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A preliminary study of oasis evolution in the Tarim Basin, Xinjiang, China

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Abstract

The causes of oasis evolution in the Tarim Basin of north-west China are discussed. Climate change and human activities play different roles in oasis evolution on different temporal scales. The impacts of climate change on oasis evolution are macroscopic and continuous, while the influences of human activities are local and disconnected.

The climate of the Tarim Basin, since the late Pleistocene, has tended towards hyper aridity. The existence of oases has depended entirely on the runoff from thawed glaciers and snow, as well as orographic rainfall. Climate change on a geological scale led to variation of runoff flowing into oases. The alteration of water resources caused by climate change, therefore, was the fatal factor for oasis evolution in the Tarim Basin.

Climate change was still the principal factor influencing the oasis evolution during historic times although human activities increasingly impacted oasis evolution in the Tarim Basin with the development of the settled human populations. In historic times, the socio-economic prosperity of oases and their expansion occurred largely during warm periods, while desertification and the deterioration of natural resources in oases mainly occurred during cool periods. Continuous trends of aridity brought about the damage of some ancient states in the oases of the Tarim Basin.

Changes in oasis environments in modern times are mainly influenced by human activities in the Tarim Basin. Population growth and improvement of socio-economic conditions lead to the rapid expansion of cultivated land with reclamation and evident shrinkage of native vegetation. Irrational reclamation of land and utilization of natural resources in oases by humans have had increasingly destructive effects on oasis environments in modern times.

Keywords: Oasis evolution; Climate change; Human activities; Desertification

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1. Introduction

Oases are unique intrazonal landscapes in arid and semi-arid regions of the world. In China they are mainly distributed in temperate and warm temperate desert areas between the west of the Helan Mountain (in the Ningxia Hui Autonomous Region) and the north of Qinghai-Tibet Plateau. The Tarim Basin, and the Taklamakan Desert in its center, is surrounded by high mountains, namely the Tianshan in the north and Kunlun and Altyn ranges in the south (See Fig. 1). As the lift of surrounding mountains and consequent formation of the basin since the late Tertiary, the climate of the Tarim Basin became extreme arid (Zhu et al., 1980, pp. 8–13). Only comparatively abundant precipitation in the mountains can provide valuable water resources for the plain and piedmont areas. With plenty of runoff and ground-water, oases are established in river deltas, alluvial–diluvial plains and edges of diluvial–alluvial fans, and thus a green ring was formed by oases around the edge of the Tarim Basin.

Oasis evolution in arid and semi-arid regions has two opposite processes, oasification and desertification. Both of them are largely related to the abundance or

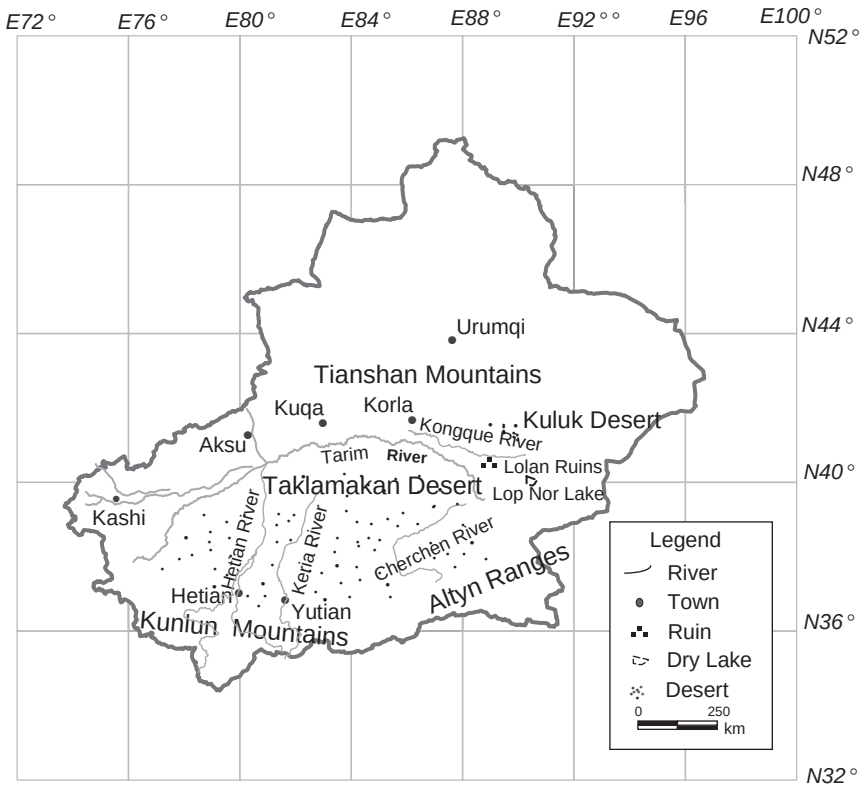

Fig. 1. Overview of the Tarim Basin in Northwest China.

shortage of water resources in the oases. Alteration of water resources in oases determines the processes of oasis evolution. The impacts of human activities on oasis evolution basically occurred as well just through direct or indirect influences of water resources in oases. The objective of this study is to explore the impacts of climate change and human activities, in different temporal scales, on oasis evolution to further understand its causes and processes in arid and semi-arid regions.

2. Impacts of climate change on oasis evolution in geologic ages

In the north-west China, no matter whether its western part controlled by the west wind climate or the eastern part controlled by the monsoon climate, the climatic and environmental changes were remarkably violent since the late Pleistocene. During these ages, climate changes occurred alternately between the cool coinciding with aridity and warmth coinciding with moistness with advent of the Ice age, Little Ice Age and the Interglacial stages, etc. (Li, 1990).

As the Northern Hemisphere of the earth was in the Altithermal in the Interglacial stages, the climate was warm and the ice and snow thawed massively in the Polar Regions as well as in the mountains. The sea level ascended and evaporation of the oceans increased, and the atmospheric moisture enhanced correspondingly in these stages. The summer monsoon controlled by the subtropical high was then strengthened markedly and its occupation time prolonged in the year. The precipitation, meanwhile, rose and the Mongolia anticyclone retreated, and the sodding and soil-forming processes in the oases, namely oasification, predominated in these stages in the Tarim Basin (Dong and Chen, 1995).

As the Northern Hemisphere was in the Ice ages, on the contrary, the climate became cool, the glacier and the frozen ground expanded, the sea level descended and the evaporation of oceans declined, which decreased the atmospheric moisture. Accompanied by the cooling effect of the glacial and frozen ground, the Mongolia Anticyclone strengthened subsequently. In these stages the climate became drier and cooler, and the vegetation was sparse and desertification process predominated in the north-west China. Alteration of the aridity corresponding to the cool and the moistness corresponding to the warmth were apparently related to the global climate change. These facts revealed the relationship between the desertification or oasification and the climate change with global ice age or interglacial stage alterations (Dong and Chen, 1995).

Tarim Basin, as located in deep hinterland and bounded by high mountains, rarely meets the summer monsoon from the oceans. Owing to diffusing and sinking of the Qinghai-Tibet Plateau hot low to adjacent surroundings, the warm and moist air is difficulty to penetrate deep into the Tarim Basin. As a result, the precipitation is sparse in the basin and the climate has been continuously in aridity since the late Tertiary, especially since the later Pleistocene. However, as the ice and snow melt more extensively and the precipitation rose relatively in high mountains in the Altithermal, as well as the emergent precipitation was supplemented with the south-west monsoon to the Tarim Basin in these stages, the runoff flowing into the oases

increased apparently and the soddy soil-forming processes predominated in oases. The vegetation luxuriated and the sand dunes fixed, and the oases expanded subsequently. The oasification, therefore, was the predominant process in the Tarim Basin in these stages (Dong and Jin, 1990). The sedimentary data from seven lakes in the north-west China, including the Lop Nor Lake in the eastern edge of the Tarim Basin, clearly demonstrated the more humid environments with high level and desalinization of lakes in the Altithermal in Holocene (about $7.0–6.2 \times 10^3$ a. BP) than that in modern times (Shi and Kong, 1993). Tens of centimeters to several meters sediments of white clay and sub-clay (about $7.0–5.0 \times 10^3$ a. BP), discovered under the modern eolian sand in the center of Taklamakan Desert, proved that the soil-forming processes, or oasification, occurred in the Tarim Basin in the Altithermal (Wang and Gao, 1990).

On the other hand, as the climate was in the cool stages, the melting of ice and snow in mountains dropped, and the runoff flowing into the oases declined consequently. Vegetation of the oases degraded and the shifting-sand dunes expanded. In these stages, oases shrank to the area that ground-water was relatively abundant, and the desertification process predominated in the Tarim Basin. It is concluded from the above, therefore, that the oasis evolution in the Tarim Basin was entirely determined and temporally concurrent with the climate change in geological ages (Dong and Chen, 1995).

The geological and limnological history of the Lop Nor Lake, located in the eastern Tarim Basin, can also demonstrate the influences of climate change on variation of water resources of the plain. During the early stage of the Quaternary, the mountains around the Tarim Basin lifted unceasingly and the depressions in the front of mountains were filled up with sediments. The water formerly flowing into the Kashi-Kuqa Depression and the Eastern Tarim Basin Depression turned eastwards to the Lop Nor in this period and expanded the area of Lop Nor Lake which once dried up in the end of the Pliocene. During the middle of the Pleistocene, as the height of mountains around the Tarim Basin exceeded 2000–3000 m, the oriented prevailing wind appeared, and the deserts in the eastern and western Lop Nor Lake were formed and the water level of the Lake declined correspondingly. In the middle of the Late Pleistocene, the Kaidu River and Kongque River flowed once again into the Tarim Basin, leading to the delta formation in the Loulan area. In the end of the late Pleistocene and early of the Holocene, the climate of this area became arid and cool, and the Lop Nor Lake dried up again and the sandstorm prevailed in the middle and lower reaches of Tarim River. During 3000–3600 a. BP the Lop Nor Lake was filled up twice again with water and the rivers crisscrossed on the Loulan Delta, and the human activities of fishing, hunting and cultivation appeared in the Loulan Delta (Wang, 1996). As the climate cooled and the sand dune expanded during 1800–2000 a. BP. The rivers in Loulan Delta were silted with sand and the Kruqe Desert was formed eventually in Loulan area (Wang and Gao, 1990).

It is known from the above that since the late Pleistocene the oasis evolution in the Tarim Basin was dominantly determined by the runoff flowing into the oases. The variation of runoff and water resources in oases depended largely upon the climate

change, especially the temperature variation. Temperature fluctuation would influence the water resources in oases and cause the oases evaluation. Climate change, therefore, is the fatal factor for oasis evolution in the Tarim Basin in geological ages.

3. Causes of oasis evolution during historic times

Climate change on thousand-year scale in the Tarim Basin would also influence environments of the oases to some extent and lead to the oasis evolution. Zhou and Zhu (1994) claimed, by studying the destruction of the Keriya Oasis in the center of Taklamakan Desert, that a number of ancient oases in the Tarim Basin had disappeared before the 10th century. It was unlikely that the large-scale human agricultural activities and the water conservancy projects that could alter the water resources distribution in oases and bring about the dry of river and destruction of the oases appeared in the upper and middle reaches of the rivers in these times. The major reasons that caused the oasis disappearance in these times, therefore, were the continuous shortage of water resources resulted from the climatic aridity and the alteration of riverbank in oases in the Tarim Basin.

Climate change, during the historic times, once significantly influenced the population distribution, national economy, cultural development and the territory variation in ancient China (Wang and Zhang, 1996). During the warm and humid periods, the national economy and culture became thriving and comparatively prosperous. Several powerful and prosperous dynasties in ancient China were established in these periods. By the studies of plant phenology in Chinese historic records, Zhu (1972) divided the last 5000 years into four warms and four cool periods, respectively. The first warm period was during 5000–3000 a. BP, namely the late half of the Holocene. The average annual temperature was higher by 2° than that of modern times. This period was also the age of Yangshao Neolithic adaptations and Late Shang Civilization in the northern China. The second warm period, in accordance with Zhu's division, was from pre-Qin Dynasty to the early years of Han Dynasty from 770 BC to the first century (AD). During this period, the Chinese ancient culture developed tremendously and various schools of thoughts and their exponents appeared and disseminated. In the book "The Historical Record Biography of Dawan", the author described the environments in the north-west China in this period as "the water and grasses can be seen frequently on the Silk Road", and "a number of pavilions appeared on the road and more than hundreds to thousands of people passed each year westward from Dunhuang to Loulan". This description revealed that water resources in the Tarim Basin were comparatively abundant and it was convenient to use for people along with the Silk Road (Li, 1991; Ren, 1994). We deduced, therefore, that the oasis area in the Tarim Basin in this period was greater than that in modern times. The third warm period occurred during 600–1000 AD, especially during the 8th and 9th centuries. The Zhehuoluo, an ancient state in the southern edge of the Tarim Basin, abandoned at about 4th century, was revived in this period, indicating that the water resources in oases

became considerably abundant again and the water requirement for the people can be supplied in this times (Li, 1991).

On the contrary, as the climate fluctuated into the cool periods, the climate abnormalities increased. Social upheaval and the war frequented, and the oases turned desertification. For example, during the period of 200–589 AD, the climate was cooler than that of modern times. The author of the book "The Biography of Faxian", described the landscapes of the Tarim Basin in this period as "without a mere bird in the sky and a single beast on the ground". When passing the Hetian River in southern Tarim Basin, the author found "no people on the way and difficulty in passing the desert". In accordance with the records of the biography, the water resources in the Tarim Basin was deficient obviously and the desertification was more severe in this times than that in the Han Dynasty. The Loulan, an ancient state established in the lower reaches of the Kongque River, experienced extremely drought and water shortage, and was destroyed finally after continuous 61-year-long drought in this period (Li, 1991). Based on the studies of the climate change on thousand-year scale in the Tarim Basin, Ren (1994) concluded that the expansion of oases generally occurred in the warm periods, while the abandon of the ancient towns and emergence of eolian in oases largely occurred in the cool periods in the northwest China over the last 5000 years.

Some scholars (Xia and Liu, 1993; Wang, 1996), on the other hand, claimed that most of the damaged oases in the Tarim Basin were largely brought about by human activities in historic times. We should admit, however, that variation of water resources in oases caused by climate fluctuation in historic times strongly influenced the environments of the oases. Although the impacts of human activities on oases increased apparently with the population growth in historic times, it was unlikely to cause a number of ancient oases destroyed thoroughly. We cannot simply suppose that destruction of the Loulan State and disappearance of the other ancient oases in the Tarim Basin during 300–400 AD is an occasionally coincident issue with the climate cooling in the same periods. It was continuous water shortage caused by climatic abnormality that eventually led to these oases destruction (Zhou and Zhu, 1994).

4. Influences of human activities on oases in modern times

The range of temperature fluctuation on hundred-year scale is about 0.5° (Zhu, 1972), which would influence the occurrence of the climatic abnormality frequency as well. During the 1960–1970s, for example, the rotation velocity of the earth slowed down relatively and the climate of the Northern Hemisphere tended to cool (Ren, 1994). The volcanic activity frequented, and the desertification aggravated worldwide and the El Nino occurred increasingly in this period. It was found that the significant climate warming with the precipitation rising during 1970s and 1980s in the Tarim Basin coincided considerably with worldwide climate warming in the same period (Li, 1991). Within the last 40 years, the climatic patterns in the Tarim Basin have basically reflected the characteristics of warm-moistness and cool-aridity

patterns (Ren, 1994). Obviously, the range of temperature fluctuation on hundred-year scale is less, which is unlikely to cause enough variation of the water resources in oases and further bring about the oasis evolution in the Tarim Basin. The human activities, therefore, are the major factors on influence of oasis environments in modern times.

4.1. Changing the patterns of oasis distribution

There was incipient agriculture present in oases in the Tarim Basin earlier than 3000 years ago (Fan, 1993). As the topography is smooth in deltas in the lower reaches of rivers and not necessary to build the complicated water conservancy project for irrigation, only a few simple channels were needed to draw the runoff into the oases. The ancient oases, therefore, mainly distributed in the lower reach of the rivers.

With the introduction of water conservancy technology into the Tarim Basin, people can build dams and draw the water for irrigation from the upper reaches of rivers, thus the oases expanded upward to the middle and upper parts of the alluvial fans. As the cultivated land extended to the front of mountains, the water could be utilized largely in the upper and middle parts of the oases, leading to the reduction of water evaporation and leakage consequently. More lands could be exploited so as to provide the requirement for population growth (Wang, 1991; Fan et al., 1998) (See Table 1). The runoff flowing downwards to the lower parts of the oases declined with the land expansion in the upper parts of the oases, and the oasis area reduced subsequently in the lower reaches of rivers. As the development of agriculture and the population growth in oases, the cultivated land needed further expanding. The water from rivers simply cannot satisfy the requirement for irrigation and the reservoir must be constructed to regulate the runoff for irrigation. Especially during the last 50 years, the area of cultivated land expanded drastically in the Tarim Basin and a number of reservoirs were constructed. Most of the reservoirs were built in the depression and the lower part of the alluvial plains, the cultivated land reclaimed during the last 50 years, therefore, mainly distributed in the periphery and edge of oases (Fan et al., 1998).

Table 1
Variation of population ($\times 10^4$ people) and cultivated land area ($\times 10^4$ ha) of some oases in the Tarim Basin during the recent decades

	Population		Cultivated land area	
	1949	1990	1949	1990
Kuqa Oasis[a]	25.0	60.5	8.4	12.0
Kashi Oasis[a]	152.0	280.0	32.0	49.0
Aksu Oasis[a]	27.4	84.5	10.1	28.4
Hetian Oasis[b]	18.2	71.1	6.3	9.4

[a] Wang (1991).
[b] Fan et al. (1998).

4.2. Utilizing the natural resources in oases

In accordance with our studies, the natural vegetation in the Tarim Basin was destroyed seriously with land reclamation in recent decades. Trees were felled irrationally and grassland degraded with over-grazing. The vegetation in the lower reaches of the Tarim River, for example, had been destroyed and the regenerative capacity of vegetation lost basically with the river drying-up and over-utilizing. The average width of the "green belt" along with the banks of lower reach of the Tarim River have narrowed from 5–10 km in 1950s to 1–2 km in 1980s (Fan et al., 1998), and the area of *Populus euphratica* decreased by 69.6% in this region within the last 40 years (Li and Wang, 1995). The wild animals declined quantitatively with the vegetation degradation. Such as the wild camel, once nearly being 1000 in 1950s, is rare to see now in the lower reach areas of Tarim River. Red deer living in the Tarim River Valley declined from over 10,000 in 1950s to less than 3000 in 1990s (Fan et al., 1998). Irrational irrigation and backward drainage system have caused the cultivated land salinized extensively in the Tarim Basin. The irrigation quota of cultivated land in oases in the Tarim Basin exceeded $12 \times 10^3 m^3 ha^{-1}$, some area over $22.5 \times 10^3 m^3 ha^{-1}$ (Wang and Liu, 1993), which resulted in the waste of water resources and the salinization of cultivated land on large scale. For example, the area of seriously salinized land in the Weiganhe Oasis in the northern Tarim Basin accounts for over 10% of the total land area of the oasis. Irrational irrigation of cultivated land accelerated the expansion of land salinization, and caused the ground-water decline and vegetation degradation and desertification.

5. Summary

Existence and evolution of oases in the Tarim Basin depends completely upon the water resources flowing from the mountains. Climatic change and human activities play different role in oasis evolution on different temporal and spatial scales. Impacts of climatic change on oasis evolution are macroscopic and continuous, while the human activities are local and disconnected.

From the late Pleistocene the climate of Tarim Basin tended towards a hyper aridity, and existence of the oases depended entirely on the runoff from thawed glacier and snow as well as rainfall in mountains. Variation of the water resources caused by climatic change was the fatal factor for the evolution of oases in geologic ages in the Tarim Basin.

In historic times the climatic change was still the principal factor for oasis evolution although the human activities took the effect increasingly on oasis evolution with the development of settled human population. It is continuous aridity that directly brought about the damage of some ancient oases in the Tarim Basin in historic times.

The variation of oasis environments in the Tarim Basin in modern times is dominantly influenced by human activities. Population growth and improvement of socio-economic conditions led to the rapid expansion of cultivated land with

shrinkage of native vegetation and sandification and salinization in oases. Desertification has become the major obstacle to the sustainable development of oases in the Tarim Basin.

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