J. Geogr. Sci. (2009) 19: 750-764
DOI: 10.1007/s11442-009-0750-4

Wet-dry changes in the borderland of Shaanxi, Gansu and Ningxia from 1208 to 1369 based on historical records

DAI Junhu[1], GE Quansheng[1], XIAO Shufang[1,2], WANG Mengmai[1,2], WU Wenxiang[1], CUI Haiting[3]

1. Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China;
2. Graduate University of Chinese Academy of Sciences, Beijing 100049, China;
3. College of Urban and Environmental Sciences, Peking University, Beijing 100871, China

Abstract: More than 240 items of historical records containing climatic information were retrieved from official historical books, local chronicles, annals and regional meteorological disaster yearbooks. By using moisture index and flood/drought (F/D) index obtained from the above information, the historical climate change, namely wet-dry conditions in borderland of Shaanxi Province, Gansu Province and Ningxia Hui Autonomous Region (BSGN, mainly included Ningxialu, Hezhoulu, Gongchanglu, Fengyuanlu and Yan'anlu in the Yuan Dynasty) was studied. The results showed that the climate of the region was generally dry and the ratio between drought and flood disasters was 85/38 during the period of 1208–1369. According to the frequencies of drought-flood disasters, the whole period could be divided into three phases. (1) 1208–1240: drought dominated the phase with occasional flood disasters. (2) 1240–1320: long-time drought disasters and extreme drought events happened frequently. (3) 1320–1369: drought disasters were less severe when flood and drought disasters happened alternately. Besides, the reconstructed wet-dry change curve revealed obvious transition and periodicity in the Mongol–Yuan Period. The transitions occurred in 1230 and 1325. The wet-dry change revealed 10- and 23-year quasi-periods which were consistent with solar cycles, indicating that solar activity had affected the wet-dry conditions of the study region in the Mongol–Yuan Period. The reconstructed results were consistent with two other study results reconstructed from natural evidences, and were similar to another study results from historical documents. All the above results showed that the climate in BSGN was characterized by long-time dry condition with frequent severe drought disasters during 1258 to 1308. Thus, these aspects of climatic changes might have profound impacts on local vegetation and socio-economic system.

Keywords: wet-dry change; borderland of Shaanxi Province, Gansu Province and Ningxia Hui Autonomous Region (BSGN); historical climate; Yuan Dynasty

Received: 2009-05-08 **Accepted:** 2009-07-22
Foundation: National Natural Science Foundation of China, No.40471047; No.40871033; The Knowledge Innovation Program of Chinese Academy of Sciences, No.KZCX2-YW-315
Author: Dai Junhu (1968–), Ph.D, specialized in plant ecology and physical geography. E-mail: daijh@igsnrr.ac.cn

1 Introduction

Borderland of Shaanxi Province, Gansu Province and Ningxia Hui Autonomous Region (BSGN), located in Midwest of the Loess Plateau, is a geographically important transitional region (ECPGC, 1985) of China. Study of the historical climate change of this region is not only important in its own right, but also helps to have a better understanding of the natural process of climate change in China's borderland between semi-humid and semiarid regions.

BSGN, especially Liupan Mountain was an important area on the military map during the Mongol–Yuan Period. From 1205 to 1227, Mongol troops launched five major attacks against Xi-Xia[①,②], during which Genghis Khan himself died near Liupan Mountain[③]. After conquering Xi-Xia, Yuan Dingzong ordered Mongol to "seize Liupan Mountain and dominate Shaanxi and Gansu[④]". During the period of Yuan Xianzong and Yuan Shizu, the southern region of Ningxia was not only one of the original bases from which attacks on Sichuan, Dali and South Song Dynasty were launched, but also a military center, and it was also a crucial place over which the Mongols fought each other[⑤]. During the two critical periods when Yuan Dynasty was established and unified, the military actions in Liupan Mountain played a vital role. In later Yuan Dynasty (Zhang *et al.*, 1991) and Ming Dynasty[⑥], the political and military function of BSGN still remained important. Although historical documents related to this period are limited, the records about BSGN on nature and economy are still relatively abundant, including some valuable information about the climate.

The study period has received great attention and has been involved in many studies on historic climate changes on the millennial scale (Zhang *et al.*, 1997; Zhang *et al.*, 1994; Zheng *et al.*, 2005). Zhang *et al.* (1997) reconstructed six regional wet-dry series for the climate in North and East China during the past 1000 years based on historical documents and concluded that several extreme drought events occurred during this period. They proposed that around 1230 both temperature and humidity in eastern China changed significantly (Zhang *et al.*, 1994). This finding was supported by the study of Zheng and Wang (2005). High resolution precipitation series reconstructed recently using tree rings (Zhang *et al.*, 2003; Shao *et al.*, 2004; Liu *et al.*, 2006) also affirmed the occurrence of this phenomenon.

In light of the above mentioned work, we conduct a comprehensive analysis on the available information from historical documents related to climates in the east of Northwest China from the early 13th to late 14th century, and further use the results to determine the details of wet-dry change and extreme drought events and their impacts during this period.

2 Geography of study area

The study area is located in the east of Northwest China, centered at Liupan Mountain, bounded by the eastern part of northern Shaanxi to the east, by eastern part of eastern Gansu

① The First Record of Taizu Emperor, Volume 1, The History of Yuan.
② Biography of Heroes (Aishen), Volume 61, The History of Jin.
③ The Situation of States in Successive Dynasties , Section 8, Volume 8, Essentials of Historical Geography.
④ The Record of Xianzong Emperor, Volume 6, The Revised History of Yuan Dynasty.
⑤ The Record of Shizu Emperor, Volume 11, The History of Yuan Dynasty.
⑥ Shaanxi, Volume58, Essentials of Historical Geography.

to the west, and by western part of Guanzhong and southeastern Gansu to the south. The recording locations are distributed in the range of 103°53′–110°26′E and 33°24′–38°26′N (see Figure 1). The available records cover northwest Shaanxi and Sichuan provinces in early Yuan Dynasty and Shaanxi and Gansu provinces in later periods, including Ningxialu, Hezhoulu, Gongchanglu, Fengyuanlu and Yan’anlu in the Yuan Dynasty. The center of the study area lies between the current cities of Guyuan, Xifeng and Baoji.

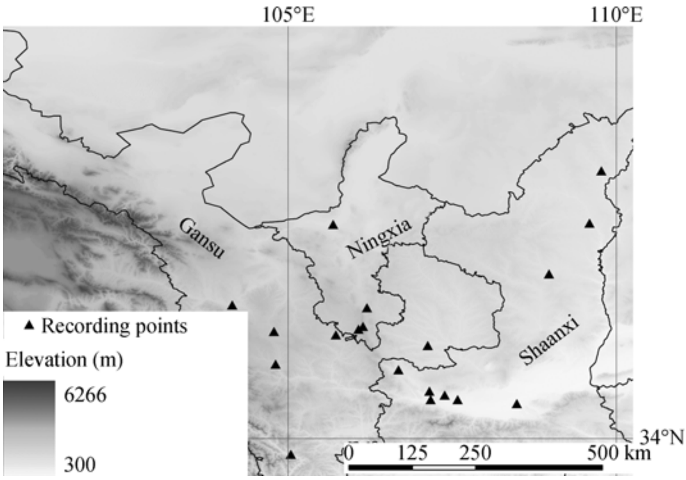

Figure 1 Illustration for locations of paleoclimate records in borderland of Shaanxi Province, Gansu Province and Ningxia Hui Autonomous Region (BSGN)

The zonal vegetation in this region is a transitional type between deciduous broad-leaved forest and grassland. Located on the margin of the monsoon region in East China, the study area is also a transitional zone between arid and humid climates. From west Guanzhong to the western part of the study area, the aridity changes from 1.0–1.2 to 1.5–4.0 (ECPGC, 1985). These obvious transitional characteristics make this region an ecologically sensitive zone. The wet-dry change may have significant effects on natural ecosystem and social production.

3 Materials and methods

3.1 Data sources

In the early 13th to the mid-14th century’s China, feudal economy continued to develop, while conflicts between political powers often occurred. This led to frequent dynastic changes and made the historical records and materials very complicated. The following are main sources of the materials used in this paper.

(1) Official Historical Books: This includes several parts of *History of Yuan*. Although much information about historical climate can be found in it, being a rushed work, this book only gives brief and sketchy, if any, accounts of some periods, especially the time before the Yuan Dynasty was established. For example, it was mentioned in Volume 1 that Shizu (Genghis Khan) was such a great conqueror that he devastated over 40 civilizations and

slaughtered millions, and it was a pity that at the time there was no historian to tell the story of his great achievements. According to Volume 2 of the book, after Dingzong's death, his successor was not selected until three years later, and as a consequence, many events had not been recorded. Since a lot of historical accounts were missing from this book, records from other dynastic official historical books, mainly including *History of Song*, *History of Liao* and *History of Jin*, were extracted as references.

(2) Local chronicles: Local chronicles mainly recorded facts and events related to regional history, geography and economy. Enormous amount of highly valuable detailed information about natural environment can be found in local chronicles before Qing Dynasty (Chen, 1998). In this paper we have referred to county annals of Longxi, Guyuan, Longde and Longxian.

(3) Event-based Historical Records (Jishibenmo): Event-based Historical Records, one of the three historical genres in China's historical literatures, focused on detailed accounts of influential events and were valuable complements to official history chronicles. The following Event-based Historical Records were referred to in this paper: Event-based Historical Records of Yuan Dynasty, Event-based Historical Records of Song Dynasty, Event-based Historical Records of Jin Dynasty and Event-based Historical Records of Xi-Xia. We mainly used these records to clarify some brief or uncertain climatic records from official historic books.

(4) Other historical materials: In addition to the above sources, various materials on disaster statistics were also taken into account as references, mainly including the notebook of meteorological disasters in Shaanxi, Gansu provinces and Ningxia Hui Autonomous Region.

The collected records contain the information of drought, flood or heavy rain in BSGN. They have obvious meteorological significance and may represent wet-dry conditions of each year. Since historical documents often tend to neglect certain events or exaggerate the scales or consequences of others, the range of study area was amplified in order to reduce the errors in the records. 240 items of records were extracted and included in this paper (sample record lists are shown in Table 1).

Table 1 Sample records of drought and flood events in BSGN during the period of 1208–1369

Time	Original item of the record	Source
1209	The second year of Jiading, Xihezhou, Zhaohua, Chengzhou and Tonggu were flooded. The storages, the city walls and houses were all destroyed.	The Records of Five Elements, The History of Song
1212	In May, people in Hedong and Shaanxi starved, the foodstuff was very expensive and many people starved to death. In November, the government relieved the people of Hedonglu, Nanjinglu, Shanxidonglu, Shandongxilu and Weizhou in drought disasters.	Biography of Weishao King, The History of Jin
1213	The first year of Zhenyou (1213), in May, the climate of both Shaanxi and Hedong were very dry, and one dou millet was sold at eight thousand qian in Jingzhao.	Biography of the Weishao King, The History of Jin
1216	In May, plague of locusts happened in Henan and Shaanxi, the wheat in Fengxiang, Fufeng, Qishan, Meixian were destroyed by the locusts.	The Records of Five Elements, The History of Jin.
1223	In May of the 16th year of Jiading in Song Dynasty, the climate was very dry. It did not rain in Xingling from January to May, and people had no food and committed cannibalism.	A History of Xi-Xia. Vol.41
1226	In March of 1226, Shaanxi was very dry.	Biography of Aizong, The History of Jin

Time	Original item of the record	Source
1248	In this year, it was very dry. The rivers were dried up and the wild grass suffered severe blast. 90% of cows and horses died. The people could not survive.	Biography of Dingzong, The History of Yuan
1269	In December of the fifth year of Zhiyuan, Jingzhao (Xi'an) was very dry.	The Records of Five Elements, The History of Yuan
1280	The 17th year of Zhiyuan, it was dry in Lintao and Gongchang, and the people had no food to eat. In December, the government supplied food to the victims of Gongchang and Changde.	Biography of Shizu, The History of Yuan
1288	In September of the 25th year of Zhiyuan, people starved because of drought, and the government exempted the grain tax about 4400 Dan. In November, people in Gongchanglu starved, and the government exempted half of land tax and brought three thousand Ding to the victims.	Biography of Shizu, The History of Yuan
1289	In November of the 26th year of Zhiyuan, the land of Fengxiang in Shaanxi was flooded.	Biography of Shizu, The History of Yuan
1295	In April of the first year of Yuanzhen, the river in Lanzhou was dried up for three days. In July, Gongchang, Huanzhou, Qingyang, Yan'an and Xi'an were very dry.	Biography of Chengzong, The History of Yuan
1304	In July of the eighth year of Dade, Fufeng, Qishan and Baoji of Fengxiang were dry.	The Records of Five Elements, The History of Yuan
1306	In May of the 10th year of Dade, it was dry in Jingji. It was very dry and the wheat died in Anxi from spring to summer.	The Records of Five Elements, The History of Yuan
1315	In spring of the second year of Yanyou, it was dry in Gongchang and Lanzhou.	The Records of Five Elements, The History of Yuan
1318	In May of the fifth year of Yanyou, it rained heavily and caused landslide in the Nanshan Mountain and killed many people in Longxi.	Biography of Renzong, The History of Yuan
1318	In August of the fifth year of Yanyou, it rained heavily in Chengji of Qinzhou. There was landslide and the animals drowned.	The Records of Five Elements, The History of Yuan
1324	In June of the first year of Taiding, it rained heavily in Shaanxi. The rivers of Weishui and Heihe were flooded and destroyed the houses of the people.	The Records of Five Elements, The History of Yuan
1325–1328	Shaanxi had no rain since the second year of Taiding. People had no food to eat and sometimes committed cannibalism.	Biography of Wenzong, The History of Yuan
1328	In August of the first year of Tianli, it was dry in Shaanxi. People committed cannibalism.	The Records of Five Elements, The History of Yuan.
1329	The second year of Tianli, it was dry in Guanzhong, cannibalism was common at that time.	Biography of Yanghao Zhang, The History of Yuan
1331	In August of the second year of Zhishun, the government brought five thousand Ding for the victims in Shaanxi because the drought disasters had lasted several years and people had no food to eat.	Biography of Wenzong, The History of Yuan
1333	In June of the first year of Yuantong, Jinghe river flooded in Guanzhong.	Biography of Shundi, The History of Yuan
1336	In March of the second year of Zhiyuan, it was windy and dry, leading the wheat to die.	Biography of Shundi, The History of Yuan
1340	In July of the sixth year of Zhiyuan (1340), it rained such a long time in Nanping of Yanping that the water flooded and several hundred people drowned. Three hundred houses and many fields were destroyed. Another day in the same month, the river in Aozhi of Fengyuanlu flooded and many people drowned.	Biography of Shun, The History of Yuan
1358	In Spring of the 18th year of Zhizheng (1358), it was very dry in Jizhou and Qishan of Fengxiang and the people starved or had to eat others.	The Records of Five Elements, The History of Yuan
1359	In May of the 19th year of Zhizheng, the plague of locusts happened in Shandong, Hedong, Henan and Guanzhong, and left people no food to eat.	The Records of Five Elements, The History of Yuan
1367	In January of the 27th year of Zhizheng, Ganzhou and Wuweilu were flooded.	The Records of Five Elements, The History of Yuan
1369	It was very dry and people had no food to eat.	General Local Chronicles of Shaanxi. Vol.40

3.2 Methods

Records on drought and flood disasters during the study period were extracted from historical documents and were examined using traditional document processing methods. We analyzed the wet-dry conditions of BSGN during the study period and classified them using moisture and flood/drought indices.

(1) Flood/drought index: Our approach was mainly based on the classification standards and implementation methods established by Central Meteorological Observatory and its organized meteorological and geographical departments for investigating wet-dry condition for the past 500 years in China. We also borrowed some ideas from General Collection of Meteorological Records of China in the Past Three Thousand Years. According to the duration, intensity, range and degree of damage, the flood/drought condition was classified into seven grades—Heavy-flood, Mid-flood, Mild-flood, Normal, Mild-drought, Mid-drought and Heavy-drought, which were represented by index values 3, 2, 1, 0, –1, –2 and –3 respectively (see Table 2).

Table 2 Criterion of drought-flood grades in BSGN during 1208–1369

Historical records on the drought and flood	Degrees	Value
It rained heavily and the river flooded and damaged the houses. The river flooded and killed people and destroyed crops. It rained several days and the crops did not yield.	Heavy-flood	3
Some region rained and the crops were damaged. The rents were exempted. The lands were submerged.	Mid-flood	2
The crop was damaged by rainstorm and heavy rain.	Mild-flood	1
No records of the flood and drought recorded. Some records on the rainfall and locusts in local region were recorded.	Normal	0
People had no food to eat due to drought. It did not rain for one or two months in a year.	Mild-drought	–1
It was dry and it rained from July or June. It was dry and did not snow in the winter. The grains were not harvested because it was dry, and the tax was exempted.	Mid-drought	–2
It did not rain for several years and the people had to eat other people. It was very dry and it did not rain in the whole year. It was very dry and it rained from August.	Heavy-drought	–3

The grading rules were as follows: The years with no records were graded as 0; the years with only one record were graded according to Table 2; if there were more than one record in a year, the grading was done using Table 2 based on the recorded calamity that had longer duration, greater damage or suffering. For example, records show that the year 1295 had heavy rainfall in May that damaged crops, and severe drought in April and June. Since the drought was determined to be more serious, the year was graded as Mid-drought.

(2) Moisture index: We also used moisture index to assess the humidity conditions of the study area. The moisture index is determined by comparing the frequency of drought to that of excessive precipitation. Based on the related works of Brooks (1950), Zhu (1925) introduced "ratio of D/F" as a means to measure China's historical climate change. Although the frequencies of drought and flood may reflect the climate conditions approximately, they tend to have large variations due to the inaccuracy and heterogeneity of history records, which makes Zhu's method have large variability and difficult for comparison. To overcome this

disadvantage, Zheng *et al*. (1977) introduced moisture index, which is defined as follows:

$$I = 2 * F/(F + D)$$

where I ($0 \le I \le 2$) is moisture index, F and D are the times of flood and drought at a location during a certain period respectively.

When $F = D$ (including $F = D = 0$), I equals 1 and represents normal climate; when $F < D$, I is less than 1, and represents dry climate; when $F > D$, I is between 1 and 2 and represents moist climate. This method considers the total numbers of drought and flood disasters of several Fu (or prefecture) and Zhou (or county) as population, and the times of disasters recorded in the same region as samples (Gong *et al.*, 1983), which has apparent statistical significance.

The method has been successfully applied in previous studies. Zhang and Zhang (1979) used it to analyze historical climate fluctuations in China and obtained satisfactory results. Later, Zheng *et al.* (1977) studied the wet-dry condition change in Southeast China during the past 2000 years by using moisture index. In this paper we are concerned with the historic climate in BSGN and hope that the moisture index method can help uncover the pattern of humidity change.

4 Results

4.1 The general characteristics of wet-dry conditions of BSGN during 1208–1369

Figure 2 displays the drought-flood grades of BSGN during 1208–1369. The bars represent annual flood/drought indices and the curve represents the 5-year moving-average values of the flood/drought indices. Most of the annual flood/drought indices were negative, which suggests that there were more drought years than flood years. Drought was the main characteristic in BSGN during the study period and several serious droughts occurred. This findings were confirmed by previous works on this region. The historical climate studies in Gansu revealed that its climate was seriously dry in the 13th century during which disasters of drought happened in 23 years, while floods occurred only in 4 years (Li *et al*., 2000). The researches on Xi'an came to similar conclusions that the climate was dry in the 13th and 14th centuries with serious droughts obviously outnumbering floods (Qian, 1991).

The years with drought/flood disasters are listed in Table 3. There were 85 drought years,

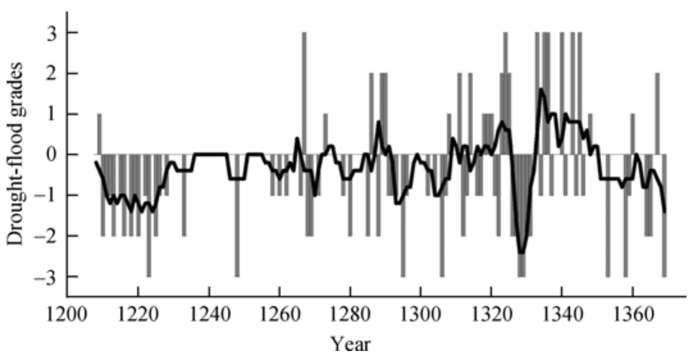

Figure 2 Wet-dry change in BSGN during 1208–1369

which is more than twice as many as flood years (38). Furthermore, the average annual grade of drought was much higher than that of flood, and long-lasting droughts were more frequent than long-lasting floods. All these indicate that drought was the main meteorological disaster during this period. This is consistent with the numerous mentionings and descriptions of disasters related to arid climate in historical literatures, such as “dry climate”, “people starved”, “drought twice as serious as before”, “wheat seedlings lost during drought and autumn crop seeds not sown”, “numerous drought victims forced to leave home”.

Table 3 Statistics of years occurring drought and flood disasters in BSGN during 1208–1369

Period	Years with drought disasters	Years with flood disasters
1208–1369	AD 1208, 1209, 1210, 1211, 1212, 1213, 1214, 1215, 1216, 1218, 1219, 1220, 1221, 1223, 1225, 1226, 1228, 1233, 1248, 1258, 1260, 1662, 1265, 1266, 1268, 1269, 1271, 1278, 1279, 1280, 1281, 1285, 1286, 1288, 1289, 1290, 1291, 1292, 1293, 1295, 1296, 1298, 1299, 1302, 1304, 1305, 1306, 1307, 1309, 1311, 1312, 1313, 1314, 1315, 1316, 1317, 1319, 1321, 1322, 1323, 1324, 1325, 1326, 1327, 1328, 1329, 1330, 1331, 1332, 1333, 1334, 1335, 1336, 1337, 1341, 1344, 1345, 1346, 1348, 1353, 1358, 1359, 1360, 1364, 1365, 1369	AD 1209, 1221, 1267, 1273, 1283, 1286, 1289, 1290, 1295, 1308, 1309, 1311, 1312, 1314, 1318, 1319, 1320, 1321, 1322, 1323, 1324, 1325, 1326, 1328, 1329, 1331, 1332, 1333, 1335, 1336, 1338, 1340, 1341, 1343, 1345, 1348, 1360, 1367

From the above analysis, we come to the conclusion that the climate of BSGN in Mongol–Yuan Period was characterized by long duration, prevalent, frequent and extreme droughts. Since the study region was located in the transitional zone between semi-humid and semiarid climate and also on the border between crop and ranch regions, the damages caused by drought had serious impacts on the socio-economy.

4.2 Phase analysis of wet-dry change

From flood/drought indices, the times when extreme climatic events occurred can be easily seen and the overall proportions of the frequencies of wet and dry conditions can be calculated. On the other hand, the moisture indices can better reveal the phases and durations and other details of the historic wet-dry changes. Figure 3 shows the curves formed by moisture indices taken per 5 years and per 10 years in BSGN during the study period.

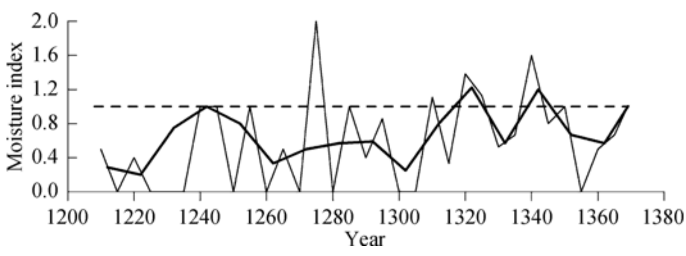

Figure 3 Moisture index per 5 (thin line) and 10 (thick line) years in BSGN during 1208–1369

(1) Characteristics of each phase

According to the changes of moisture index, the study period can be divided into three phases—1208–1240, 1240–1320 and 1320–1369.

1) 1208–1240: This was a dry period. Prior to 1220, drought dominated with the exception of occasional mild floods. After 1220, severer droughts occurred even more frequently.

Historical records show that the flood in the second year of Jiading (1209) was the only flood that happened during the next thirty years. In contrast, there were many records of drought. For example, almost all the years from 1215 through 1226 were dry. Accounts like "very dry in Shaanxi", "extremely dry in Xi-Xia", "In Hexi of Xi-Xia, plants died of drought, people had nothing to eat" were common in historical literature. After that, the moisture index increased slightly largely due to the lack of records of either drought or flood. Around the 1230s, BSGN was dominated by the Mongols and hence their historical accounts of this period could be more valuable. Unfortunately, the Mongol historians did a poor job on documenting climate events at that time. The lack of consistent and accurate historical records may have some negative impacts on our study.

2) 1240–1320: This period continued to be dry and disastrous droughts happened frequently. From the curve formed by moisture indices taken every 10 years, it can be seen that the indices were less than 1 during 1240–1315, indicating that this period was dominated by drought. The two driest periods were around 1260 and 1300, with moisture index less than 0.4. Droughts were frequently reported in various historical literatures in this period. For example, "In the second year of Zhiyuan (in 1265), drought happened in Xijing"; "In the third year of Zhiyuan (1266), drought happened at Fengxiang and Jingzhao[①]". Around 1280, the situation improved somehow although the value of moisture index was still low. Around 1300, drought struck again. For example, "In the sixth year of Dade (1302), Shaanxi was dry. In the eighth year of Dade (1304), drought hit Fufeng, Qishan and Baoji[②]". "The ninth year of Dade (1305), drought happened in Fengxiang and Fufeng[③]". In the tenth year of Dade, Tianzi left for Jinan via Shaanxi to take his new position and at that time Shaanxi had received no rainfall for three years. When he passed Huashan Mountains, he prayed for rain for the farmers in Shaanxi. Record shows that Shaanxi suffered continuous drought for more than five years during that period of time. Moisture indices taken every 5 years revealed that extreme droughts happened frequently in this period and that most of the drought events happened in the 1260s or at the end of the 13th century.

3) 1320–1369: This period was not as dry as before but droughts still struck alternately with the floods. Two severe floods happened around 1323 and 1340, which relieved the region's arid climate temporarily. As the moist periods did not last long, and severe drought made a comeback in 1328–1329, the aridity still persisted. During March through May of the first year of Zhihe (1328), droughts were suffered in Shaanxi Fu, Sichuan Fu, Henan Fu, Qishan, Shicheng, Fengyang, Yan'an[④] and so on. "Second year of Tianli (1329), people in Shaanxi had no food and many starved. The wheat harvest was poor and seeds could not be sown in autumn; people suffered terribly". Similar evidences[⑤] can be found in the study by Liu (1992) and in the History of Yuan Dynasty. To sum up, this was a period of drought in the history and it needs further attention and study. After 1235, the arid condition was alle-

① Shu Zheng Dian, Compilation of Calendar, Great Collection of Ancient and Modern Books.

② The twentieth record of Chengzong Emperor, Vol. 20, The History of Yuan Dynasty.

③ The First Record of Upright Officials, Vol. 119, The History of Yuan.

④ The Record of Taiding Emperor, Vol. 30, The History of Yuan.

⑤ The Record of Mingzong Emperor, Vol. 31, The History of Yuan.

viate. Since 1240, the region experienced a short-lasting humid period and the moisture index approached 1.2. From 1235 to 1368, BSGN entered another dry period, which is consistent with the conclusion by Gu *et al.* (2007) in their study on the historical climate change of Guanzhong.

(2) Extreme drought and flood events

From the above analysis, it can be concluded that the climate of BSGN in Mongol–Yuan period was characterized by frequent drought and flood events that had disastrous impacts over wide areas. The most severe drought events happened around 1220, 1250–1260, 1300 and 1328–1329 while the worst flood events around 1240, 1315–1325 and 1340–1345. It can be noted from related historical literatures that the frequencies and severity of droughts were much higher than flood and thus had greater impacts.

4.3 Characteristics of wet-dry changes

The analysis on the cumulative frequencies and power spectrum of drought and flood disasters revealed that wet-dry change in BSGN during the Mongol–Yuan period was characterized by obvious transitions and periodicity.

(1) The transition of the change

From the cumulative frequency of drought and flood disasters (Figure 4), it can be seen that two transitions of regional humidity occurred in 1230 and 1325. Prior to 1230, the frequencies of disasters were low but there was a sudden increase in 1230. Then the frequencies increased steadily until 1325, when another sharp increase occurred. This observation on the transition in 1230 was consistent with the study by Zhang *et al.* (1997).

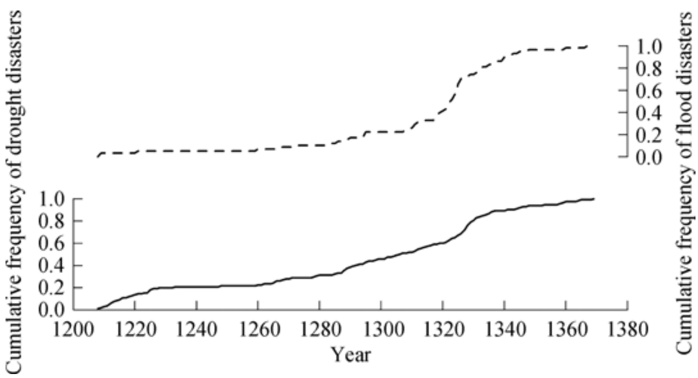

Figure 4 Cumulative frequency of drought and flood disasters in BSGN during 1208–1369

(2) The periodic change

The analysis on the power spectrum of drought and flood grades (Figure 5) showed that the wet-dry change had 10- and 23-year quasi-periods, which were consistent with solar cycles. Many previous studies revealed that the periodicities of the precipitation and the wet-dry change were related to solar activity (Xu *et al.*, 1986; Liu *et al.*, 1996; Hao *et al.*, 2007; Zhang *et al.*, 2008; Tan *et al.*, 2008) in China. This is verified again in our case.

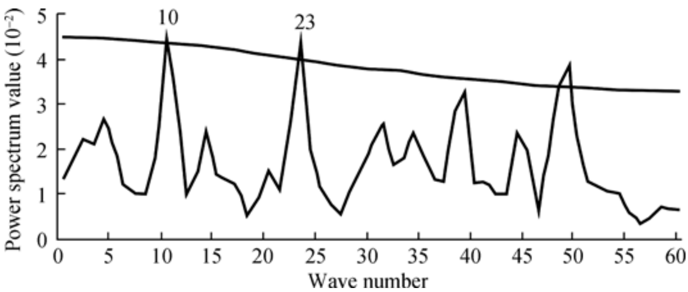

Figure 5 Power spectrum analysis of drought and flood grades in BSGN during 1208–1369

5 Conclusions and discussion

5.1 The wet-dry change of BSGN during 1208–1369

Based on numerous historical literatures, we used moisture index and flood/drought index to study the wet-dry change in BSGN in the Mongol–Yuan Period. The main conclusions are as follows:

Firstly, in general, it was a dry period. The frequency of drought (85) was significantly higher than that of the flood (38) during the study period.

Secondly, the period can be divided into three apparently different phases according to the wet-dry change. First phase was 1208–1240, which was dominated by drought with only occasional flood events. During 1240–1320, long-duration drought events and extreme drought disasters occurred frequently. The drought disasters were less severe from 1320 through 1369 than before, and happened alternately with flood events.

Thirdly, the wet-dry change appeared to be periodic and experienced some transitions. The two critical transitions of regional humidity occurred in 1230 and 1325. The 10- and 23-year quasi-periods exhibited by the wet-dry change were consistent with solar cycles, indicating that solar activity had affected the wet-dry conditions of the study region in the Mongol–Yuan Period.

5.2 The analogous study

In order to verify the accuracy of the results on the historical regional wet-dry change, we compared the results of this paper with previous studies based on historical documents and natural evidences. It turns out that the conclusions of these studies on climatic change, especially wet-dry changes in this area during the study period agree with each other quite satisfactorily.

Shao *et al.* (2004) reconstructed the precipitation variation in Delingha during the recent 1000 years from tree-rings (Figure 6e). Zhang *et al.* (2008) reconstructed the humidity of Longnan using stalagmite and meanwhile, and the study suggested that the value of $\delta^{18}O$ represented regional humidity (Figure 6b) .The regional humidity in Longxi was reconstructed by Tan *et al.* (2008) from historical documents (Figure 6a). All these studies involve historical humidity changes and the study regions were adjacent to, or very similar to the study area of this paper.

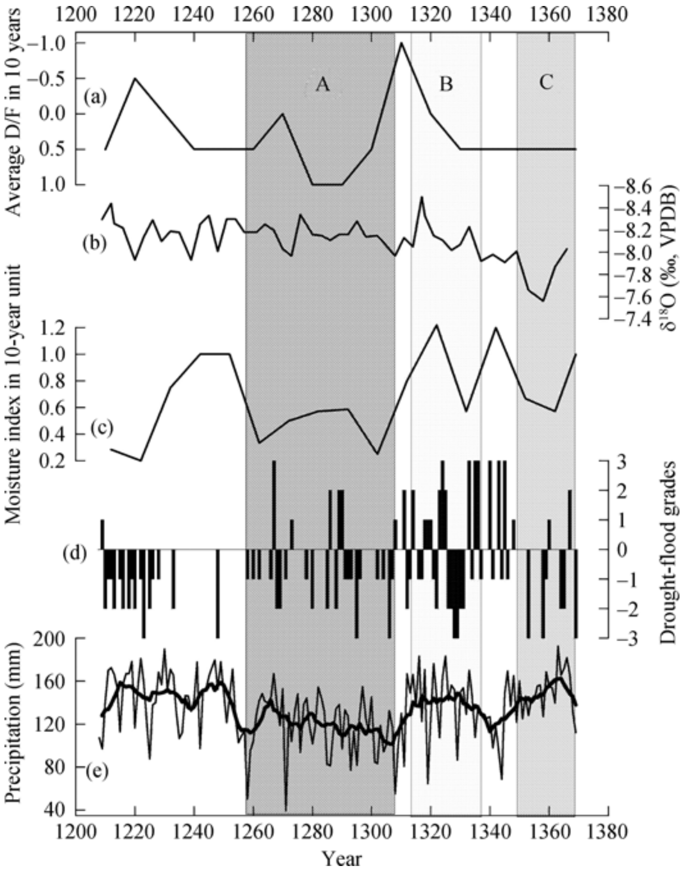

Figure 6 Comparison on humidity change trend between the results and other reconstructed results
(a) data cited from Tan *et al*. (2008); (b) data cited from Zhang *et al*. (2008); (e) data cited from Shao *et al*. (2005).

Similar conclusions regarding the humidity changing series were drawn by the above studies, especially for the period of 1258–1310 which was characterized by long-duration drought and frequent severe drought disasters (A period in Figure 6), and for the short humid period of 1310–1338 (B period in Figure 6). All the studies came to very consistent conclusions regarding the dry period of 1350–1368 (C period in Figure 6), except that the results using tree-rings had slight differences from those using other proxy data. In light of these comparisons, we cautiously suggest that the BSGN went through a generally dry climate during the Mongol–Yuan period, especially between 1258 to 1308, when the region suffered long-duration drought and the similar situation was experienced by the whole North China (Zhang *et al.*, 1994). We hope that the dry climate of the BSGN in the Mongol–Yuan Period and its historical social impacts can be paid more attention in further studies.

5.3 The impacts of the climate change

The humidity change in BSGN during the Mongol–Yuan Period was an important part of the regional environmental evolution, and had significant impacts on the ecological system and socio-economy. It has raised great concerns from related studies.

(1) The ecological responses to climate change

According to the pollen analysis conducted by our study team on Liupan Mountains, during 1214 to 1372, among the many species of pollen from the lake sediment, the herb pollen accounted for about 90%, including *Artemisia*, Leguminosae, Compositae, Labiatae, Ranunculaceae, Polygonaceae, Scrophulariaceae and Chenopodiaceae; tree pollen accounted for about 10%, including Betulaceae and *Larix* and so on. It is generally agreed that Chenopodiaceae prefer dry climate and are sensitive to the change of the humidity. Hence the ratio of *Artemisia* and Chenopodiaceae (A/C) may be correlated to the change of the humidity. We discovered that the percentage of Chenopodiaceae changed as follows: from 1214 to 1254, it decreased gradually and reached the minimum in 1254; the percentage increased rapidly since 1254, until 1293 when it reached its maximum and began to decrease from then on. With the error of dating technique considered, the changes of the percentage of Chenopodiaceae were consistent with the results we obtained earlier concerning humidity change including a wet period around 1240 and an extremely dry period around 1280. The values of A/C appear to have a trend contrary to that of the moisture index, which was also consistent with our conclusion.

(2) The relationship between agricultural policy and climate change in Yuan Dynasty

The droughts had significant effects on the agriculture-stock production in the Mongol–Yuan Period. For example, in early Yuan Dynasty, Liupan region was used as pasture[①] but it has become an agricultural area today. This could have been caused by the dry climate at that time. During Yuan Dynasty, the pastoral area continued to extend to the south and invade agricultural areas, possibly because the dry climate could not sustain the animal farming.

After he became ruler in China, Kublai Khan started to learn to take agricultural production seriously. In 1286, he promulgated 15 policies about agriculture and sericulture among these policies, several items were directed towards drought and other natural disasters. The third item encouraged the planting of *Medicago sativa* as a measure of famine relief. The fifth and sixth formulated measures and plans for land reclamation and victim relief, and required the perfection and maintenance of the Pingcang and Yicang (Chen, 2007). The ninth item concerned measures against locust invasion, which is also proof that in early Yuan Dynasty the climate was very dry and plagues of locusts were common and destructive, and the government had to make efforts such as *Medicago sativa* cropping and locust control to overcome drought and famine.

(3) The impacts of drought and flood disasters on socio-economy

The climate change had significant impacts on social economy system. The connections between extreme climate events and socio-economic development as well as political reforms have attracted more attention recently. Some scholars have discussed the associations of extreme climate events with important historical events such as China's historical evolution and changes of dynasties (Zhang *et al*., 2008; Yancheva *et al*., 2007). In this study we are concerned with the humidity change of the BSGN in the Mongol–Yuan Period, and our

[①] The history of Yuan Dynasty·The seventh volumes·of Shizu.

[②] Essential of the Four Categories·The category for Ji results show that the main characteristics of the climate in the study period were long-duration and frequent drought and other disasters. The long-duration droughts had far-reaching impacts on the socio-economic development. Some related studies also showed that East Asia suffered frequent natural disasters during the 13–14th centuries. Especially during the 14th century, the climate in North China was very cold (Yang *et al.*, 2002). The dry-cold climate together with the outbreak of the plague caused many sufferings. The Mongol rulers were unpopular and large-scale rebellions accelerated the destruction of the Yuan empire and drove the Mongols back where they came from (Denis *et al.*, 1994).

In this paper the humidity changes of the BSGN in the Mongol–Yuan Period and their impacts on natural ecosystem and socio-economy are analyzed. It is still worth further efforts to study the connections between these conclusions and the situations prior to and after the study period and over the adjacent areas.

References

Brooks C E P, 1950. Climate Through the Ages. 2nd edn. London: Ernest Benn, 295–307.

Chen Gaohua, 2007. Changpingcang and Yicang of Yuan Dynasty. In: He Zhiqing (ed.). Disaster Study of China's Ancient Times. Beijing: China Social Science Press, 198–218. (in Chinese)

Chen Guangyi, 1998. The history of Local Chronicles of China. In: Zhou Yiliang (ed.). College Historical Book Series. Fuzhou: Fujian People's Publishing House, 1–27. (in Chinese)

Denis T, John K F, 1994. The Cambridge history of China. In: Herbert F, Denis T (eds.). Alien Regimes and Border States, 907–1368. Cambridge, New York, Melbourne, Madrid, Cape Town, Singapore, Sao Paulo: Cambridge University Press, 584–586.

Editing Committee for Physical Geography of China (ECPGC), 1985. Physical Geography of China: General Theory. Beijing: Science Press, 249–256. (in Chinese)

Gong Gaofa, Zhang Piyuan, Wu Xiangding *et al.*, 1983. Research Methods of Historical Period Climate Change. Beijing: Science Press, 18–57. (in Chinese)

Gu Jing, Zhao Jingbo, Zhou Jie, 2007. Drought disaster and climatic change in Yuan Dynasty in Guanzhong area. *Marine Geology & Quaternary Geology*, 27(6): 111–117. (in Chinese)

Hao Zhixin, Zheng Jingyun, Ge Quansheng, 2007. Precipitation cycle in the middle and lower Yellow River. *Acta Geographica Sinica*, 62(5): 537–544. (in Chinese)

Li Dongliang, Liu Dexiang, 2000. Meteorology of Gansu Province. Beijing: China Meteorological Press, 378. (in Chinese)

Liu Guangshen, Mi Jiarong, Qi Changmou *et al.*, 1996. Relationship between the solar forcing and periodic variations of precipitation in the northeastern China. *Journal of Changchun University of Earth Sciences*, 26: 422–427. (in Chinese)

Liu Yu, An Zhisheng, Ma Haizhou *et al.*, 2006. Precipitation variation in the northeastern Tibetan Plateau recorded by the tree rings since 850 AD and its relevance to the Northern Hemisphere temperature. *Science in China* (Series D), 49(4): 408–420. (in Chinese)

Liu Zhaomin, 1992. Climate Change in Chinese History. Taipei: Taiwan Business Press, 200–227. (in Chinese)

Portter S C, 1986. Pattern and forcing of Northern Hemisphere glacier variations during the last millennium. *Quaternary Research*, 26: 27–48.

Qian Linqing, 1991. Climate of Loess Plateau. Beijing: China Meteorological Press, 369. (in Chinese)

Shao Xuemei, Huang Lei, Liu Hongbin *et al.*, 2004. Reconstruction of precipitation variation from tree rings in recent 1000 years in Delingha. *Science in China* (Series D), 34 (2): 145–153. (in Chinese)

Tan L C, Cai Y J, Yi L *et al.*, 2008. Precipitation variations of Longxi, northeast margin of Tibetan Plateau since AD 960 and their relationship with solar activity. *Climate of the Past*, 4: 19–28.

Xu Zhengtao, Jiang Yaorao, 1986. Sunspots and the Mankind. Tianjin: Tianjin Science and Technology Press, 170. (in Chinese)

Yancheva G, Nowaczyk N R, Mingram J *et al*., 2007. Influence of the intertropical convergence zone on the East Asian monsoon. *Nature*, 445(7123): 74–77.

Yang B, Braeuning A, Johnson K R *et al*., 2002. General characteristics of temperature variation in China during the last two millennia. Geophysical Research Letters, 29(9), 1324, doi: 10.1029/2001GL014485.

Zhang De'er, Liu Chuanzhi, Jiang Jianmin, 1997. Reconstruction of six regional dry/wet series and their abrupt changes during the last 1000 years in east China. *Quaternary Sciences*, (1): 1–11. (in Chinese)

Zhang Hongzhi, Han Kongle, 1991. Military organization of Kaicheng and military of Liupanshan in Mongol–Yuan period. *Journal of Guyuan Teachers College*, 4: 91–95. (in Chinese)

Zhang Jiacheng, 1999. Historical drought and aridification in China. In: Li Kerang (ed.). The Drought Disaster and Its Reduction Measures in China. Zhengzhou: Henan Science & Technology Press, 117–136. (in Chinese)

Zhang Jiacheng, Zhang Xiangong, 1979. Several climate oscillations and their relationships in China the last 500 years. *Acta Meteorologica Sinica*, 37(2): 50–57. (in Chinese)

Zhang Piyuan, Wang Zheng, 1994. The stages of climate change in recent 2000 years. *Science in China* (Series B), 24(9): 998–1008. (in Chinese)

Zhang P Z, Cheng H, Edwards R L *et al*., 2008. A test of climate, sun, and culture relationships from an 1810-year Chinese cave record. *Science*, 322: 940–942. (in Chinese)

Zhang Q B, Cheng G, Yao T *et al*., 2003. A 2,326-year tree-ring record of climate variability on the northeastern Qinghai–Tibetan Plateau. *Geophysical Research Letters*, 30 (14), 1739–1742. (in Chinese)

Zheng Jingyun, Wang Shaowu, 2005. Assessment on climate change in China for the last 2000 years. *Acta Geographica Sinica*, 60: 21–31. (in Chinese)

Zheng Sizhong, Zhang Fuchun, Gong Gaofa, 1977. Humid change of Southeast China for the last 2000 years. In: Climate Change and Super Long-term Forecast Collected Works. Beijing: Science Press, 29–32. (in Chinese)

Zhu Kezhen, 1925. Climate change in Chinese history. *The Eastern Miscellany*, 22(3): 84–99. (in Chinese)