Article ID: 1673-1719 (2006) Suppl. 1-0028-07

Environmental Change and Agricultural Development in Historical Documentary Records for Northwest China

Zhang De'er

National Climate Center, China Meteorological Administration, Beijing 100081, China

Abstract: The paper investigates the historical agricultural exploitation in Northwest China, and its social benefits in the context of historical documents and their relationship with temperature and humidity backgrounds. Results show that during the Western Han Dynasty (206 BC−25 AD) and the early stage of Tang Dynasty (ca.7th century) climate was suitable for agriculture, leading to the success of large-scale wasteland reclamation in Gansu Province (called Hexi area in history), however during the late stage of the Tang Dynasty (ca. 8th−9th century) and the middle of the Ming Dynasty (ca.16th century), the climate there went into a cold stage, leading to the decline of stationing troops who opened up wasteland in the region; the prosperity of the Tarim Basin at the beginning of the Christian Era and its subsequent decline were linked to changes in water resources; and historically, the reclamation and later desertion were responsible for accelerating land desertification, and its typical examples are the formation of the Wulanbuhe Desert and the frequent occurrence of severe sand storm events in the warmer 13th century as the bad aftermath of the desertification.

Key words: Northwest China; historical climate; environmental change; agricultural exploitation; reclamation and desertion; historical documentary records

Introduction

What did the natural environment look like in Northwest China in the past 2000 years? Were the agricultural activities linked to climate background and its change? Did the exploitation lead to environmental deterioration? For answering these questions, we should draw on historical records of humanity and nature through multi-discipline integrative research. Currently, the research is under way, but some scientists have given findings concerning the above-mentioned questions through their long-term investigation. Herein an attempt is made to tentatively illustrate these problems based on the historical documents of China.

1 Variation of climate and environment in Northwest China

1.1 Current state of the climate

Viewed from meteorological water and heat conditions, present regional climate in Northwest China is inferior to that in eastern China. According to the Atlas of National Climate Regionalization [1], China climate is separated into climate belts, large climate districts and general climate zones in order of rank. Much of Northwest China covers a range of climate belts at warm temperate, middle temperate, plateau sub-temperate and sub-frigged latitudes, comprising large climate districts in sub-arid, arid and extremely arid climates. Arid Northwest China has its annual precipitation short of 400 mm, on the whole, the areas with precipitation <100 mm occupying roughly more than half of the total area, characterized by a precipitation variability exceeding 20% in most cases. Northwest China shows tremendous evaporation, leading to >2000 mm per year in sharp contrast to <100 mm of annual precipitation in many places. Aridity index denotes the valid acquisition of moisture expressed as the ratio of maximum possible evaporation to rainfall on an annual basis. Aridity indices in this vast region are > 1.6 in most areas (Fig.1), 1.6−3.5 for grassland, 3.5−16.0 for semi-deserts, and >16 for true wilderness.

Aimed at the relationships between cultivation and climate, demarcation of agroclimate zones is carried out based on indices, such as geographic area, agricultural

Received: February 5, 2006; revised: April 11, 2006
Corresponding to Zhang De'er (E-mail: derzhang@cma.gov.cn)

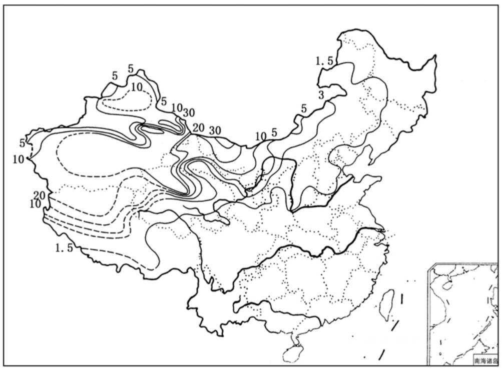

Fig.1 Distribution of annual aridity indices averaged over 1951−1970 in China (redrawn from reference [2])

pattern, crop growth/development with its yield formation, all indices are of crucial importance to cropping [2]. Following this regionalization, China is divided into three large agroclimate districts consisting of 15 agroclimate belts based on the cultivation systems and requirements of heat level of staple crops. The large arid agricultural district in Northwest China is separated into two agricultural climate belts, i.e., an arid mid temperate belt and an arid southern temperate belt, with ⩾0℃ accumulated temperature as the demarcation indices. The two belts are composed of 7 cropping zones, including, for example, Dongsheng-Lanzhou zone, and agroclimate indices of the 7 zones indicate that the ⩾ 0℃ accumulated temperature for the Tarim-Hami region ranges 4000−5700℃, suggestive of abundant heat compared to 3000−4000℃ or < 3000℃ for other 6 climate zones, where water and heat are insufficient for cropping. In addition, the Guanzhong plain and the Loess Plateau are other two cropping zones in eastern Northwest China, belonging to the southern temperate belt in the eastern large agroclimate district.

The water resources in Northwest China are unique in that atmospheric precipitation is just one of them, and other sources comprise melted glaciers water, underground water and surface runoff that undergo inter-conversion and repeated utilization. So, it is inappropriate to considerate precipitation alone as the water source of Northwest China.

1.2 Outline of the historical variations of the environment

1.2.1 Temperature variations

Comprehensive studies [3] on a variety of proxies (e.g., pollen, ice core, lake sediments, paleo-soils and archaeological materials) show that the outlined variations of temperature in Northwest China in the past 10000 years are: climate became quickly warm after entering the Holocene, with temperature rise in a fluctuating manner, and the Holocene Megathermal occurred in 8.5−3.0 ka BP, with its maximum in 7.2−6.0 ka BP. After its end, temperature dropped in a fluctuating way, but with a rise during the 10th−14th centuries as a Medieval Warm Period (MWP), and thereafter the Little Ice Age (LIA) came in the 15th−19th centuries and again, the climate became warm in the 20th century, and temperature rose quickly. As indicated in our historical documentary records [4], relatively warm and optimum intervals are the Yin Dynasty (13th−11th century BC), the Western Han Dynasty, the Sui Dynasty to the mid Tang Dynasty (ca. 7th century AD), the early Yuan Dynasty (13th century AD) and the 20th century. And there also were subscale relatively warm stages between relatively cold intervals, and the present stage is in a fast warming period after the termination of the LIA. Up to now, many researchers have reconstructed temperature curves by proxies, e.g., tree rings, ice cores, sediments and documentary records, to display the variations on a local and regional basis. Heated discussion of these curves is under way [5]. The present paper aims at the introduction to the general trend of climate, especially in Northwest China. Zhu[4] presented the temperature curve of China for the past 5000 years derived from historical records and natural evidences widely covering the eastern and western China, and therefore Zhu's curve is cited here in Fig.2, where time intervals marked by a, b, c and d are the typically warm stages (the Han Dynasty and the early Tang Dynasty) and cold stages (the Eastern Jin Dynasty, 4th century, and the late Ming Dynasty, ca.16th−17th century), respectively.

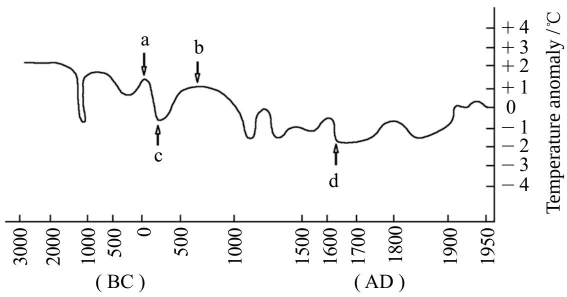

Fig. 2 Temperature variations in China for the past 5000 years (redrawn from Zhu [4]), with letters: a, the warm of the Han Dynasty; b, the warm of the Tang Dynasty; c, the cold of the Eastern Jin Dynasty; and d, the cold of the late Ming Dynasty

1.2.2 Humidity variations

The evolution of climate in Northwest China varied in a fluctuating manner, on the whole, towards aridity, with dry alternating with wet stages for several times. The water level of inland lakes is a good indictor of climatic aridity in Northwest China, with precipitation as the dominant income and evaporation as the main consumption in their water budget. Shi *et al*.[3] pointed out that the climate was quite moist in 6.0−7.0 ka BP of the last 10000 years, and afterwards the inland lake's area reduced gradually and even disappeared, showing a distinct trend of climate towards dryness over an extensive area. Shown in Fig.3 are the variations of water levels of three typical inland lakes from the Holocene. On the whole, the relative heights of lake's surfaces drops in a fluctuating manner, suggesting a general trend towards aridity.

From Fig. 3, we see that the water level of Qinghai Lake was 65 m higher in 7.0 ka BP, 45 m higher in 5.5 ka BP, and 25 m higher in 3.5 ka BP compared to today's level, indicating the gradually reduction in its water surface area. Another example is Daihai Lake in Inner Mongolia, and lake level was 45 m higher in 6.0−4.0 ka BP, dropped to 10 m higher in 2.2 ka BP and returned to 12 m higher in 2.0 ka BP compared to today's level, and then followed by a wavy drop [3].

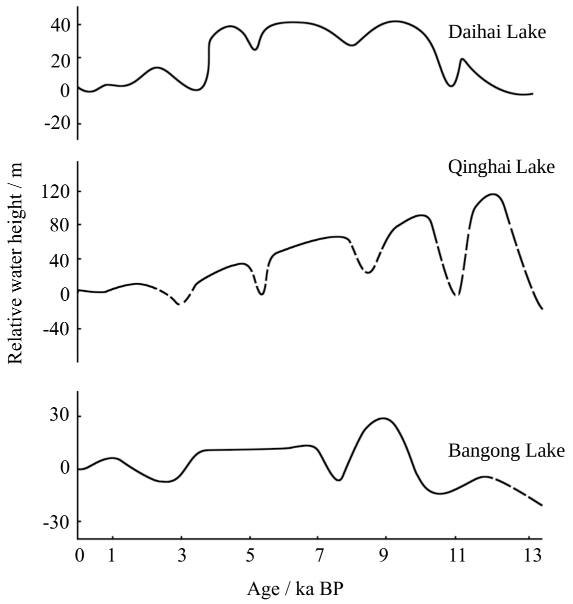

Fig. 3 Temporal evolution of the water level of three typical inland lakes (Daihai, Qinghai, and Bangong Lakes) in Northwest China, which indicates the dry/wet variation of climate (taken from reference [3], and prepared by co-worker Wang)

Similar facts of the shrinkage and drying up of inland rivers and lakes systems can be found in many historical documentary records of China. One example is the relics of City Tongwan (38.1° N, 108.9° E), the capital of Xia Kingdom of tribes, discovered by Chinese archaeologists in the Mu Us Desert, around which the description of the scenery has been read only in historical records. The city was built in 407 AD in "a place with high mountains behind and a big river (i.e. the Hong Liu River) ahead". Standing at the hill, Emperor Helianbobo once could not help admiring the surrounding scenery, saying that "How beautiful the view is. The city faces a large lake and has a stream with clear water running beside. I have visited many places but never seen such charming scenery." This indicates that the place was really water-abundant and grasslush prior to and during the 5th century, presenting people with a charming landscape. But later the river disappeared, leading to vanishing of the beautiful view, and now it quietly lies in the Mu Us Desert with drifting sands everywhere.

2 Agriculture development and climate in Northwest China as written in historical documents

A lot of historical documentary records are found concerning stationing troops for reclaiming wasteland into arable fields in Northwest China. Taking account of agricultural activities and the climate background in combination at that time, we can conclude that the extent and benefits are in association with temperature and water resources in the past.

2.1 Developing activities in appropriate climate

Seen from the historical temperature curve in Fig. 2, there are two stages of highly warmth, one in the Han Dynasty around the Christian Era and the other in the early Tang Dynasty in the 7th century. In both the stages large-scale reclamation was implemented in the Northwest portion with great success, and the encouraging economic prosperity supported by sufficient heat and usable water resources at that time.

2.1.1 Development in relation to climate in the Han Dynasty

During the Western Han Dynasty, reclaiming wasteland for arable fields was carried out almost synchronously in the Hexi Corridor region (west of the Yellow River) and the Tarim Basin in Xinjiang, with the extent ever-increasing, thereby leading to local economic prosperity at rapidity.

(1) Stationing troops to open up the wastelands in the Hexi Corridor region

Stationing troops opened up the wastelands in the Hexi Corridor region, and busy merchants traveled on the "Silk Road", through which silk fabrics and other products were transported to Southwest Asia and Europe. All these were the symbols of economic prosperity in the early Han Dynasty, which are indicative of agriculturally appropriate climate at that time.

According to Wu *et al.* [6], Wu Emperor of the Han Dynasty set up an administrative unit called Hexi Prefecture as early as 121 BC, followed by emigrating people there for reclamation in order to reinforce the borderline defense against aggressors. As described in the famous book *Shi-Ji* (Chinese history compiled by Master Sima Qian in the Han Dynasty), the contemporary natural environment was such that “In the Qilian Mountains there are five kinds of tall trees, e.g., pines and cypresses etc.; water and grass are rich everywhere; winter is warm and summer cool, a condition suitable for animal husbandry”, and again “Like the Qilian Mountains, the Yanzhi Mountains are marked by sufficient water and grass for raising cattle.” Han established reclamation areas including Fanhe zone in Zhangyi, and others in Wuwei, Dunhuang, and Juyan. These reclamations by stationed troops and inhabitants were distributed mostly over areas with sufficient water sources, i.e. river-close lands, or chains of oasis, where they could get abundant surface and underground water or near the mouth of a spring, and these reclamation areas got enough sunshine for cultivation, resulting in high benefits, and were expanded fast into new agricultural zones in Northwest China. Reclamation produced later a lot of grains both for the troops and inhabitants with their families and part of the surplus was transported to relieve famine in eastern provinces. For instance, such a relief in 42 BC was recorded in the *Han-Shu* (history of the Han Dynasty). Those newly developed zones provided important support for the commercial transport over the Silk Road and local economic prosperity.

Besides, according to the records of *Ju-Yan-Han-Jian* (writings on bamboo pieces made in the Han Dynasty and discovered in Juyan reclamation zone), there were more than 20 varieties of crops cultivated at that time, including wheat, rice and millet in the main. More importantly, these crops and their combination provide vital information from which climate conditions at that time cloud be inferred. Especially, the cultivation of rice depends on more heat and water. Despite the more complete irrigation network available then for rice growing, it could still be inferred that the annual precipitation at that time should be in excess of 150 mm per year, much higher compared to today’s rainfall (less than 50 mm). And again, based on today’s climate data for rice cropping, the aridity index over the Juyan rice zone in Han Dynasty should be undoubtedly below 10 and even 5 by no means as the “extremely arid climate” of today higher than 30 (see Fig.1). As for wheat cultivation, the climate then had to be wetter at least than today, as indicated by agrometeorologists. However, the records of *Ju-Yan-Han-Jian* did not give information of wheat variety that may be winter- or spring-sown. If the former is true, it could be inferred that the winter temperature was a bit warmer than today, and allowed snow cover to exist for wheat wintering. Even on this basis we are led to believe that Hexi area was wetter / warmer at the beginning of the Christian Era than today.

(2) Troop’s reclamation in the Tarim Basin

Almost concurrently with Hexi prosperity on an agricultural basis, the reclamation in Xinjiang made great progress in agricultural development. As shown in Wang [7], three inhabitant groups, i.e., today’s relics (Loulan, Niya and Keriya) discovered by modern archaeologists in the Tarim Basin appeared early in the Christian Era, one after another.

These buildings (nowadays relics) were inhabited long before the Christian era but these areas gained swift development only in the early stage of the era. As indicated in the book *Hou-Han-Shu* (history of the later Han Dynasty), under the biography of official Yangzhong, he mentioned the reclamation of stationing troops in Yiwu, Loulan, and Cheshi in a written statement to a higher authority. As a result, Loulan became the dominant reclamation zone in the basin, reaching its prosperity period in 1st−3rd century, when oasis and arable areas were expanded considerably, and agricultural activities played more important role compared to others. The discovered Han documents and writings on bamboo pieces described the busy agricultural activities. Obviously, Loulan prosperity bears a certain relation to water sufficiency. Wang [7] indicated that the Tarim River had a bigger increase in water level after the Christian Era, and three down-stream river courses at the same time, which is also indicative of increased discharge. The increase of discharge might come partly from precipitation increase and/or from the increase in melted snow cover and ice cap water due to warming.

Additionally, discovered in the group of Niya sand-buried relics in the south of the Tarim Basin there were wheat straw, millet stalks and relics of mulberry fields together with the description of their cultivation and irrigation in local documents, indicating importance of agricultural to local economy at Niya area. Also, rice and wheat seeds were found in the relics of fossil forts in Keriya in the south of the Taklimakan Desert. All these suggest that the local water and heat conditions were good enough to grow heliophile and hygrophilous paddy rice.

Such a situation lasted for about 300 years, afterwards the three relics group areas with the buildings in Tarim began to economically decline, and were completely deserted in the 7th century. Clearly, the decline was related more or less to the deteriorated water resources. About 330−400 AD, Loulan area was first deserted because water coming from the upstream declined year by year. The three areas suffered almost synchronously from the shortage of river water. The case can only be explained climatically without any apparent linkage to human activities, because the Tarim population started to decline after the 3rd to 4th century and thus water consumption was correspondingly decreased. And all rivers in the Tarim Basin underwent drying-up at their ends after the 4th century, this phenomenon can only be attributed to climate degradation alone [7]. The inference of deteriorated water resources is supported by evidence of ice cores from Guliya Ice Cap [8], located in the West Kunlun Mountains, south of the Tarim Basin, and the glacier accumulation at Guliya in 270−1990 AD exhibited sharp drop during the 4th to 6th century, suggesting that rainfall decreased dramatically from high level to low one (Figure omitted).

2.1.2 Development in relation to climate in the Tang Dynasty

The Tang Dynasty was an extremely powerful country in its early stage, when the Hexi development entered an agriculturally booming period. The Hexi prosperity since the Han Dynasty declined in the Jin Dynasties, the Southern and Northern Dynasties as well as the Sui Dynasty (ca. 260−620 AD). As shown in Wu *et al*. [6], China (with the inclusion of Hexi) was in booming development from the establishment of the Tang Dynasty in 618 AD to the An-Shi revolt in 755 AD, and the government implemented a policy of stationing troops in the Hexi region for land reclamation and border defense. As a result, statistics quoted from the book *Xin-Tang-Shu* (history of the Tang Dynasty) show that there were 98 stationary troops villages covering 490000 mu, equivalent to 26500 hm^2. In addition, a lot of other arable lands were under the cultivation by peasants, monks and officials. The total reclamation area in the early Tang period is equivalent to 3.3 million mu (220000 hm^2), making up roughly 40% of the present total. The tremendous achievement in Hexi development on an agricultural basis during early Tang provided material support for the commercial prosperity along the Silk Road.

The successful expansion of agricultural area in this period was connected with climate condition. As we know, cultivation requires enough heat and water. The water for irrigation came from the Shiyang, Shule and Heihe River systems, and their water sources came from the melted glaciers and snow covers in the Qilian Mountains in addition to precipitation. The volume of melted snow water is, no doubt, associated with climatic warming, with more water running down in warmer climate. As stated earlier, the period of early Tang is one of the warm stages in history. Higher temperature was responsible for melting more ice and snow.

2.2 Agricultural development in colder climate

As stated before, the temperature displayed a wavily decreasing trend in historical time of China. The warm stages in the Western Han and the early Tang Dynasties were followed by swiftly cooling.

The Hexi development experienced such an evolution process as extension, development, great prosperity, and decline (covering mid Tang to Ming, ca. 8th−17th century [6]). Although the decline of Hexi agricultural economy was determined directly by social factors, e.g., political situation and policies etc., the major climatic change in the late Tang Dynasty (ca. 756−896 AD) was also not a negligible factor. Documentary evidence bears out the period of climatic cooling. As regards the number of cold records occurred in the late Tang was twice more than that in the early Tang (ca. 618−755 AD). The evidence from the $\delta^{18}O$ content of Dunde ice core in the Qilian Mountains also shows the beginning of a cold stage at 800 AD[5]. The cold climate could not offer enough heat for crop growth, thus affecting agriculture.

Another example that climatic conditions limited agricultural development was in the mid Ming Dynasty (ca. 16th century). Soon after its establishment, the Ming Dynasty put forth a national policy for developing Hexi via reclamation [6]. The Dynasty, thus, carried out a policy for consolidating border defense by troops reclamation, and implemented a set of sensible and effective measures, e.g., to construct water conservancy projects etc., with the result that the reclaimed area increased, the population grew, and grains yields were more than enough to support local population and part of the surplus was transported for victims of natural calamities in other provinces. However, after 1450 AD the climate entered the Little Ice Age, causing a problem of heat shortage. Following the records of 1531 AD in official documents *Ming-Shi-Lu* (imperial court records of the Ming Dynasty), one reads the lines as follows: "Frost happens earlier and spring comes late; snow is frequent and rainfall becomes less"; "In the six 'Weis' (the Ming's administrative unit), such as Ganzhou, Shandan etc., the climate is not warm enough to allow cultivation for sowing until April (Lunar calendar) when snow begins melting, but frost appears just when wheat is flowering"; over 1537−1620 "weather is exceedingly cold and no seeding is possible. As a rule, fertile fields in the vicinity were used to yield one crop every three years, and arid fields farther away even every four or five years. The above situation suggests that the serious shortage of heat was unable for peasants to grow crops. As a result, climatic cooling was one of the factors leading to decline of agricultural development in Hexi.

3 Effects of human activities on environmental degradation in history

In the process of development in the western of China, the unduly reclamation of lands and its later desertion occurred again and again in history, thereby accelerating the soil desertification with adverse impacts on environment.

Following Hou [9], the formation of the Wulanbuhe Desert between today's Ningxia and Inner Mongolia is linked to the reclamation in Han and subsequent desertion. The north of the desert was the Shuofang Prefecture of the Han more than 2000 years ago, an important area for emigrants of the Han origin and reclamation. Since no war took place in nearly 60 years, the population was multiplied rapidly and the agriculture significantly developed. As recorded in *Han-Shu*, "the markets and streets are crowded, cattle and horses are everywhere on grassland", and the booming picture is proven by the relics of fossil buildings and many Han tombs discovered there. According to studies, there was a large lake called Tushenze, 120 li (ancient length unit) long in the east-west direction, indicative of abundant water in that region and it disappeared later and is buried into sands nowadays. That area had been a vast expanse of grassland before reclamation in the Han, with a 70 cm deep clay layer under vegetation, and a layer of fine sands further downward. The once reclaimed land was deserted because the Han's reclamation zone probably was shifted elsewhere somehow. But the surface had become a cover of loose naked soil, thereby acting later as a source of drifting sands under the effect of continued wind erosion. As shown in historical documents, people had inhabited there prior to Han's reclamation and although climate was undergoing a trend of being arid, the process was slow after all. The Han's reclamation and subsequent desertion are the main factors for accelerating the desertification and leading to relics to be buried into sands.

The process from reclamation to desertion to desertification is responsible for environmental deterioration. Undoubtedly, in history, the northwestern troop reclamation was always linked to military action. Whenever potential war was in the seeable future, the number of station troops was increased, leading to expanding reclamation. But when diplomatic relations were friendly, land desertion was inevitable. The barren land was exposed to strong winds and its desertification was quickened. In that case no way was available for restoring vegetation. As a result, a vast expanse of deserted land under effect of wind erosion served as a formidable source of sandstorms. The auther [10] discovered in historical records that sandstorm events were frequent around 1200 AD under a relatively warm climate background, even with frequent sand depositing events in eastern China, especially in Nanjing and Hangzhou with beautiful scenery, where people suffered from the air full of suspended sands for years in succession. That period was in a stage of high-frequency sand depositions (Figure omitted). The above statement seems to oppose the conclusion that "a period of frequent sand events corresponds to a cold, dry climate period" made by the author [11] in the study on the sand depositing climate background in history. However, it is not difficult to understand the contradiction if we further examine social factors. In Northwest China, Xixia kingdom, after its foundation in 1038 AD, put efforts for some length of time at development in Hexi region via reclamation and construction of irrigation networks, thus succeeding in economic restoration and prosperity to certain degree for about 200 years. But later the kingdom was frequent at war with its enemies, e.g., Song, Jin, and Liao States. Particularly Mongolian Emperor Genghis Khan (1162−1227 AD) made aggression against Xixia Emperor, forcing its people to flee homes and leave farmland uncultivated, thereby reproducing the terrible process of reclamation− desertion−erosion−desertification. At the beginning of the 13th century the large-scale desertion was exceedingly serious and its consequence was none other than a source of sandstorms, providing depositing sands for the eastern China and leading to environmental degradation.

4 Concluding remarks

(1) Temperature condition is the prerequisite of agricultural development in Northwest China. The warm climate stage in history promoted successful expansion of farmland on a large scale in the study region, exemplified by the reclamation activities in the Western Han and the early Tang Dynasty. But the reclamation for agricultural development was terminated because of climatic cooling. The reclamation in a cold climate resulted in failure, as illustrated by Hexi development in the period of the mid Ming Dynasty.

(2) The humidity displays a decreasing trend, on the whole, in a fluctuating manner over Northwest China for the last 10000 years. During a moist climate period, the reclamation was successful, and climate change towards dryness leading to shortage of water resources was responsible for desertion of once reclaimed land, the example being the areas of three inhabitant groups (now relics) that were prosperous early in the Christian Era and were deserted in the 3rd to 7th century in close association with the shortage of water.

(3) Excessive large-scale reclamation events and subsequent desertions in history accelerated soil desertification, resulting in environmental deterioration.

Careful examination of the natural evolution of environment in conjunction with human activities in Northwest China will develop our understanding of nature -mankind relationships with the aim to make full use of the present natural conditions for planning exploitation to reach regional prosperity.

References

[1] Editorial Committee for "Climatological Atlas of the PRC". Climatological Atlas of the People's Republic of China [M]. Beijing: China Meteorological Press, 2002: 6−12 (in Chinese).

[2] China Meteorological Administration. Atlas of National Climate Resources of China [M]. Beijing: China Cartographical Press, 1994: 211, 277−279 (in Chinese).

[3] Shi Yafeng, Kong Zhaochen, Wang Sumin. Climate and Environment of Holocene Megathermal in China [C]. Beijing: China Ocean Press, 1992: 5 (in Chinese).

[4] Zhu Kezhen. A preliminary study on the climatic fluctuations during the last 5000 years in China [J]. Scientia Sinica, 1973, 16 (2): 226−256.

[5] Shi Yafeng, Yao Tandong, Yang Bao. Decadal climatic variations recorded in Guliya ice core and comparison with the historical documentary data from East China during the last 2000 years [J]. Science in China (Series D), 1999, 49 (Suppl. I): 91−100.

[6] Wu Tingzhen, Guo Houan. Study on the History of Hexi Development [M]. Lanzhou: Gansu Educational Press, 1996: 52−55, 80, 207−210 (in Chinese).

[7] Wang Shouchun. The appearance and collapse of three groups of fossil buildings (now relics) in the Tarim Basin in relation to environmental change [J]. Quaternary Sciences, 1998 (1) :71−79 (in Chinese).

[8] Yao Tandong, Thompson L G, Qin Dahe, *et al.* Variations in temperature and precipitation in the past 2000a on the Xizang (Tibet) Plateau: Guliya ice core record [J]. Science in China (Series D), 1996, 39 (4): 425−433.

[9] Hou Renzhi. Historical variation in the Mu Us desert as shown in the relics of cities on the Hongliu River [C]// Congqing City Museum. Archaeological Collection of Water, Desert and Volcano. Beijing: Cultural Relics Press , 1977: 77−110 (in Chinese).

[10] Zhang De'er. A Compendium of Chinese Meteorological Records of the last 3000 Years [M]. Nanjing: Jiangsu Education Press, 2004: 471−548 (in Chinese).

[11] Zhang De'er. Synoptic-climate analysis of dustfall in China since the historical times [J]. Scientia Sinica (Series B) , 1984, 27 (8): 825−836.