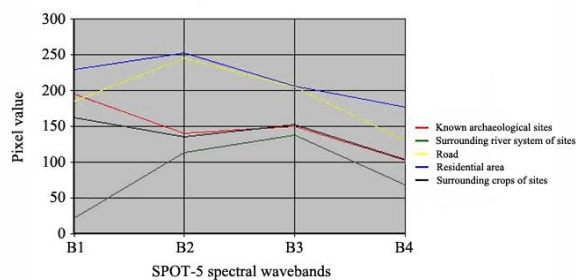


Fig. 1 Spectral curves of archaeological sites and its surrounding environments

As can be seen from Fig. 1, the known archaeological sites have different gray values in different wavebands on SPOT-5. The spectrums of the river system surrounding the archaeological sites are significantly different from those of other ground objects, and it is

easy to distinguish roads and residential areas from ground objects of other categories. Therefore, a threshold value may be set to segregate roads, residential areas and the river systems surrounding the archaeological sites from the image. Archaeological sites are greatly different from the river systems surrounding the archaeological sites, residential areas and roads, but their spectrums overlap with vegetation spectrums to a great extent. Though the correlation distance method and maximum likelihood method were adopted to categorize the images, we failed to effectively distinguish between vegetation and archaeological sites. If the study area had higher resolution or hyperspectral images, the differences in vegetation growths can be used to try further distinction. If no auxiliary information is available, other methods have to be figured out.

4 METHODOLOGY

4.1 Principle of the knowledge of the spatial relations between ground objects

In analyzing remote sensing images, there is an important geoprocessing procedure which involves below two respects: first, supplement the information that the remote sensing fails to bring back, i.e. add other information related to geoscience; second, conduct a geoanalysis according to the image information to extrapolate the information that is not reflected by the image (Zhou, 1999), both of which have to be supported by geoscience knowledge. Interactions and correlations exist among essential factors in geographic environment, and the more complicated the essential factors are, the closer their relation with the biological geoscience principles for objects and phenomena (Liu & Wang, 2006). Distribution of the archaeological sites presents inherent laws, most of which is closely pertinent to the geographic location, geomorphic type, economic type and natural environment, etc. It is of vital importance to do more integration, reasoning and interpretation work according to the experience in spatial relations between

ground objects and geoscience principles with a view to revealing the phenomena that can't be read directly from the image (Zhou, 1999). The key to the description of spatial relations is: firstly, find out the corresponding structural relation in the image according to the relations between the types of ground objects, and then convert it into the relations between ground object types to build a correlation model of a group of ground objects and to express the relatively-confirmed relationships between ground object types in the objective world in a standard format (Yan, 1998).

4.2 Technical route

Historical data shows that the ancients always chose to live by waters to maximally utilize water resources, so the ancient archaeological sites are usually distributed near stream channels. Field surveys also demonstrate that archaeological sites are surrounded by streams and palaeochannels nearby. These distribution characteristics provide a foundation for judging the existence and positions of the archaeological sites through spatial relation analysis. Spatial analysis is an analytic technique, by use of the spatial position, distribution, evolution, etc. Through which the concerning geographic objects are acquired from spatial data, and the spatial overlaying technique can be used to overlay the archaeological sites with all layers of environmental elements, so experiment can be made on the known archaeological sites to build the inner relations between them and the environmental information based on gathering such information through software analysis.

The observation of large-scale topographic map tells that there are a large number of notations on mounds, independent objects and ground objects similar to archaeological sites in exterior appearance. Known archaeological sites were included, and there was more unknown information, so these information may be used as fundamental data to judge the archaeological sites, but ineffective information must be excluded. Therefore, we may adopt such a working thought, namely, according to the microtopographic notation information of the known

and unconfirmed archaeological sites on the topographic map, their GPS spatial positioning may be combined to label their corresponding positions in the high resolution remote sensing image. Information on the environment and ground objects can be extracted through image processing, and the layered vector quantization of such information may be conducted separately. The function of GIS spatial analysis can be combined to analyze the spatial relations between the characteristics of the known archaeological sites and environmental elements, and principles for the distribution of known archaeological sites were summarized on this basis. The spatial relations between known archaeological sites and environmental layers were utilized in combination with the living habits of ancient people to filter the unconfirmed archaeological sites. The most potential information on the unknown archaeological sites was eventually discovered and extracted, and then the field test was directly made according to the GPS positioning information. The process is shown in Fig. 2.

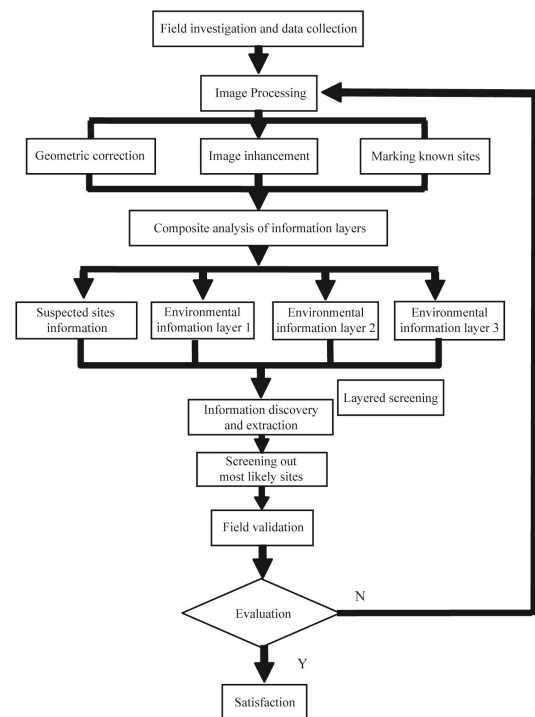


Fig. 2 Information extraction of small-sized archaeological sites based on composite analysis of multiple layers

4.3 Palaeochannels in the study area

Palaeochannels refers to the abandoned watercourses left after the rivers flowed in other directions, including the parts exposed on the ground surface and covered by sediments. Studying palaeochannels could not only help understand the history of the fluvial landform evolution in an area, but also serves as an important means to study the ancient geographic environment (Wu, 2002). Data indicates that the selection of living areas by the ancients is closely tied up with the source of water at the time, so palaeochannel information extraction must go before the concrete analysis of the relations between site selection and water sources. It is unlikely to obtain an overall picture of the palaeochannels through field surveys, yet such overall picture could be reflected clearly in the remote sensing image (Fig. 3). According to this analysis, palaeochannels in the area includes the parts exposed on the ground surface and covered by sediments, which are registered by beaded lakes or discontinuous rivers on the ground surface. The spectrum of the water body in the short infrared band (the 4th band of SPOT-5 image) in the image is mainly characterized by strong absorption and smaller image luminance than that of other substances, making it the most differential from the other substances. By comparison with spectral characteristics of the surrounding ground objects, in the short infrared band, the water body reflectivity decreased significantly, the luminance difference from vegetation, residential areas and other main ground objects was distinct and the spectral curves can separate completely. As the mountain shadows were few in the study area, when the threshold value was set at 50, the water body can be well extracted. The information extraction model of water body is established as follows:

If $DN < K$ Then Water body ($K=50$)

If $DN \geq K$ Then Non water body ($K=50$)

Of which, DN refers to the luminance value of short infrared band (the fourth wave band) of SPOT-5 image, and K refers to the threshold value (the same below). Information extraction goes through the clustering and

removal analysis in ERDAS 8.5, then the water body information was being extracted when produced patches were combined and removed, and also the modern river system that was included in the removal information was wiped off by reference to topographic maps. Comparing with the B3-B2-B4 false color composite image, little information missed the extraction.

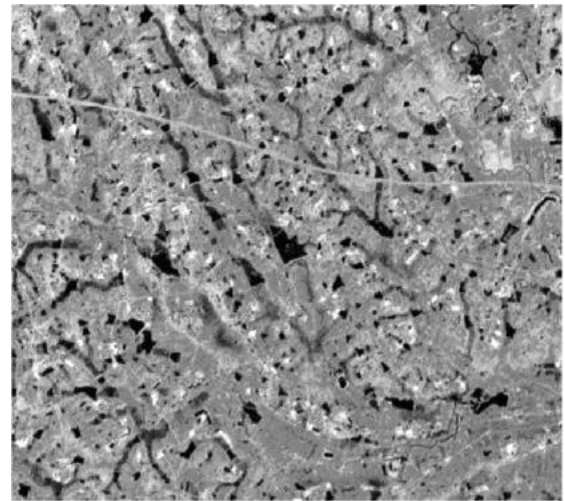


Fig. 3 SPOT-5 image showing the palaeochannels of some areas of Zhegao River Valley

Though the buried palaeochannels are covered by the surface soil, the soil has high moisture content that cultivates good vegetation comparing with the high reflectivity soil in other areas. It was reflected in the remote sensing image as a winding linear ground object in the pattern of a dark ribbon, most of which are connected with ponds and lakes, forming exceptional interpretation keys that can be extracted based on the spectral difference from ground objects. A great many of experiments have proved that, at the threshold value of 70, information on buried palaeochannels and modern rivers can be well reflected. The extraction model is as follows:

If $DN < K$ Then Palaeochannels or water body ($K=70$)

If $DN \geq K$ Then Non water body ($K=70$)

Two extracted palaeochannel images were combined into overall palaeochannels data (Fig. 4) in this area through raster image processing. The extraction result

proved to be favorable through primitive remote sensing image comparison and field survey test verification.

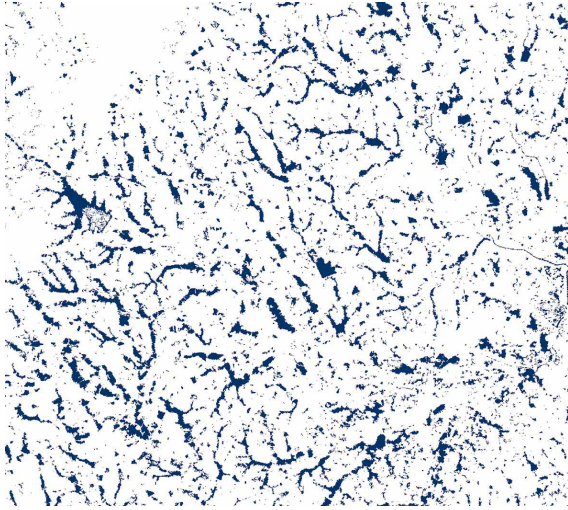


Fig. 4 Processed SPOT-5 image showing the palaeochannels of some areas of Zhegao River Valley

5 RESULTS AND ANALYSIS

5.1 Layer overlapping

All layers were built using the ArcGIS 9.0 software and following below steps to make a comprehensive overlay analysis of the aggregation of data on the known archaeological sites, unconfirmed archaeological sites, paleochannels, DEM, etc.:

(1) A scanned topographic map of the study area that was transformed through projection was loaded, the Zhegao Town as the center of the topographic map was selected. The key marks in the nearby range of 7 km were 42 pieces of microtopographic information on independent objects (including known and unconfirmed archaeological sites), and a new area layer was built to digitize and store them.

(2) The raster image information from previously extracted palaeochannels was loaded, the palaeochannel centerline was drew accordingly and saved in the form of linear layers; the vector layers of buffer zones with different distances from the centerline was built, serving as an area layer.

(3) The rectified remote sensing image of the study area was used as the base map, and at the same time the

previously built point layer of independent objects, the linear layer of palaeochannels and the layer of the buffer zones was loaded to display the layer information in an overlaying manner.

(4) DEM of the study area was used to overlay with the archaeological sites information.

5.2 Spatial analysis

The analysis of the buffer zones showed that the known 7 archaeological sites were all out of the 15 m buffer zones and located at somewhere between 15-200 meters away from the palaeochannel centerline. Most were at watercourse turns, intersections of rivers or zones surrounded by waters from three sides, and the sites were distributed along the river (Fig. 5).

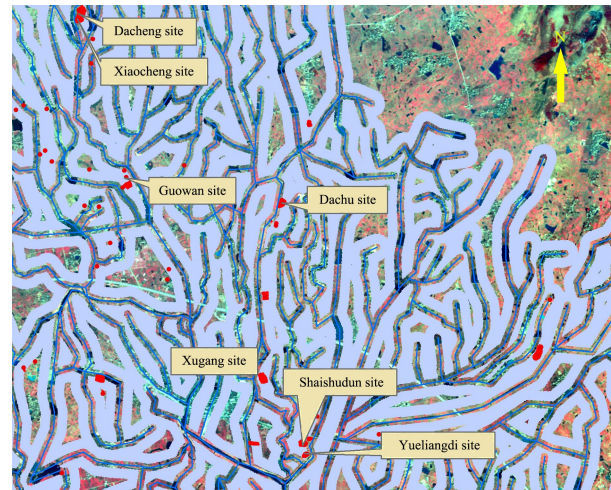


Fig. 5 Distribution of palaeochannels buffer zones (blue strips) and known archaeological sites (red dots)

In the figure 5, there are archaeological sites, layer of the unconfirmed places, the palaeochannel centerline, layer of the palaeochannel buffer zones and layer of the remote sensing images from the top to the bottom. In combination with the ancient people's living habits, such a distribution which was near the water source demonstrates that the ancient people, in order to survive, relied mainly on natural resources, therefore their life was intimately related to water sources. When selecting their habitual residence, they gave priority to the location of water sources. Living at the turns or intersections of rivers helped them further utilize water resources in life

and production, defense possible intruders and commune. Plus the network-like water system of these rivers, all the above provided convenience for different ancient settlements to contact one another and conduct culture exchanges.

Contour elevation analysis and field observation data showed that the known archaeological sites were all located somewhere between 10-20 m contours (Fig. 6). Since the ancient people had limited power to change the natural conditions, they were restricted by the natural environment, had to live somewhere higher than the water surface in order to avoid floods. Related research indicates that 10 m contour was the largest lakeshore range in the Chaohu Lake in history (Wu, *et al.*, 2010). During the Shang and Zhou Dynasties, the Chaohu Lake basin was warm and humid (Wang, *et al.*, 2008), being subject to abundant floods during the high flow period. That the ancient people chose to build some high table lands or piled up some highlands at places properly away from rivers, hence making it easy for them to get water and to avoid floods. Living at highlands near the water source also conforms to the natural conditions by the Zhegao River Valley.

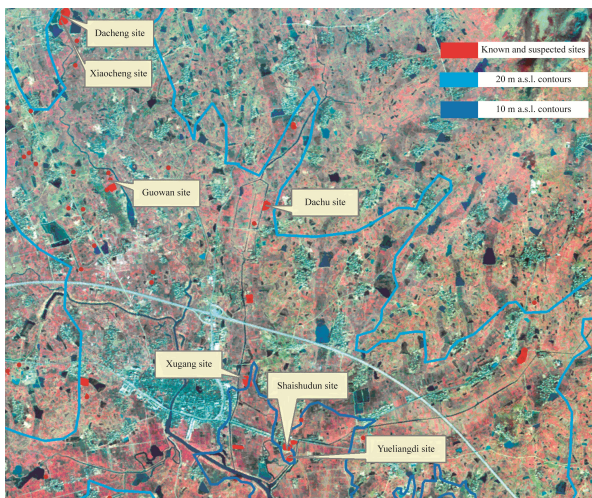


Fig. 6 Elevation distribution of the known and suspected archaeological sites

It was measured with software ranging function that the archaeological sites were featured by distributing

alternatively along both river banks (Fig. 7). Along the same palaeochannel, they were distributed alternatively and the actual distance between two archaeological sites was 6 km. During Shang and Zhou Dynasties, agriculture had been greatly developed, and living far away from mountains and near water sources facilitated farming more and conformed to human farming radius in an agricultural society, i.e., people normally would not walk one or more hours to conduct agricultural production. By the time, the ancient people had settled down. With the improvement of the productive forces, people living in the same archaeological site increased gradually, families enlarged, and the burden on the ecological carrying capacity became heavier. People then would choose to live nearby to take care of one another to alleviate the burden on resources. That's why there are small-sized archaeological sites around some larger ones, and it is impossible for people to survive without contacting one another. Different families had to have contacts, too. The relics fragments exploited from the archaeological sites also showed the existence of cultural exchanges among archaeological sites, thus two archaeological sites would not be too far away from each other.



Fig. 7 Distance measuring between archaeological sites

It's found based on the relief map and the analyses of interpreted remote sensing images that the known archaeological sites had the same features of landform combination in terms of their existing environment, i.e., there were palaeochannels, flatlands and mounds near them. Plains are suitable for the ancient agricultural production, and the archaeological sites came into being

mainly by artificial piling up or mound digging. However, around the non-archaeological sites, we can not see the co-existence of the above three elements.

5.3 Information extraction

The unconfirmed archaeological sites were selected on the basis of the analysis results of the spatial laws of the known archaeological sites, which were used as the empirical knowledge. A model was built according to ArcGIS Model Builder (Fig. 8) and rules were set to extract information on the archaeological sites. Specific process is as follows: the ArcGIS software was used to set a buffer zone which was 15-200 meter away from the palaeochannel centerline, and the points not in the zone were wiped off; the points that were below the 10 m contour or above the 20 m contour were wiped off; by referring to the remote sensing images got via multi-spectral synthesis, and by the man-computer interactive processing, some mounds near palaeochannels, which were earthworks of modern water conservancy proved by Earlier field investigation, could be seen and were all wiped off; some mounds that were on one side of the palaeochannel and were relatively far from surrounding mounds were wiped off. At last, all selected points must be checked whether they have association with the geomorphic evolution of the plains and downlands by overlapping the selected points with the relief map. The most possible archaeological sites were left then (Fig. 9).

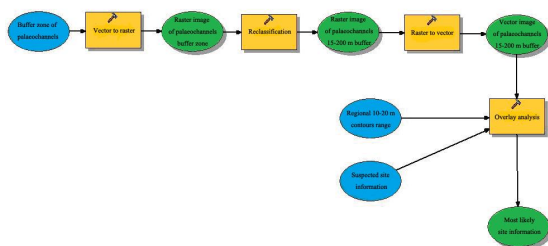


Fig. 8 Technological process of ArcGIS Model Builder

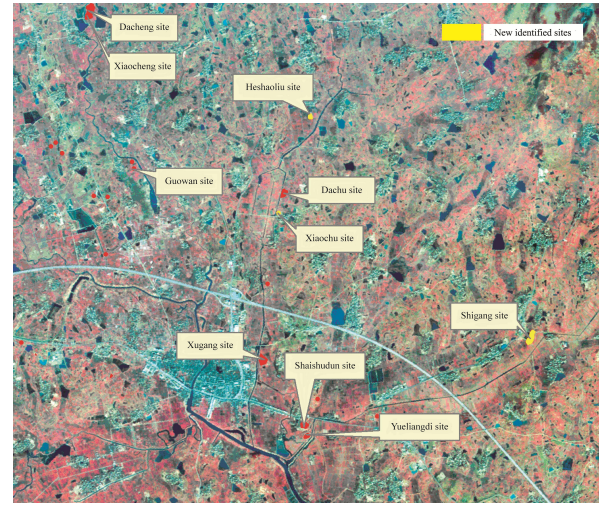


Fig. 9 Results of extracting small-sized archaeological sites along palaeochannels in the Zhegao River Valley

According to the locations of the archaeological sites in the image, we did a field check with some staff from Management Institute of Cultural Relics of Chaohu City in Oct. 2008, and found that the extracted information on the archaeological sites not only summarized the known archaeological sites, but also confirmed another three archaeological sites belonging to the Shang and Zhou Dynasties. These points not selected were all not the archaeological sites, so the extraction was very good.

6 CONCLUSIONS

(1) Based on the knowledge on spatial relations between ground objects and the comprehensive analysis of multi-source information, we can get information on small-sized archaeological sites which can not be directly identified in remote sensing images. With palaeochannels interpreted from remote sensing images as the reference, in combination with the GPS positioning labels of the known archaeological sites, on the basis of summarizing and analyzing the relationships between the known archaeological sites, the palaeochannels and the contours, and in view of the analysis and processing of the suspected points on the relief map using GIS spatial analysis function, the most possible archaeological sites were selected. After being compared with the records of actual observation, the efficiency was significant. This

method can narrow down the scope of census, save a great deal of time, manpower and material resources for the archaeological work, and may lead to the discovery of archaeological sites which had not been discovered for a long time with traditional methods.

(2) The archaeological sites are closed tied up with rivers. The archaeological sites in the Zhegao River Valley are generally within 10-20 m contours and a 15-200 m buffer zone along both sides of the palaeochannels, and mostly at large turns or sections of rivers, i.e., within an area surrounded by water or rivers on three sides. The archaeological sites present the feature of alternative distribution, with the pitch of alternative distribution being about 3 km. That makes the actual distance between two archaeological sites 6 km, which is rightly the radius of agricultural and hunting activities in earlier times in the study area.

(3) To adopt SPOT satellite images and the GIS technology to obtain information on archaeological sites presents advantages which are unmatched by the

traditional archaeological census. Since it is combined with the knowledge on the relations between ground objects, as an important content in remote sensing interpretation, it plays a major role in archaeological exploration. It is a must to conduct field investigation to get information on the archaeological sites on the basis of spectral characteristics or spatial relations between ground objects. Certainly, specific methods may be adopted accordingly in different investigated areas. With the support of earth observation, what's reflected more is the macro information on the archaeological sites, and more details have to be got by field archaeology so as to make the archaeological work scientific and ensure it can give full play to the role of geoinformatics.

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