Tree Ring–Based Reconstruction of October to November Runoffs in the Jiaolai River since 1826

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Abstract: The Horqin Sandy Land is a typical desertification region in China, which is beset with ecological and environmental problems that affect economic and social development. Hence, the hydrological impact factors (underground water level and surface runoff) in this region need to be investigated. The current study reconstructed the runoff sequences from the southwest edge of the Liaohe River to the XiaWa station of the Jiaolai River during the months of October to November from 1826 to 2005. A comprehensive timeline for the regional tree wheel width of the Horqin Sandy Land was employed. The timeline has been used for 183 years. For the past 180 years, the runoff has experienced six and four consecutive wet and dry seasons, respectively. From 1982 to 2005, the runoff reached the longest stream segment of a continuous low-flow runoff, with a mean average runoff of only 63.58% for the entire period. The runoff had 3, 11, 15, 24, and 30-year quasi-periodic variations, consistent with changes in similar areas worldwide. The change was gentler from 1826 to 1917. In 1956, the runoff increased, then significantly decreased for nearly 50 years. The drop rate was 1.7766 million m^3 every 10 years, which shows a consistent downward trend with the precipitation (14.74 mm/10 year). The overall reduction in precipitation accounted for 29.86% of the initial value, which is significantly less than 75.58% for the runoff. If the runoff and precipitation drop continue, more extensive and lengthy ecological and environmental problems are foreseen to occur. **DOI:** **10.1061/(ASCE)HE.1943-5584.0000763.**

Author keywords: Northeast China; Horqin Sandy Land; Jiaolai River; Runoff; Response analysis; Sequence reconstruction.

Introduction

China is one of several countries experiencing severe desertification. The rapid progression of dry land degradation has become an important ecological and socioeconomic problem (Wang et al. 2002; Wang and Zhu 2004). The Horqin Sandy Land is located between east longitude 117°45 to 124°06 and north latitude 42° 36 to 45°20 (Fig. 1). The land belongs to the alluvial plain of the Liaohe River. In ancient times, Horqin Sandy Land was a prairieland with lush vegetation and beautiful scenery. Today, the area has become a typical Chinese desertification area, one of four sandy lands in China. Related research on the environmental changes in this area began in the 1950s, producing several substantive results (Wang and Zhu 2004; Dong et al. 1998; Wang et al. 2004a; Li et al. 2006; Zhao et al. 2008) on the process, evolution, structure, and drive mechanism of desertification. The results have suggested that climate fluctuations can directly affect the process of desertification via different periods of precipitation and temperature combinations to some extent (Wang et al. 2004b; Zhao et al. 2008). The desertification is primarily subjected to millennial and centennial-scale climate fluctuations (Dong et al. 1998; Peng et al. 2012). Hence, a long time scale research on hydrological climate changes is particularly important.

Runoff and precipitation are closely related (Cheng et al. 2002; Wang et al. 2009). The amount of runoff not only directly affects river ecology, but also has a profound impact on changes in river environments. Consequently, the future trends of the ecological environment and past runoff variations need to be explored (Ling et al. 2011; Zhang et al. 2011; Xu 2011; Gupta et al. 2011; Zarghami et al. 2011).

Many studies have been conducted on runoff in the Liaohe River. This river is located in the Horqin Sandy Land (Hao et al. 2008; Yang et al. 2009; Fang et al. 2009; Jiang et al. 2010; Wang et al. 2011; Zhang and He 2011; Gu et al. 2011), and the study periods cover the years 1950 to 2008. These works have involved the Liaohe River, Liaohe tributaries, and other tributaries of the Laoha River. Zhang et al. (2007) demonstrated that the runoff measured in the Liaohe Laoha River has significantly decreased since 1950. Fang et al. (2009) revealed that from the 1960s to the early 21st century, the annual runoff of the Laoha River has followed a significantly decreasing trend. The decadal variation is much greater than the annual rainfall. Wang et al. (2011) indicated that the runoff measured in Liaohe Tieling showed a significant reduction trend since the mid-1960s.

However, these studies are primarily based on observed data from hydrological observation stations, and the life of these data is generally 50 years. These data are clearly insufficient for studying longer time-scale changes in runoff. Hydroclimatic information revealed by tree-ring records is an effective means to address this limitation. Tree ring–based reconstructions present information that feature accurate positioning, good continuity, high resolution, and precise correlation with hydrological climate changes (Fritts 1976; Shao 1997). These reconstructions have been applied in research on hydroclimatic events abroad, such as runoff, drought, flood,

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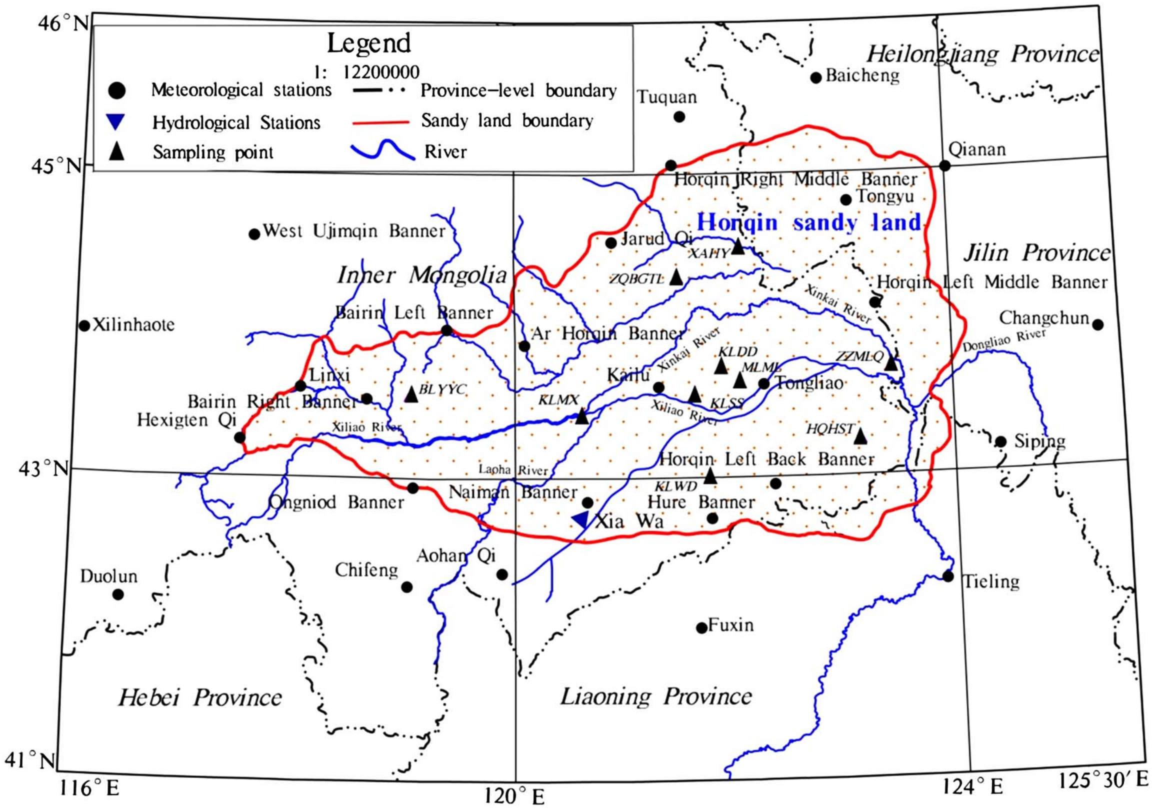

Fig. 1. Location of Horqin Sandy Land, sampling points of elm tree rings, and distribution of meteorological and runoff stations

rainfall, temperature, glaciation, and volcanic activity (Stockton and Meko 1975; Hughes et al. 1978; Cook and Jacoby 1983; Briffa et al. 1995; Van et al. 1998; Clevel 2000; Magda et al. 2001; Meko et al. 2001; Woodhouse 2001; Esper et al. 2003; Law et al. 2006).

In China, the study objects of Sabina, spruce, pine, white stick, larch, and elm in cold and dry regions have been examined to establish the chronology, reconstruction, and relationship of the tree ring with the hydrological climate. Such regions have included Qinghai-Tibet Plateau, Qaidam Basin, Xinjiang, Qilian Mountain, Changbai Mountain, Qinling, and Inner Mongolia. Great progress has been made in this research (Shao et al. 1997a, b; Gou et al. 2006; Ma and Liu 2009; Zhu et al. 2008; Eryuan et al. 2008; Liu et al. 2004; Li et al. 2010; Ma et al. 2011). Part of the runoff was reconstructed in the Urumqi mountain basin, Black River, Tongtianhe, Huangshui, and Yellow River (Li et al. 1997; Kang et al. 2002; Qin et al. 2004; Wang et al. 2004c; Sun et al. 2011; Chau et al. 2005; Qu et al. 2012). The long sequence of changes in runoff characteristics was analyzed.

The tree ring has rarely been used to study the reconstruction of long sequences of the river runoff in sand. Regardless of the short time changes in runoff characteristics and the reconstruction of a long sequence, studies on the Jiaolai River are relatively limited. The current paper used the 183-year Horqin sandy area elm tree ring width chronologies established by Ma et al. (2011) in a station in the Jiaolai River tributary during the months of October to November from 1826 to 2005 to study the runoff characteristics. The results provided some basic information on long-term changes in the Liaohe source runoff, ecological and environmental protection, and catchment economy progress.

The difficulty of this study was reliability in the determination of the reconstruction process and sequence, and the division and analysis of runoff at abundant and low stages in long time scales. The various data for precipitation, runoff, and chronology were used to rebuild the runoff through analyses of the relationship of precipitation runoff chronology in multiple time scales. To guarantee the credibility and availability of the runoff reconstruction results, the multiple index method is commonly used to test the stability and reliability of the reconstruction equation. Based on analytical methods such as the mode ratio coefficient, the abundant changes and trends of the reconstruction sequence were analyzed.

Data in Use

Chronological Data

This research area covered most of Horqin Sandy Land. Samples were obtained from elm tree species, sample point distribution (Fig. 1), sampling time for 2009, and sampling not facing interference from fire or insect pests. Each sample point had 20 samples, and each tree had one to two core samples. Table 1 lists the basic information of all samplings. The ring width chronology and reconstruction of elm in the sandy land were used (Ma and Liu 2011). The ring width chronology from 1826 to 2008 (183 years) is shown in Fig. 2 (Ma and Liu 2011).

Hydrological and Meteorological Data

The selected precipitation data were in accordance with the chronology established by the meteorological stations. The monthly (yearly) precipitation data from 1951 to 2010 were obtained from the eight meteorological stations closest to the sites. These stations were the Horqin Left Back Banner, TongLiao, Kailu, Horqin Left Middle Banner, Jarud Qi, Horqin Right Middle Banner, and Horqin Left Right Banner. Integrated data were also obtained from the

Table 1. Information about Sampling Points

Number	Code	North latitude (°)	East longitude (°)	Elevation (m)	Sample size/core samples	Sample length (years)
1	KLDD	43.66	121.83	207	26/52	119
2	MLML	43.59	122.02	193	23/43	122
3	KLSS	43.54	121.55	224	12/24	203
4	HQHST	43.19	123.04	159	25/47	145
5	ZZMLQ	43.67	123.42	134	22/44	125
6	KLWD	42.98	121.69	291	21/42	206
7	XAHY	44.50	122.00	180	23/46	136
8	ZQBGTL	44.33	121.58	204	24/43	155
9	KLMX	43.41	120.59	343	26/52	138
10	BLYYC	43.53	118.83	506	28/56	132

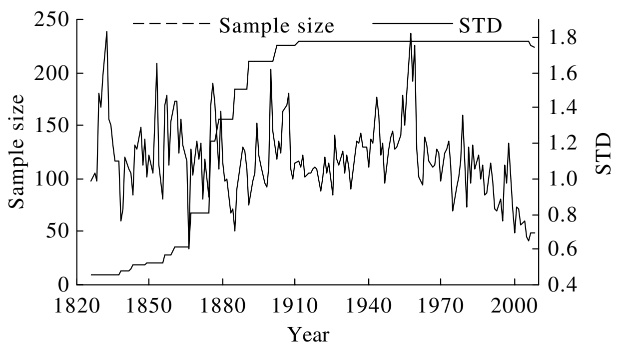

Fig. 2. Regional elm STD chronologies and sample size

meteorological department. The uniformity of every meteorological element indicated that precipitation data from the sites did not exhibit significant deviations or random changes and that data changes were relatively homogenous and consistent. Hence, the data were considered to be reliable representations of the climate conditions in the region. Data from adjacent sites were used to interpolate measurements because some of the stations had incomplete information. The average data for the eight stations were used for area face value.

According to the same basin and proximity principle, the monthly (yearly) runoff data were collected from 1957 to 2010 of the XiaWa station in the Jiaolai River. This station is located at the edges of Horqin Sandy Land and the import point to the sand of the Jiaolai River. The measured runoff data were close to the natural values because of low human activity upstream.

The ground precipitation in Horqin Sandy Land is basically similar to the upstream watershed area. By combining all factors, the selected hydrological station and precipitation sites were used in the present study.

Establishment of Chronology

By using ARSTAN (a hydrological software package) calculation procedures and according to the actual situations of different samples, negative exponential and spline functions (step length of 50–100 years) were used to overfit the growth trend. The growth trend was overfitted by using the polynomial function method, moving average, and large sample sliding average curve. For the tree-ring sample sequence based on the different fluctuations of magnitudes, the different overfitting method of growth trend was adopted. When the fluctuation of the sample sequence was smaller,

Table 2. Statistical Indexes for Standard and Residual Chronology

Chronology	STD	RES
Average	1.114	1.000
Median	1.100	0.973
Coefficient of skewness	0.521	0.803
Kurtosis coefficient	3.904	4.288
Average sensitivity	0.322	0.359
Standard deviation	0.217	0.172
Order autocorrelation coefficient	0.638	0.021
Average correlation coefficient of between sequences and primary sequence	0.603	0.657
Average correlation coefficient of the trees	0.439	0.466
Signal to noise ratio	15.600	16.200
General representative samples	0.920	0.922
Variance amount explained by first principal component (%)	40.300	43.200
Sample signal strength >0.80 since the first year (tree)	1,826(10)	1,823(9)

the negative exponential function method was adopted; when the sample sequence fluctuation was larger, the spline function method was adopted. The two methods can commendably overfit the radial growth trend of trees to effectively avoid the end amplification effect and to maintain lower frequency climate information. These methods have a better plant physiological basis than other methods. After eliminating the growth trend of the elm tree, the three different forms of timeline of the width of sampling points for elm trees around the area were established: standardization chronology, difference chronology, and regression chronology. The results indicated very good correlation (average correlation coefficient between 0.403 and 0.479) between the core and the average sequence of antichtone sampling points. Meanwhile, the correlations among core samples of each sample point were also very good. The established chronology of the sampling points was strongly consistent (the correlation coefficient of the chronology sequence ranged between 0.566 and 0.713). The width of the regional integrated chronology of elm trees was built by all sampling points to form the regional standardization chronology, difference chronology, and regression chronology (1826 to 2008, a total of 183 years). The standardization chronology is shown in Table 2. All characteristic parameters in the standard chronology (STD) and residual chronology (RES), such as general representative samples, adequately showed that the chronology series included more environmental information and that elm tree species found in Horqin Sandy Land are suitable for the research using tree-ring climatology.

Related Analysis and Explanation

Correlation of Chronology and Runoff

Tree-ring climatology considers that rings formed in the year t are influenced not only by the climate at that time, but also by the climate of the previous one to two years (Fritts 1976). The standard chronological sequence and standard chronological $t+1$, $t+2$, and $t+3$ sequences in relation to the runoff in low-lying stations, in addition to the correlation coefficients, are shown in Table 3. The standard chronology had a significant relationship with the runoff in March, April, August, September, October, and November, and with the annual runoff. The correlation in October and November was the highest.

The results of the correlation analysis between the annual and monthly runoff showed that the runoff in July accounted for 30.19% of the annual runoff, with a maximum correlation

Table 3. Correlation Coefficient of Standard Chronology and Runoff

Standard chronology	Runoff in March	Runoff in April	Runoff in August	Runoff in September	Runoff in October	Runoff in November	Runoff in March
Standard chronology	0.365[a]	0.296[b]	0.455[a]	—	0.512[a]	0.549[a]	0.281[b]
Standard chronology in year $t+1$	0.384[a]	0.491[a]	0.298[b]	—	0.483[a]	0.545[a]	0.277[b]
Standard chronology in year $t+2$	0.301[b]	0.374[a]	0.449[a]	—	0.520[a]	0.584[a]	0.454[a]
Standard chronology in year $t+3$	0.444[a]	0.558[a]	0.386[a]	0.368[a]	0.566[a]	0.626[a]	0.455[a]

[a]99% confidence level.
[b]95% confidence level.

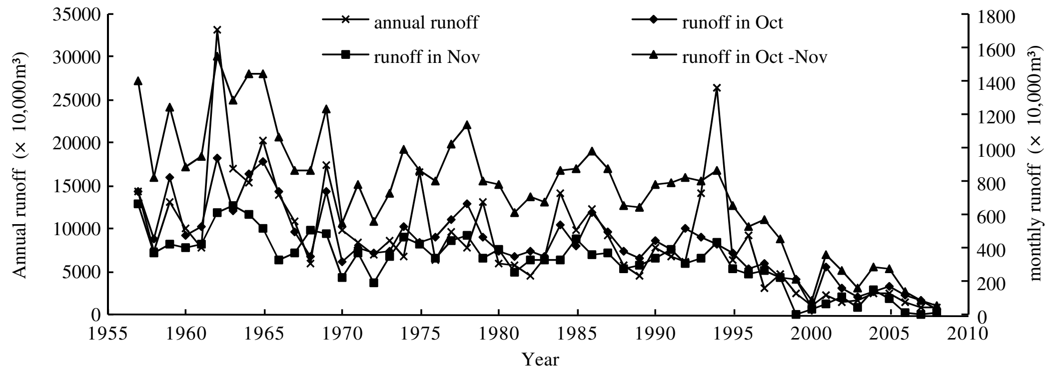

Fig. 3. Contrast curve among annual runoff, runoff in October, runoff in November, and added runoff values of October and November

coefficient of 0.814. Although the runoff values in October and November were responsible for only 4.82 and 3.63% of the annual runoff, the annual runoff coefficients in these months, 0.755 and 0.699, respectively, ranked only second and third to July. Based on the contrast curve among the annual runoff values, runoff in October and November, and runoff in October to November (Fig. 3), the four curves basically showed a similar trend. Therefore, the chronology for the October to November runoff was constructed to analyze wet and dry season changes and cycle changes, which can represent the changes in annual runoff to some degree. The reconstruction could also be conducted in August, considering the better correlation coefficients in October to November, which has a more significant meaning in reconstruction.

Explanation of Physiological Mechanism of the Relationship between Trees and Runoff

The primary supply source of runoff formation is precipitation. In different seasons at different times, groundwater comes from direct precipitation or snowmelt that supplies the runoff. According to the correlation between the precipitation sequence in Horqin Sandy Land and the runoff series in the XiaWa station (Table 4), the precipitation in July, August, and September in addition to the annual precipitation, significantly correlated with the March to April, July to November, and annual runoff values. Among them, the precipitation in July had a significant correlation with the March to April, July to November, and annual runoff values. The runoff in July accounted for 30.19% of the annual runoff, whereas the precipitation in July was 32.18% of the total annual precipitation, which was the largest contribution to the runoff. The rainfall in August was significantly related to the August to October runoff, and the August runoff accounted for 24% of the annual runoff. On the other hand, the precipitation in August accounted for 21.46% of the annual precipitation and ranked second in terms of runoff contribution. The precipitation in September had a significant correlation with the September to November runoff, and the runoff in September was 7.51% of the annual runoff. By contrast, precipitation in September accounted for 8.84% of the total annual precipitation. The annual precipitation was significantly related to the March to April, July to November, and annual runoff values. When precipitation transforms, some directly forms surface runoff and some permeates the ground to supply surface runoff in the form of underground runoff. Based on a combination of the preceding relationships, the formation of precipitation runoff was concluded to have some lag. Therefore, the precipitation in July, August, and September was greater and accounted for a significant proportion of the annual precipitation. The precipitation not only plays an important role in the formation of monthly surface runoff, but also affects the runoff in October to November, to some degree.

Precipitation also plays an important role in the growth of trees, especially the precipitation in July, August, and September, which were significantly correlated with the chronology (Ma et al. 2011).

Table 4. Correlation Coefficients of Runoff and Precipitation

Period	Runoff in March	Runoff in April	Runoff in July	Runoff in August	Runoff in September	Runoff in October	Runoff in November	Annual runoff
Precipitation in July	0.395[a]	0.293[b]	0.469[a]	0.288[b]	0.398[a]	0.366[a]	0.445[a]	0.519[a]
Precipitation in August	—	—	—	0.572[a]	0.414[a]	0.329[b]	—	0.283[b]
Precipitation in September	—	—	—	—	0.574[a]	0.291[b]	0.285[b]	—
Annual precipitation	0.276[b]	0.316[b]	0.443[a]	0.359[a]	0.417[a]	0.415[a]	0.430[a]	0.381[a]

[a]99% confidence level.
[b]95% confidence level.

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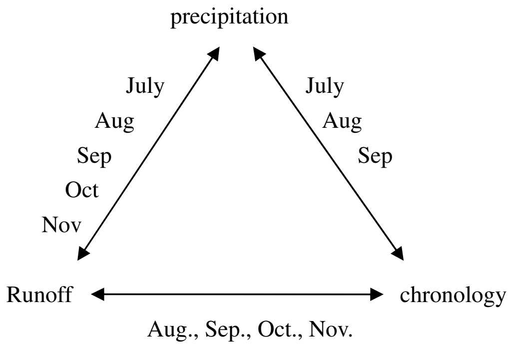

Fig 4. Correlation of precipitation, runoff, and chronology

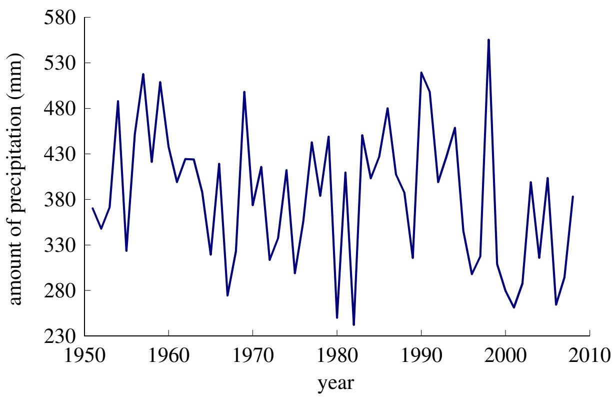

Fig 5. Results of the variations in annual precipitation in Horqin Sandy Land for many years

Summer is the peak of elm growth, and during these months, elm growth mostly depends on water. Good water conditions during this period effectively and rapidly promoted elm growth. This phenomenon was the same in September.

Considering the comprehensive situations in Tables 1 and 2, Figs. 4 and 5 show that precipitation played a major role in runoff formation and tree growth. In July, August, and September, the precipitation played an important role, not only on tree growth, but also on runoff formation. Changes in the runoff also represented changes in the precipitation. Runoff played a role in the supply of groundwater through the change of underground water level to influence the growth of the trees. Considering the lag effect, the precipitation in July, August, and September had a significant impact on the runoff in October to November and the corresponding change in underground water level, affecting the growth of the trees. This phenomenon explained the good relationship between the chronology and the August to November runoff. The good relationship among the chronology sequences in years $t+1$, $t+2$, and $t+3$ with the runoff also completely illustrated the delayed runoff response and fully explained that the groundwater shows lagging responses to runoff and will exert an influence on the tree growth.

Reconstruction Runoff

According to the preceding response relationship, the standard sequence and standard chronology in years $t+1$, $t+2$, and $t+3$ were used to reconstruct runoff in the XiaWa station of the Jiaolai River from October to November from 1826 to 2005. The following equation was adopted:

$$R_t = -800.79 + 438.43 \times I_t + 98.01 \times I_{t+1} + 231.54 \times I_{t+2} + 818.15 \times I_{t+3}$$
$$[N = 49, \quad r = 0.74, \quad R^2 = 0.54, \quad R^2_{\text{adj}} = 0.51, \quad F(4.44) = 13.05, \quad P < 0.001] \quad (1)$$

where R_t = runoff from October to November in year t; I_t = index of standard tree-ring chronology in year t (dimensionless); I_{t+1} = index of standard tree-ring chronology in year $t+1$ (dimensionless); I_{t+2} = index of standard tree-ring chronology in year $t+2$ (dimensionless); and I_{t+3} = index of standard tree-ring chronology in year $t+3$ (dimensionless).

Compared with the reconstructed sequence exhibiting the same trend as the corresponding sequence of the measured value (Fig. 5), some extreme values were not completely consistent with the reconstructed values. In other words, part of the tree-ring reconstruction results underestimated extreme hydrological and climate events (Fritts 1976). However, the reconstruction equation yielded good results for the reconstruction of the average minimum winter temperature. The reconstructed and measured values demonstrated good synchronization.

Additional tests on the stability and reliability of the reconstruction equation were necessary to ensure the credibility of the reconstruction value when a value generated beyond the calibration period was used. According to common international practice, the reduction error (RE), sign test (S_1), first difference symbols for the test (S_2), and average test value for the product (t) were calculated. An RE of 0.54 was obtained. When the RE is higher than 0.3, the reconstruction value is considered credible (Li et al. 2000). The values of the sign test results and first-difference symbols for the test results were 33/49 and 31/48, respectively. These values were significant at the 0.05 level, indicating that the reconstructed and measured value sequences were in good agreement with the changes in high to low frequencies. The average test value for the product was 2.91, which was significant at the 0.01 level, indicating a significant difference between the identical and opposing serial number sequences. All parameters indicated that the reconstruction equation was stable and reliable. The reconstruction results for the runoff derived from this equation were also credible.

Consequently, the runoff series for the XiaWa Station of the Jiaolai River in October to November from 1826 to 2006 was rebuilt according to the reconstruction equation. The reconstruction sequence is shown in Fig. 6.

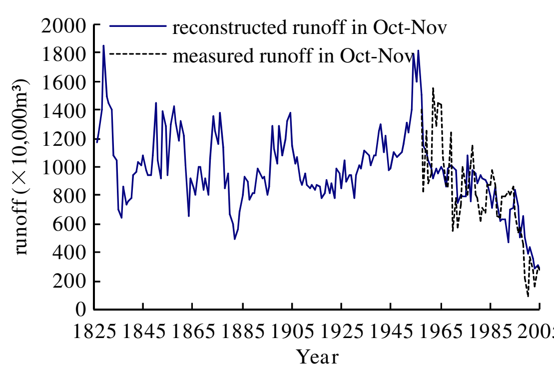

Fig. 6. Contrast curve of the runoff, in measured and reconstructed values, in October and November

Characteristics of Runoff

Changes in Wet and Dry Seasons

According to the reconstructed runoff series, the average runoff in the XiaWa station of the Jiaolai River in October to November from 1826 to 2006 was 9.7238 million m^3. The maximum value of 18.5171 million m^3 was found in 1829 and the minimum value of 2.8576 million m^3 was found in 2005. The extreme value (maximum/minimum) was 6.48, which illustrated that the runoff in the Jiaolai River had greater amplitudes between years.

Reconstructing the sequence in mean runoff changes can reflect wet and dry season changes between years. The mean changes are shown in Table 5. These data showed the wet periods were more obvious in the 1820s, 1850s, 1900s, and 1950s during the era of scale changes, whereas dry periods were remarkable in the 1880s, 1910s, and 1970s to 2000s.

For further quantitative analysis of the reconstructed sequences in wet and dry season changes, the coefficient ratio, K_p, which is the ratio of the runoff to the mean runoff for many years, was calculated. The following definitions were made for different K_p values: more than 1.16, special wet years; between 1.06 and 1.16, partial wet years; between 0.95 and 1.06, flat water years; between 0.84 and 0.95, partial dry years; and less than 0.84, special dry years. The reconstruction sequence is shown in Fig. 7. This sequence indicated that the years of reconstructed sequences in special wet, partial wet, flat water, partial dry, and special dry years were 40, 23, 40, 30, and 47, accounting for 22.22, 12.78, 22.22%, 16.67, and 26.11% of the total number of years. The proportions of special wet, flat water, and special dry years were large, with the special dry years the largest. This result revealed that the runoff in the Jiaolai River had a negative contribution to the reconstruction period.

Table 5. Mean Runoff Changes in the Reconstruction Sequence

Years	Mean runoff ($\times$10,000 m^3)
1820s	1,415.61
1830s	1,017.40
1840s	975.48
1850s	1,225.76
1860s	961.44
1870s	1,088.97
1880s	719.28
1890s	971.15
1900s	1,127.83
1910s	862.07
1920s	911.33
1930s	1,019.15
1940s	1,119.74
1950s	1,410.31
1960s	972.87
1970s	887.31
1980s	824.57
1990s	635.25
2000s	344.35

According to the principle of at least five continuous years, the special and partial wet years were combined with the wet years, whereas the special and partial dry years were combined with the dry years. The results are shown in Fig. 7. The consecutive wet years in the reconstruction sequences were 1826 to 1834, 1856 to 1861, 1872 to 1877, 1897 to 1905, 1938 to 1943, and 1946 to 1960. The durations ranged from six to 15 years and the total was 51 years. A total of 24 out of these 51 years occurred in the 19th century, and the remaining 27 occurred in the 20th century (primarily in the 1960s). The longest wet period occurred from 1946 to 1960, with the mean annual runoff at 12.9962 million m^3, which was 1.33 times the average runoff for the entire reconstruction period. There were four periods of continuous dry years: 1835 to 1840, 1880 to 1885, 1912 to 1922, and 1982 to 2005. The durations ranged from six to 24 years and the total was 47 years. Only 12 out of these 47 years occurred in the 19th century and the remaining 30 occurred in the 20th century (primarily from the 1980s to the late 20th century). The five years in the early 21st century were continuous dry years (from 1982 to 2005). The continuous dry time reached 24 years and the mean annual runoff was 6.1823 million m^3, which was only 63.58% of the average runoff for the entire reconstruction period. The continuous dry periods occurred not only in the 1980s, but also from the early 1960s to 2005. The overall runoff showed a decreasing trend. From the 1950s to the 2000s, the runoff decreased from 14.1031 to 3.4435 million m^3, with a drop rate of 1.7766 million m^3/10 years. The runoff significantly declined, which proved that the runoff in the Jiaolai River gradually decreased for nearly 50 years, thereby forming the longest continuous dry season during the reconstruction period.

Periodic Changes

An analysis of the runoff reconstruction with the power spectrum revealed that the runoff reconstruction sequence had 3, 11, 15, 24, and 30-year quasi-periodic variations under the 0.05 significance level. This result almost had the same cycle as the precipitation

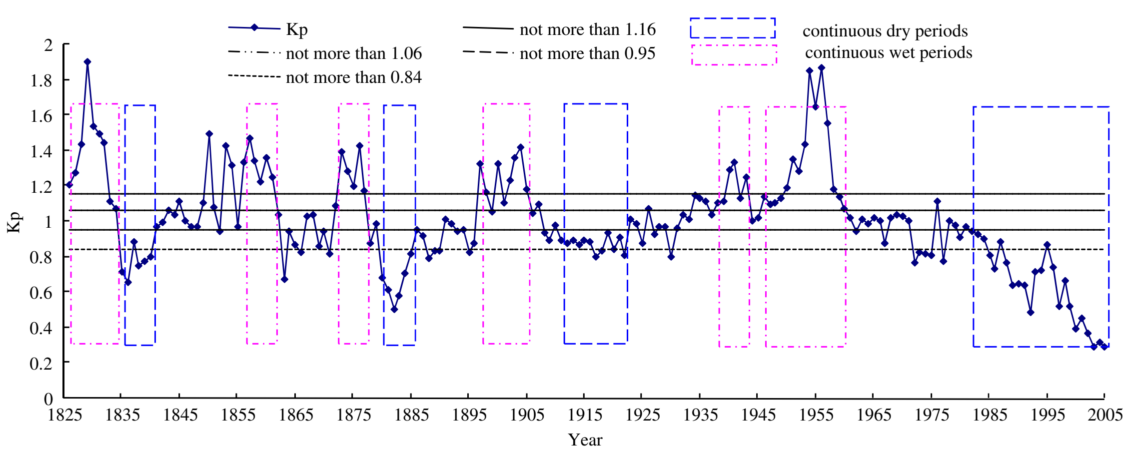

Fig. 7. Changes in the K_p of the runoff reconstruction sequence and the distribution in continuous wet and dry seasons

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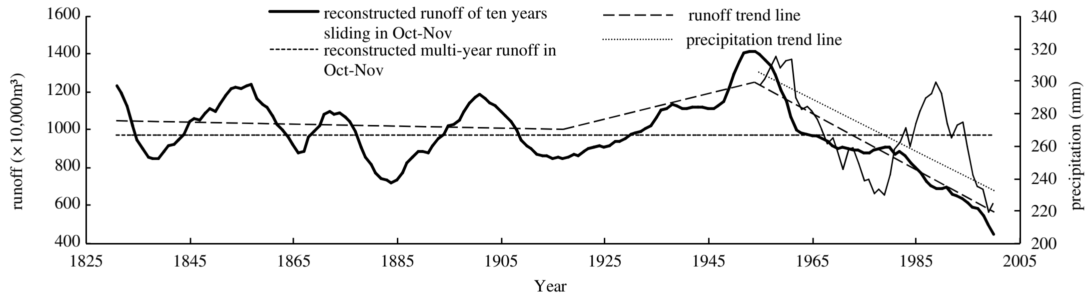

Fig. 8. Moving averages and trends in the runoff reconstruction sequence and the measured precipitation for 10 years

changes in Horqin Sandy Land. This similarity signified that precipitation played an important role in the formation of runoff.

Variation Trends

The runoff sequence was reconstructed for a 10-year moving average, as shown in Fig. 8. The trend line shows that the runoff change was gentler from 1826 to 1917 (92 years) in the Jiaolai River for the entire 180 years. Subsequently, the runoff increased in 1956, then significantly decreased for nearly 50 years. This finding was consistent with the aforementioned wet and dry seasonal changes.

Discussion and Conclusion

The present study used a comprehensive timeline for the regional tree wheel width of Horqin Sandy Land to reconstruct the runoff sequences in the XiaWa station of the Jiaolai River during the months of October to November from 1826 to 2005. The reconstructed sequence exhibited the same trend as the corresponding sequence of the measured value. The calculated results of various tests showed that the reconstruction result was stable and reliable. However, because of a lack of influence factor data (e.g., underground water, soil moisture content, and soil components) for elm growth in this study, the quality of reconstruction was affected to a certain extent. Many factors need more comprehensive monitoring and collection in the future, further improving the quality of the reconstruction.

There were greater amplitudes in runoff values in the Jiaolai River between years. The reconstruction sequence had six continuous wet period years over a total of 51 years, including 27 years that occurred in the early 20th century to the early 1960s. The multiyear average runoff in the wet period from 1946 to 1960 was 1.33 times the entire reconstruction period mean annual runoff. The runoff also went through four continuous dry periods for a total of 47 years, including 30 years that occurred in the 1980s to the late 20th century. The multiyear average runoff from 1982 to 2005 was only 63.58% of the entire reconstruction period. Overall, the runoff gradually decreased for nearly 50 years (from the early 1960s to the present), and the drop rate in runoff was 1.7766 million years $m^3/10$ years. This result demonstrated that the runoff change in the Jiaolai River followed certain rules with varying degrees of change, similar to other areas around the globe (Zhang and He 2011; Gupta et al. 2011).

Runoff in the Jiaolai River had 3, 11, 15, 24, and 30-year quasi-periodic variations. Among these, the 11-year variation had the same cycle as solar activity. The 24 and 30-year cycles were also consistent with the precipitation cycle. This result fully explained that the runoff change in the Jiaolai River followed certain rules with varying degrees of change, similar with other areas around the globe.

Overall, for the entire 180 years in the Jiaolai River, the change in runoff was gentler from 1917 to 1826. After this, the runoff gradually decreased in 1956. For nearly 50 years, the runoff had a significantly decreasing trend. A comparison with the 10-year sliding curve of the precipitation in the Horqin Sandy Land measured in July to November (Fig. 7) revealed that the precipitation decreased for nearly 50 years, i.e., from 296.10 to 207.67 mm in the 1950s to 2000s, with the decreased rate of 14.74 mm/10 years. The overall decrease accounted for 29.86% of the initial value, which is a significant amount. By contrast, the proportional decrease in precipitation accounted for the initial value being much smaller than the proportion of runoff reduction, accounting for approximately half. In other words, a slight decrease in precipitation may lead to a significant reduction in runoff. Zhang et al. (2007) drew a relatively similar conclusion. They proposed that in the past 50 years, the relationship between runoff and precipitation has shown an overall downward trend. The results of the present study provide further information on runoff changes in the Liaohe River, in addition to possible strategies for ecological environmental protection and catchment economy progress.

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