Identification of artificial paleo-irrigation canals using remote sensing images in ancient Juyan

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Abstract: Irrigation is the basic guarantee for agricultural production and development in arid regions. As one of the main features and symbols of farming culture, artificial canals can be seen as the most important water conservancy facilities in irrigation systems serving arid areas. Many historical records and archaeological discoveries have indicated that there were prosperous agricultural activities in ancient Juyan Oasis in historical period of interest. There are many remnants of past human activities in farming in the desert and Gobi Desert. In this study, based on different kinds of historical documents and archaeological data, combined with hundreds of typical sample points from field investigations and some high resolution remote sensing images, artificial canals were identified and extracted, which were mainly used for irrigation in the past. The remnants of these artificial canals are dispersed around the cultivated areas located near important city sites. The current condition of each artificial canal is closely linked to its construction, its usage and its abandonment of the nearby city sites. The present study illustrates the capability of high resolution remote sensing images to identify and map the remnants of narrow targets in large desert environment, such as artificial paleo-irrigation canals.

Key words: Artificial canals, Irrigation, Ancient Juyan Oasis, Environmental change, Archaeology

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1 INTRODUCTION

Channel changes have played an important role in the development of agricultural activities in the downstreams of river basins. In particular, these changes have a directly impact on farmland irrigation in arid regions, where the irrigation water is derived primarily from river water by constructing various artificial conservancy facilities. Understanding the regional environmental change and development of agricultural processes is necessary to research the historical changes in natural water system and artificial canals in the past (Alizadeh, et al., 2004). As one of the main features and symbols of agricultural development in arid regions, artificial canals can be seen as the most important water conservancy facilities for irrigated agriculture. The study of these canals is important for understanding past environmental conditions and agricultural development at a small scale and restoring these historical artificial canals in arid regions (Nelson, et al., 2010; Heyvaert, et al., 2012; Qin, et al., 2012).

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Downstream environments of the arid inland river basins of northwestern China have changed dramatically during the past 2000 years. Heihe River Basin is the second largest arid inland river of northwestern China, which originates from the Qilian Mountains in the northern part of the Qinghai-Tibetan Plateau, flows across the Zhangye Basin of Gansu Province, and enters into the Ejina Banner of Inner Mongolia. Ancient Juyan Oasis is located downstream of the river, which is southeast of the modern Ejina Oasis and northwest of the Badain Jaran Desert (Fig. 1). Ancient Juyan Oasis had a prosperous of agricultural civilization by nourishing from ancient Ruoshui water in historical periods. Archaeological evidence and historical literatures demonstrate that ancient Juyan had once been the important positions in the frontier defense at different stages throughout history (Sommarstron, 1956, 1958; Li, 1991; Li and Sang, 2010), including the Han Dynasty (B.C. 121-A.D. 220), the Wei Jin Southern and Northern Dynasties (A.D. 221-581), the Sui and Tang Dynasties (A.D. 583-762), the Western Xia Dynasty (A.D. 1028-1226) and the Yuan Dynasty (A.D. 1285-1375). The rapid deterioration of the surrounding environments led to the completely desertification of the study area during the past hundreds of years. The ancient Juyan Oasis, which located in the downstream of arid inland river basin, has been one of the typical oases for its location movement of human activities from past to current.

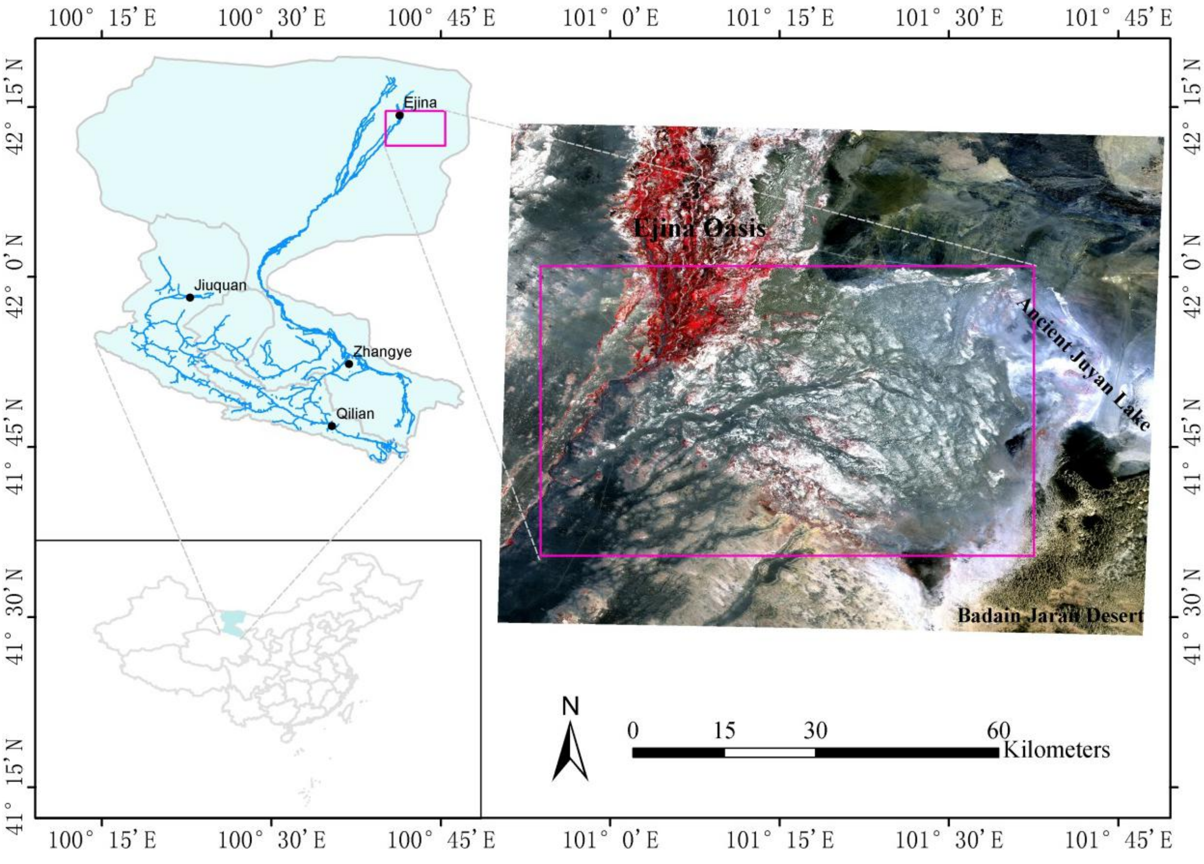

Fig. 1 A sketch map of the Heihe River Basin in northwestern China. The box with pink color shows the study area, which is in the downstream of the river and northwestern area of the Badain Jaran Desert.

Previous work concerning historical environmental changes has been conducted in the downstream region of the Heihe River Basin (Zhu, et al., 1983; Feng, 1988; Liu, 1992; Liu et al., 2010). However, few studies about the historical artificial canals have been performed and most of them are macroscopic and qualitative. (Zhang, 1988; Li, 1991; Wu, 2002; Xu, 2008; Lan, et al., 2009). The spatial distribution of historical artificial canals is unclear for the present, and few studies have been done quantitatively on them with a fine scale. This study therefore attempts to identify and extract the historical artificial canals, reveal their spatial distribution, compare and discuss the similarities and differences of irrigation system and canals between the past and modern irrigated farmland, and provide a fine scale quantitative evidence to research the historical human activities and the past environmental changes in ancient Juyan Oasis.

2 DATA and METHODS

2.1 Methodology

Because of farmland abandonment, strong erosion and severe desertification during the past 2000 years, the remains of the historical artificial canals are intermittently distributed throughout the desert, and most of these ancient canals are surrounded or separated by numerous sandbags and sand dunes. It is difficult to distinguish and extract them from a single source. This research employs a multidisciplinary approach to identify and rebuild the historical artificial canals, and try to reveal the entire agricultural irrigation system in historical period. The data used includes remote sensing images with high spatial resolution, historical documents and literatures, archaeological data and field investigations. According to the linear feature and texture feature, the different sources of information were then synthesized to identify and extract the historical artificial canals.

2.2 Field investigation

It is very important to perform the field survey to find and understand the field characteristics of artificial canals and distinguish them from natural paleo-channels. Field investigations were carried out in August of 2010 and May of 2012, respectively. And some special remnants were identified, surveyed, sampled, recorded and positioned by GPS, such as artificial canals, paleo-channels, ancient farmland, main sites. In order to ensure the representativeness and reliability of the artificial canals surveyed during the field work, some landmarks for selecting the sample points investigated in the field were developed prior to the field work using high spatial resolution satellite images from Google Earth. The following principles were applied: the obvious and typical artificial canals, the relics with canal-like features, the canals surrounded by sandbags and sand dunes, the canal-like targets with linear and texture features, the farmland-like areas and the points of paleo-channels.

2.3 Remote sensing data and image processing

Three kinds of remote sensing images were used in this study. Google Maps images were downloaded from the internet (http://maps.google.com), and the spatial resolution of these images are approximately 0.5 - 2 m. CORONA images photoed by KH-4A were obtained from the United States Geological Survey website in September 29, 1969, and the spatial resolution is approximately 3 m. Landsat-Enhanced Thematic Mapper Plus (ETM+) images from May 28, 2002, were downloaded from the Globe Land Cover Facility website (http://glcf.umiacs.umd.edu/index.shtml).

Several remote sensing images with high resolution were used in the present study. It is necessary to do some preprocesses for these images to extract and analyze the historical artificial canals more accurately. First of all, geometric corrections to Google Maps and CORONA data were carried out using ground control points

(GCPs) from the field investigations. Then, mosaicked images from CORONA and Google Maps data were obtained using imaging processing software that utilized multi-scene images. The images used for this study were clipped with the boundary of study area. The images of CORONA and Google Maps were geocoded into the same framework (UTM, WGS 84 datum) using the ETM+ image, which is helpful for analyzing and comparing the different data. In the end, some stretching and enhancement processes were carried out for all of the images to highlight the artificial canals, especially for the early black and white satellite image from CORONA. All of the above preprocesses were completed in these softwares: ENVI, ERDAS and ArcGIS.

3 RESULTS AND DISCUSSION

3.1 The distribution of historical artificial canals in study area

The feature of artificial canals usually appears as a groove above the rammed earth at a certain distance from the ground, and their width is much narrower than that of paleo-channels. Both sides of the most artificial canals are usually farmland-like with evidence of wind erosion. According to the materials used to construct the canals and the canal surroundings, all of the artificial canals in the study area can be divided into two types. The first type consists of canals that were rammed and built by clayey soil with solid and rammed earth (Fig. 2a). While another type of canals were constructed by mixing sand with gravel, which are always distributed throughout the Gobi Desert (Fig. 2b).

a) The field characteristics of rammed earth canal b) The field characteristics of sand stone masonry canal

Fig. 2 Photographs of the field characteristics of the historical artificial canals

The historical artificial canals appear as linear features in the remote sensing images with high spatial resolution, and the widths of the canals vary based on the different functions the canals had in the transference of water. The color of the canals in Google Maps images is white or light cyan, while they are white or light black in the CORONA images. The current remains of the historical artificial canals in the region are displayed as intermittent segments with a discontinuous distribution in the remote sensing images because of the prevalence of northwest winds, extreme drought and high evaporation, as well as thousands of years of wind erosion, damage and coverage by desertification, rebuilding and reusing. It is impossible to rebuild the original styles for most of the historical artificial canals, especially for those which were dispersed throughout the cultivated land of the Han Dynasty in the downstream of the study area.

Synthesized the sample points positioned during the field investigations and the image features, the historical artificial canals that were mainly used to irrigation farmland in the ancient Juyan Oasis were identified and extracted by comparing several remote sensing images (Fig. 3). According to the canals linked to the different water sources and the relationships between different canals, all of the artificial canals could be divided into three classes at least. The first order irrigation (irriga.) canals, the second order irriga. canals and the third order irriga. canals. Although the second and third order irriga. canals had irregular and complex shapes, both the linear feature and texture feature of them are clear in the remote sensing images and the field investigations.

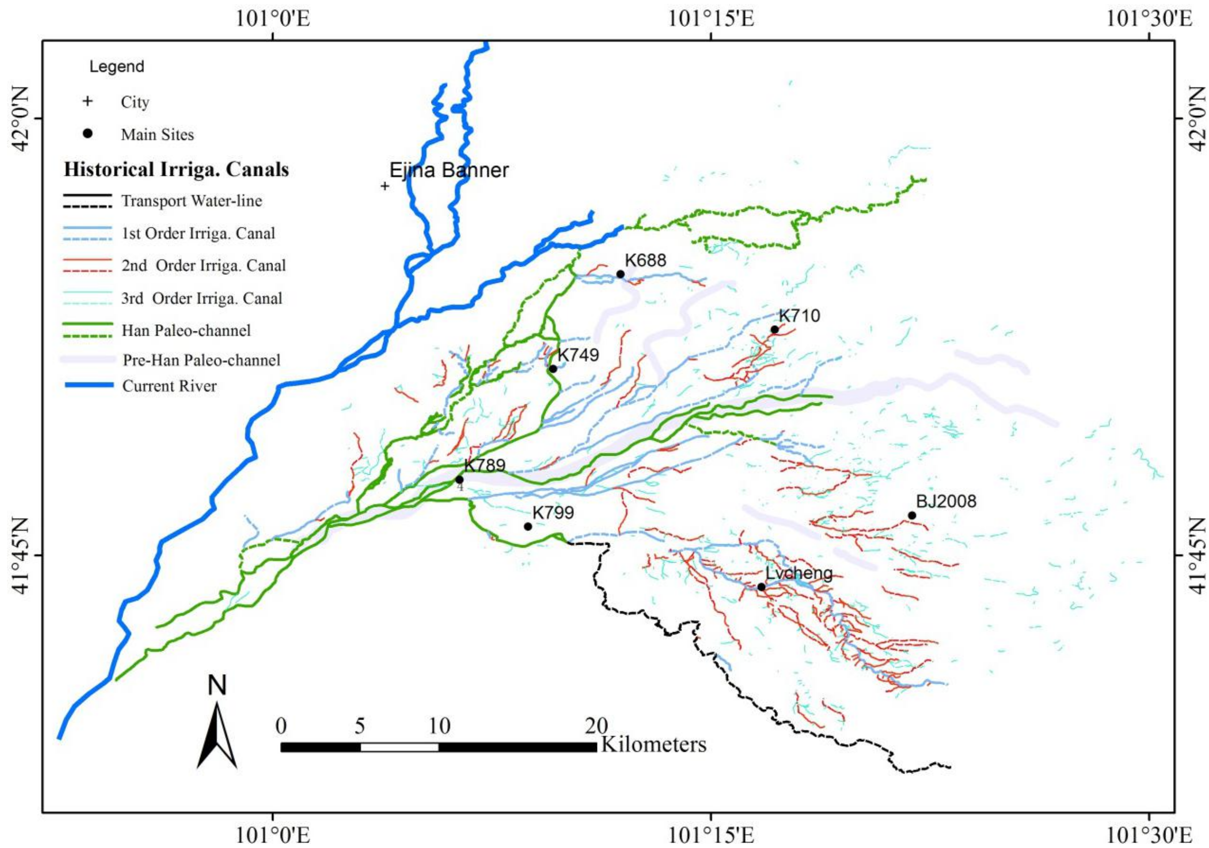

Fig. 3 Spatial distribution of the artificial irrigation canals extracted from remote sensing images

Overall, the farmland area of the ancient Juyan Oasis is very large and the remains of the historical artificial canals are distributed throughout the entire reclaimed region. All of the main sites and the nearby farmland had artificial canals for transporting water. In accordance with the relationships between the historical artificial canals and the main sites and nearby farmland, the condition of these canals is not the same as that of the main sites and farmland at different times. The remaining conditions of the historical artificial canals are consistent with the years of abandonment of the main sites nearby. The historical artificial canals near the Lvcheng are the most preserved canals in the study area and the entire irrigation system can be identified and mapped with the remote sensing images (Fig. 4). This canal system can be seen as a microcosm and a representative agricultural irrigation system of the ancient Juyan Oasis. In terms of the entire irrigation system, the past irrigation method could be generalized as the transport of water from natural river channels to the final small blocks of farmlands by different levels of artificial canals. The organization of the irrigation system used in the ancient Juyan Oasis during historical period was similar to that of the modern irrigation systems executed in the arid regions of China (Hu, et al., 2008). The raw materials and construction methods of the ancient and modern canals are different. The construction and classes of modern irrigation systems are more detailed and rigorous compared with the ancient systems.

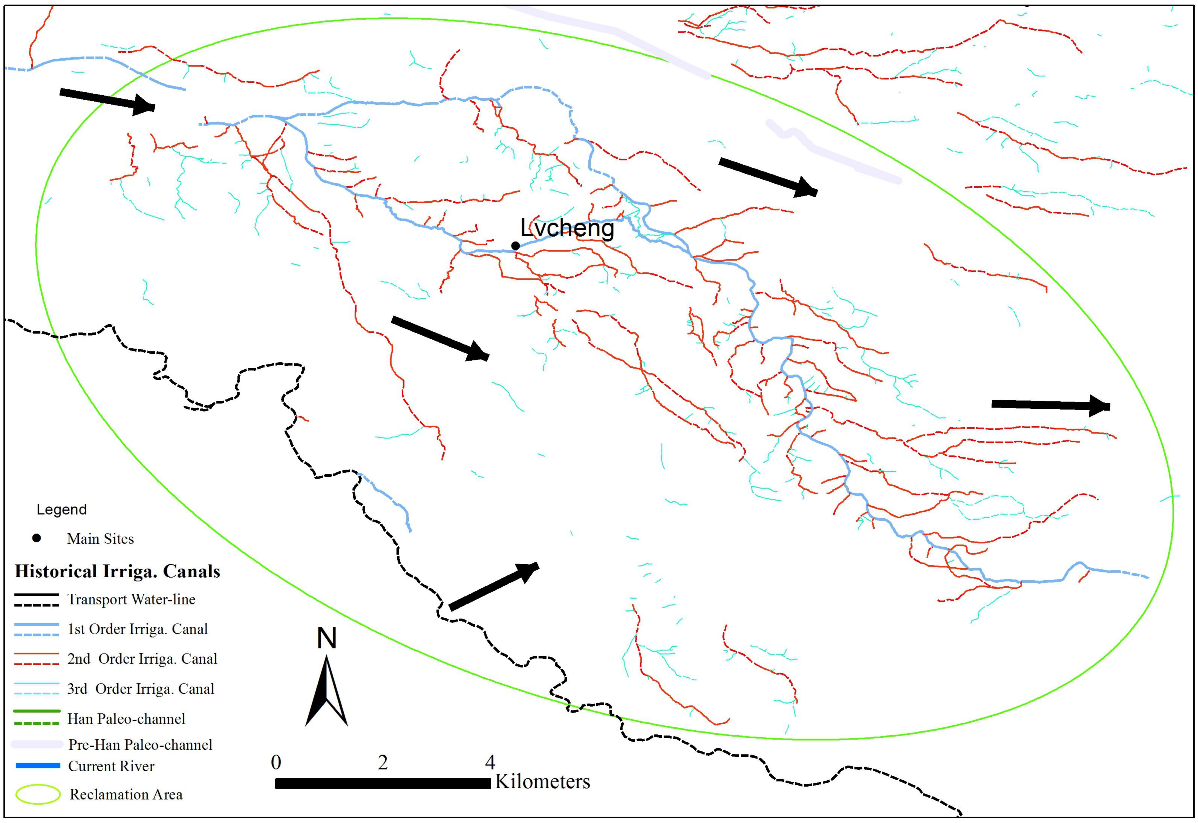

Fig. 4 The historical artificial canals and the entire irrigation system around the Lvcheng site

3.2 Relationship between the historical artificial canals and environmental changes

Some previous research showed that the ancient river could have had two branches to the north of Bukhen-torei (Zhu, et al., 1983; Jing, 2003; Li, 2003): 1) one branch flowing to the north along the modern East River and 2) second branch flowing into the ancient Juyan Lake in a northeastern direction across the north of K789. According to the features of paleo-channel and previous studies, there could have been some sub-branches along the northeastern branch of the ancient river, e.g. the northern sub-branches flowed in the direction of K688, and the southern sub-branches flowed in the direction of Lvcheng to the south of K799 (Fig. 3).

Changes of the historical artificial canals were affected by the influence of water volume from natural river, channel shifting, policies, time variations and the movement of human activities. On one hand, the canals were easily damaged due to the quality of the construction materials (which led to frequent repairs) and were rebuilt in other places when using in a long period. Thus, the remained ruins of these canals are confusing and unclear to distinguish. On the other hand, some early sites and farmlands in the Han Dynasty were abandoned by later controllers because of the deteriorated environmental conditions, which resulted in the abandonment of the canals near the site or farmlands. These early historical artificial canals were severely damaged and remain as discontinuous segments because of disrepair and wind erosion year by year.

The ancient Juyan Oasis is nearly desertified and numerous relics from different periods of controlling regimes have been covered by sand. It is insufficient evidence to discuss and analyze the timeframes for the construction, usage and abandonment of all of these artificial canals. There is no available method to conduct the research of the detailed environmental changes that occurred during the historical periods. Based on the previous studies (Zhu, et al., 1983; Jing, 1994; Li, 2003, 2004), it is known that desertification of the study area actually experienced over a very long development.

3.3 The mapping accuracy of the historical artificial canals affected by the use of remote sensing images with different spatial resolution

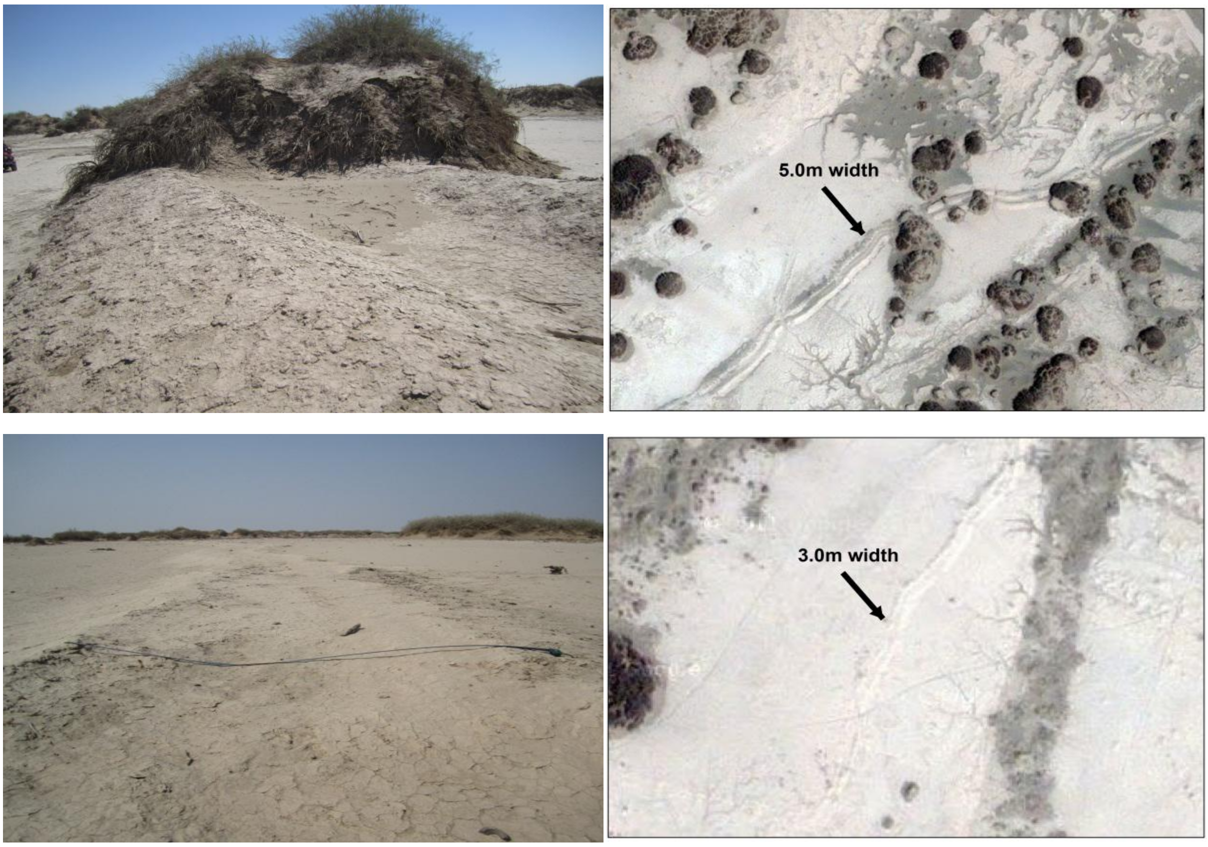

Fig. 5 Characteristics of the historical artificial canals with different widths. The left photographs show the field characteristics taken by a digital camera during the field work, while the right images display the canal features from the Google Maps images.

Historical artificial canals are much narrower than natural channels. According to hundreds of sample points investigated carefully in the field work, the width of most of the artificial canals was approximately 1.5 m – 7 m. The most widest canal is approximately 10 m at most. It is so difficult to distinguish these small targets in remote sensing images with ordinary resolution, which could only be identified and extracted by remote sensing images with high resolution. The vast majority of the historical artificial canals with different widths could be identified and extracted by Google Maps image with a spatial resolution of 0.5 m – 2 m. And the linear feature and texture feature of the different canals were clear in these images (Fig. 5). While only some of the large canals of the first order irriga. canals can be distinguished in the CORONA images, which have resolutions of approximately 3 m, and the features in these images are varied with the different widths of targets. An ETM+ image with a resolution of 15 m can barely display the historical artificial canals with any width, and it does not display any of the features of these canals.

Furthermore, the ancient Juyan Oasis has been almost entirely desertified. Continuous sand dunes are distributed throughout the northern and eastern parts of the oasis. Some historical artificial canals are surrounded and cut into segments by sand dunes and sandbags, which are difficult to identify in remote sensing images. As for extensively desertified parts of the study area, where are mainly distributed throughout the northern K688, eastern K710 and southeastern BJ2008, it is very difficult to carry out the field investigations and impossible to completely distinguish these areas in the optical remote sensing images. Only a small number of the remaining segments of the historical artificial canals can be intermittent identified. All above mentioned factors are the limitations in this study. In the future, a possible way to study and identify these small historical artificial canals buried in the desert employs the new radar remote sensing data with high resolution, such as TerraSAR-X, COSMOSky-Med.

4 CONCLUSIONS

Compared and analyzed some sample points investigated carefully in the field and some remote sensing images, historical artificial canals of the ancient Juyan Oasis were identified and extracted. In addition, the sources of irrigated water and irrigation methods during the historical period of the study area were discussed, and the correlation between the historical artificial canals and the past environmental changes of the region was also discussed briefly. The preliminary conclusions of this study are as follows: ⑴ Large amount of artificial paleo-irrigation canals remained in ancient Juyan Oasis, but none of them conserved in good condition completely. Most of these canals were cut into several parts by shifting sands, tamarix cones and haloxylon ammodendron, while some others that only the profiles can be identified were severe damaged by wind erosion. High resolution of the remote sensing images could be used to extract those small artificial canals in large desertified areas, and identify the entire paleo-irrigation system used during the historical periods. ⑵ Almost all of the artificial paleo-irrigation canals spread around some important sites. The closer the distance to the site, the paleo-irrigation canals are more complex and dense; while the farther to the site, the paleo-irrigation canals is more simple and sparse. The remaining integrity of the historical artificial canals distributed throughout different farmlands is not consistent, which may be related to many factors, such as the number of years for which different sites and nearby farmland were used; the times for the artificial canals were constructed, used and abandoned; and environmental changes surrounding the canals. ⑶ River water was the main water source used to sustain the agricultural development of the study area during the past. The irrigation method used in historical agriculture in the study area is similar to the irrigation system of modern agriculture used within arid regions of China. The differences between the ancient and modern systems include the raw materials used in their construction, the methods used to build them, the distribution patterns and the levels used to classify the different canals.

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