

Chapter 10

A Drought Reconstruction from the Low-Elevation Juniper Forest of Northwestern Kyrgyzstan since CE 1565



Feng Chen, Shulong Yu, Qing He, Bakytbek Ermenbaev
and Rysbek Satylkanov

Abstract Naryn River provides large amounts of water resource for Central Asian countries. Thus, the severity and frequency of drought variation relate to runoff has important influences on social and economic development of this region. In this study, the new tree-ring width chronologies of juniper trees from the low-elevation site of the western Tien Shan are used to reconstruct drought variation for northwestern Kyrgyzstan and place the short instrumental period (1950–2013) of Standardised Precipitation-Evapotranspiration Index (SPEI) in a long-term context. The SPEI reconstruction successfully reflects the dry and wet periods over the past 451 years, and captures a recent wetting trend that generally agrees with the drought reconstructions for the spruce-dominated area. However, some differences between the tree-ring records from spruce-dominated and juniper-dominated areas reflect regional climate differences. The comparison between drought events in the SPEI reconstruction and historical event of Central Asia reveals drought variations have had profound influences on some historical archives over the past several centuries. This study provides the first long-term SPEI reconstruction and drought evaluation from the low-altitude area of Central Asia, contributing to climate change issues in Central Asia.

Keywords Northwestern Kyrgyzstan · Tree rings · SPEI · Drought reconstruction
Central asia · Historical archives

F. Chen (✉) · S. Yu · Q. He

Key Laboratory of Tree-ring Physical and Chemical Research of China Meteorological Administration/Xinjiang Laboratory of Tree-ring Ecology, Institute of Desert Meteorology, Meteorological Administration, Urumqi 830002, China
e-mail: feng653@163.com

B. Ermenbaev · R. Satylkanov

Tien-Shan Mountain Scientific Center, Institute of Water Problems and Hydro Power, National Academy of Sciences of the Kyrgyz Republic, 720033 Bishkek, Kyrgyzstan

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10.1 Introduction

Tree-ring width series have been applied to reconstruct regional- to large-scale drought/precipitation variation over the pre-instrumental period in the drylands of the world (e.g. Cook et al. 2004; Gray et al. 2007; Neukom et al. 2010; Touchan et al. 2011; Fang et al. 2010; Yang et al. 2014; Gou et al. 2015; Chen et al. 2015a). Most of drought/precipitation reconstructions or related index value (e.g. runoff) from Central Asia are inferred from the Xinjiang province in China (Yuan et al. 2007; Zhang et al. 2013; Chen et al. 2014, 2015b), where drought events are common and the socio-economic development is limited by scarce water resources. Despite the large impact of droughts on the socio-economic welfare of numerous Central Asian countries, relatively little is known about the drought frequencies in these regions. Henceforth, the development of reliable, highly resolved moisture sensitive tree-ring chronologies certainly contributes to a more accurate assess of the recent climate change in this region.

During the last three years, the situation have been changed greatly, and many new moisture-sensitive tree-ring chronologies have been constructed (Chen et al. 2013, 2016; Zhang et al. 2015; Seim et al. 2016a, b; Opała et al. 2017). Among these studies, spruce trees have provided the primary information source about past drought/precipitation variations of Central Asia (Chen et al. 2013, 2015a, b; Zhang et al. 2013, 2015, 2016). Although previous dendroclimatic studies revealed that the tree-ring width variations of juniper trees in Central Asia can record drought events, only a few studies carried out to develop precipitation/drought reconstructions from juniper tree-ring records (Esper et al. 2001; Chen et al. 2016; Seim et al. 2016a).

Here, we present a 451-year annual drought reconstruction for the low-elevation juniper forest region near the Toktogul Reservoir in the western Tien Shan of north-western Kyrgyzstan. The reconstruction is based on a tree-ring width chronology developed from long-living turkestan juniper (*Juniperus turkistanica* Kom.). We used this drought reconstruction to examine interannual to decadal moisture variations during the pre-instrumental period. Additionally, our reconstruction was compared to neighbouring drought reconstructions in order to unravel the spatio-temporal moisture variability in Central Asia. Finally, using the drought records, we explore linkages between drought variation and the historical events of Central Asia over the past five centuries.

10.2 Data and Methods

10.2.1 Study Area

The sampling area (41° 34'N, 72° 32'E, 795–820 m a.s.l.) is situated within a 40 km radius of the Toktogul dam near the Naryn River within the western Tien Shan range (Fig. 10.1). Turkestan juniper trees typically grow in an open canopy woodland

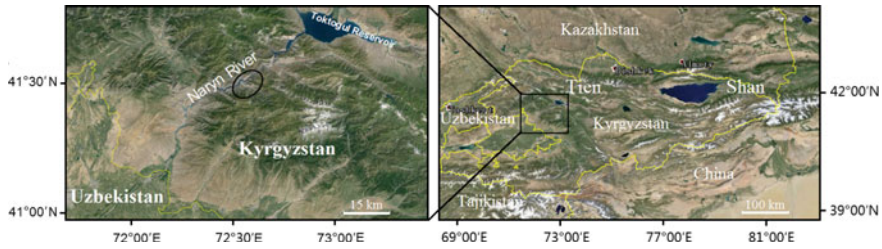


Fig. 10.1 Location of the sampling site (ellipse), the study area (square), and Naryn River

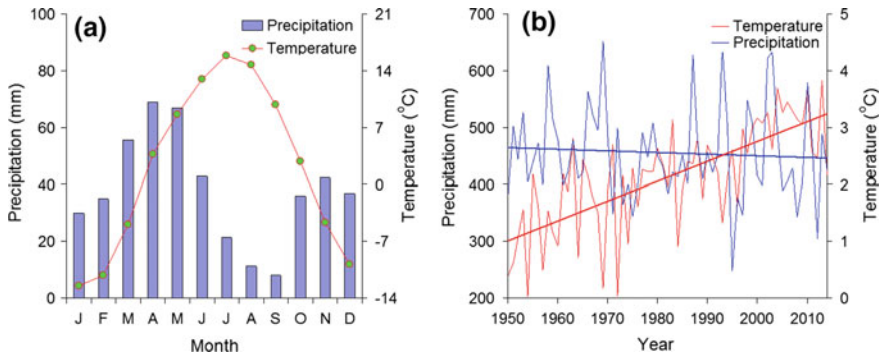


Fig. 10.2 **a** Climograph of mean monthly temperature and total monthly precipitation for our study area (1950–2014). **b** Annual average temperature and total precipitation for our study area (1950–2014)

induced by the semiarid continental climate conditions in the region. Many Turkestan juniper trees are growing on stone cliffs of the Naryn River valley, in elevations between 800 and 950 m a.s.l. Based on monthly CRU (Climatic Research Unit, Harris et al. 2014) climate data, the climate of the Naryn River valley is characterized by cool summers and cold winters (Fig. 10.2a), with average January temperatures of $-12.5\text{ }^{\circ}\text{C}$ and average July temperatures of approximately $15.8\text{ }^{\circ}\text{C}$. Average annual total precipitation is 455 mm, and approximately 44% of precipitation falls as snow from previous December to current March. Just 18% of annual total precipitation falls during the summer and early autumn (June–September). Annual mean temperatures showed a significant upward trend (Fig. 10.2b).

10.2.2 Tree-Ring Width Chronology Development

To develop the drought reconstruction for this area, samples were collected during the autumn 2013 and 2015. 45 juniper trees were cored from stone cliffs along the Naryn River valley with increment borers. Two cores of opposite sites were collected per

tree, in order to cope with growth asymmetries. After mounted and sanded, the annual widths of cores were measured with a TA Unislide Measurement System (Velmex Inc., Bloomfield, New York) at 0.001 mm precision. The quality of cross-dating was examined with the computer soft COFECHA (Holmes 1983). After trends not related to climate change removed with the negative exponential curve, the detrended tree-ring series were used to develop the standard (STD) and residual (RES) chronologies with the computer software ARSTAN (Cook 1985). Due to the sample size decreases in the early period of the chronology, the expressed population signal ($EPS > 0.85$) was used to truncate the tree-ring width chronology due to a weaker coherence of the individual tree-ring width series (Wigley et al. 1984).

10.2.3 Statistical Analysis

Due to the lack of continuous observation data in this region, monthly CRU (Climatic Research Unit) average temperature, total precipitation (1950–2014, Harris et al. 2014) and Standardised Precipitation-Evapotranspiration Index (SPEI, Vicente-Serrano et al. 2010) gridded data (averaged over $41^{\circ} 30' - 43^{\circ} N$, $72 - 73^{\circ} E$) for 1950–2013 were used in this study. Based on these data we used Pearson's correlation to unravel the climate sensitivity of our juniperus tree-ring width chronology. For that purpose, we consider the climate elements of the previous ('p') and current ('c') growing season (from previous July to current September).

Once the predictand with highest explanatory power was selected, the linear regression model was developed and applied for the reconstruction. SPEI data from 1951–1981 were used for verification and from 1982–2010 for calibration. Verification statistics included the sign test (ST), coefficient of efficiency and the reduction of error (RE) (Cook and Kairiukstis 1990). In this study, the wet and dry periods were determined if the 20-year low-pass values were lower or higher than the mean value from 1565 to 2015 continuously for more than 10 years. To demonstrate the geographical representation of our drought reconstruction, we computed correlations of our drought reconstruction with the SPEI dataset by the KNMI climate explorer (<http://climexp.knmi.nl>) for the common period (1951–2013). Toktogul Reservoir ($41^{\circ} 30' N$, $72^{\circ} 22' E$, 700 m a.s.l.), located in the Jalal-Abad Province of Kyrgyzstan, is the largest of the reservoirs on the path of the Naryn River. It was created in 1976 after construction work lasting 14 years on a dam to flood the Kementub Valley. To establish links of our drought reconstruction with water resource availability and the related historical processes in Central Asia, correlations of our SPEI reconstruction with the streamflow series of Naryn River from the hydrological station of Toktogul Reservoir were conducted during the period 1951–1995. In addition, we used a superposed epoch analysis (SEA, Haurwitz and Brier 1981) to determine the resilience of juniper growth under extreme dry climate conditions.

10.3 Results

10.3.1 Tree-Ring Width Chronology Response to Climate and SPEI Reconstruction

The running EPS value is higher than 0.85 from 1565, indicating a significant coherence among the individual tree-ring width time series during CE 1565–2015 (Fig. 10.3). Thus, we use the chronologies spanning the period 1565–2015 to develop the SPEI reconstructions. The correlation analysis indicated the standard chronology were positively correlated with monthly total rainfall in previous July, October and December, and current February–April, July–August at the 95% confidence level. The standard chronology was significantly linked with monthly mean temperature in previous July–August, December–February, and current May, July at the 95% confidence level (Fig. 10.4). Higher positive correlations were found between the standard chronology and SPEI. Similar significant correlations were found between the residual chronology and climate factors. After screened the relationship between seasonally averaged climate factor and the tree-ring chronologies, the standard chronology and mean $P_{\text{July-C}_{\text{May}}}$ SPEI consistently showed the highest correlation ($r = 0.64$, $p < 0.01$, $n = 63$). Meanwhile, high correlation ($r = 0.70$, $p < 0.01$, $n = 63$) between the residual chronology and mean $P_{\text{October-C}_{\text{September}}}$ SPEI was also revealed.

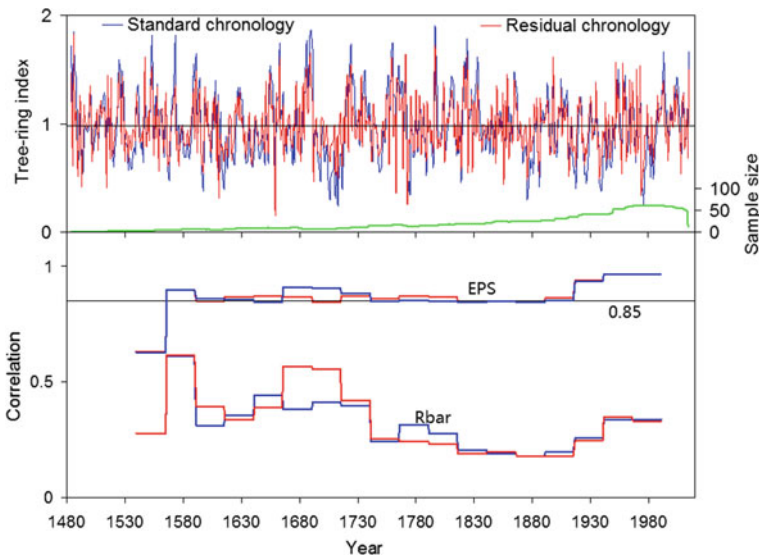


Fig. 10.3 The standard and residual chronologies (1484–2015), EPS and Rbar statistics

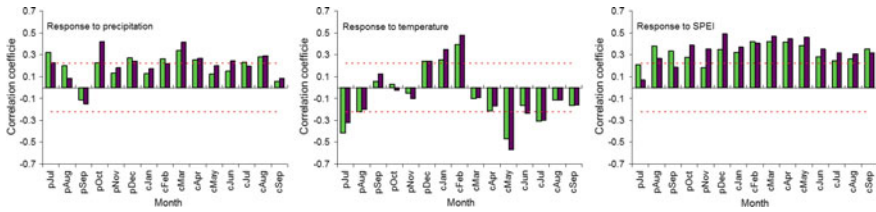


Fig. 10.4 Correlations of the chronologies with the monthly total precipitation, average temperature and SPEI during the common period (1950–2014 and 1950–2013). The dotted lines represent significant variables ($p < 0.05$)

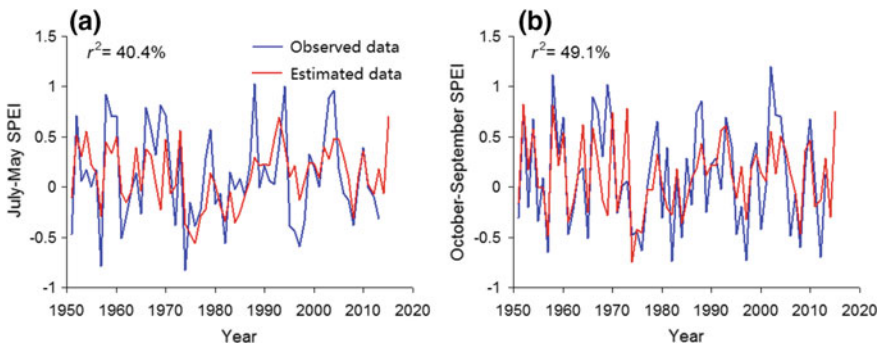


Fig. 10.5 **a** Comparison of the observed and reconstructed $P_{July-C_{May}}$ SPEI for northwestern Kyrgyzstan from 1951 to 2015. **b** Comparison of the observed and reconstructed $P_{October-C_{September}}$ SPEI for northwestern Kyrgyzstan from 1951 to 2015

Using the standard and residual chronologies as predictor, the linear regression models ($Y = 0.89STD - 0.786$ and $Y = 1.069RES - 0.963$) were designed to develop the mean July–May and $P_{October-C_{September}}$ SPEI reconstructions. Figure 10.5 shows that the SPEI reconstructions simulate the actual SPEI series very well. The two SPEI reconstructions could explain 40.4 and 49.1% of the instrumental SPEI variance over the calibration period from 1951 to 2013, respectively. Results of the split calibration-verification test showed that the values of RE and coefficient of efficiency were positive), indicating the validity of our SPEI reconstructions (Table 10.1). The results of sign test were both significant at the 0.05 level. These results revealed that the two reconstruction models are suitable for the SPEI reconstruction. Based on the standard and residual chronologies, we developed the two SPEI reconstructions back to 1565. The reconstructions exhibited considerable fluctuations on annual and decadal scale. We used the standard version of the SPEI reconstruction in the following analysis, which retains low and high-frequency signals.

Table 10.1 Verification and calibration statistics for the drought reconstruction models of north-western Kyrgyzstan

	Calibration (1982–2013) RES/STD	Verification (1951–1981) RES/STD	Calibration (1951–1981) RES/STD	Verification (1982–2013) RES/STD
r	0.74/0.59	0.71/0.68	0.71/0.68	0.74/0.59
r^2	0.55/0.35	0.50/0.46	0.50/0.46	0.55/0.35
RE		0.47/0.45		0.50/0.34
Coefficient of efficiency		0.45/0.43		0.49/0.31
Sign test		$(24^+/7^-)/(25^+/6^-)$		$(25^+/7^-)/(24^+/8^-)$
Sign test of the first difference		$(25^+/5^-)/(23^+/7^-)$		$(24^+/7^-)/(25^+/6^-)$

10.3.2 The Drought Characteristics of Northwestern Kyrgyzstan

The SEPI reconstruction provided the long-term background to evaluate regional drought variations over the past 451 years (Fig. 10.6). The SPEI reconstruction showed that dry periods prevailed in the 1577–1586, 1598–1625, 1632–1651, 1669–1678, 1695–1719, 1743–1753, 1772–1792, 1838–1851, 1870–1888, 1911–1950 and 1971–1987. In contrast, the intervals the 1567–1576, 1587–1597, 1652–1668, 1679–1694, 1720–1742, 1754–1771, 1793–1837, 1819–1837, 1852–1869, 1889–1910, 1951–1970 and 1988–2015 were relatively wet. The 10 most extreme dry/wet years and 10 wettest/driest decades in northwestern Kyrgyzstan were summarized in Table 10.2. Spatial correlation analyses indicated that actual and reconstructed SPEI linked significantly with the gridded SPEI and exhibit similar patterns during the period 1951–2013, albeit the signal strength of the latter is relatively low (Fig. 10.7). Figure 10.8 shows the SEA results based on the list of 10 most extreme dry years, and reveals a statistically significant ($p < 0.01$) reduction in SPEI is indicated happening in the same year as extreme events, and the extreme dry events may be persisted for 5-years.

10.4 Discussion

10.4.1 Comparisons with Other Drought Reconstructions

The developed SPEI reconstructions shows strong annual and decadal coherency to neighbouring moisture sensitive chronologies. A January–May Palmer Drought Severity Index (PDSI) reconstruction has been developed from the spruce-dominated

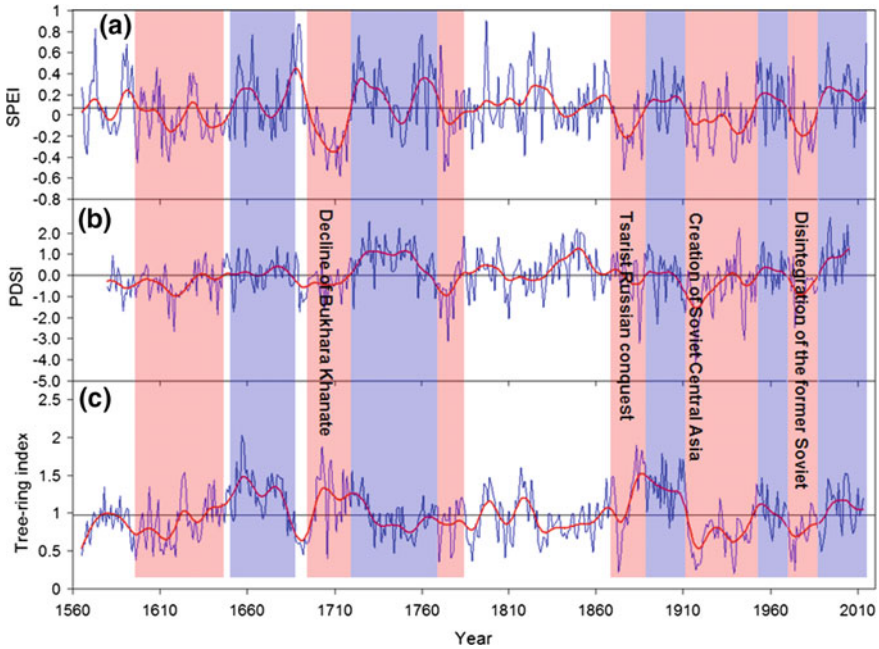


Fig. 10.6 Comparison between the reconstructed SPEI and the tree-ring records from vicinity. **a** Authors’ reconstructed SPEI (previous July to current May) in this text; **b** January–May PDSI reconstruction for the spruce-dominated area of eastern Tien Shan by Chen et al. (2013); **c** A moisture-sensitive tree-ring width series of juniper trees from northern Tajikistan (Chen et al. 2016); Dry (wet) periods are emphasized in red (blue), respectively. To emphasize low-frequency variations, all series were smoothed with a 20-year low-pass filter

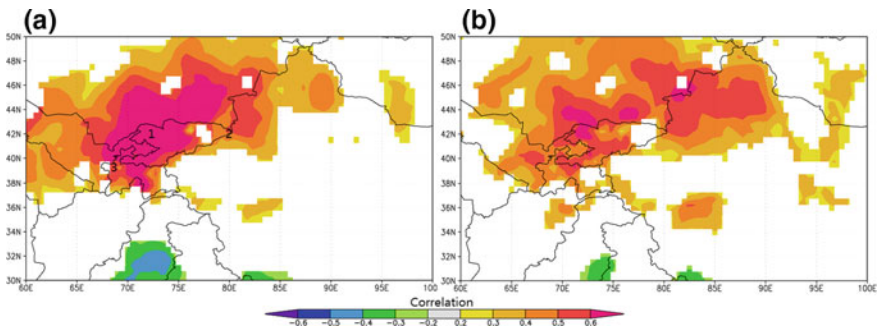
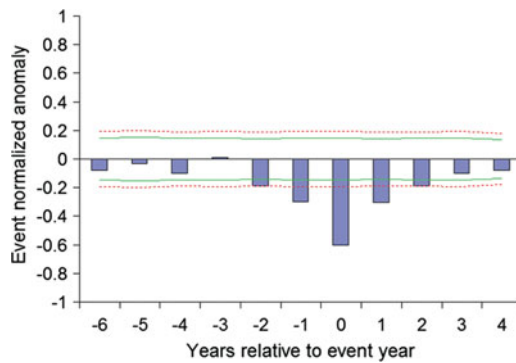


Fig. 10.7 Spatial correlation fields of instrumental **a** and reconstructed **b** mean $P_{July-C_{May}}$ SPEI for northwestern Kyrgyzstan with regional gridded $P_{July-C_{May}}$ SPEI for the period 1951–2013. The numbers 1, 2 and 3 denote the tree-ring sites of northwestern (This study) and eastern (Chen et al. 2013) Kyrgyzstan, and northern Tajikistan (Chen et al. 2016)

Table 10.2 Rankings of the dry/wet years and periods for northwestern Kyrgyzstan

10 most extreme years				10 wettest and driest decades			
Year	Driest	Year	Wettest	Year	Driest	Year	Wettest
1713	-0.58	1797	0.91	1710	-0.27	1720	0.36
1976	-0.56	1690	0.87	1700	-0.23	1680	0.32
1773	-0.53	1689	0.87	1870	-0.18	1760	0.32
1706	-0.53	1573	0.83	1940	-0.15	1820	0.29
1876	-0.53	1824	0.80	1610	-0.14	1990	0.25
1711	-0.51	1686	0.78	1910	-0.10	1730	0.23
1775	-0.48	1663	0.77	1970	-0.08	1950	0.22
1975	-0.46	1760	0.77	1640	-0.07	2000	0.22
1597	-0.45	1724	0.76	1980	-0.07	1830	0.21
1939	-0.45	1691	0.71	1770	-0.07	1660	0.20

Fig. 10.8 Results of superposed epoch analysis (SEA) testing the impact of extreme dry years. The bold and dotted lines indicate the 95 and 99% significance level, respectively



area of eastern Tien Shan, eastern Kyrgyzstan and China (Chen et al. 2013), and provided a chance to validate our drought reconstruction. Correlation between Chen et al. (2013) and this study, computed over the period 1580–2005 are 0.22 ($p < 0.001$), and increase to 0.41 ($p < 0.001$) after 20-year smoothing, respectively. Our SPEI reconstruction shows high similarities with the drought series in eastern Tien Shan (Chen et al. 2013) (Fig. 10.7). The comparison reveal that regional dry conditions during 1598–1646, 1695–1719, 1774–1785, 1870–1888, 1911–1950 and 1971–1987, and wet conditions during 1651–1690, 1720–1773, 1889–1910, 1951–1970 and 1988–2005 found in eastern and western Tien Shan, Kyrgyzstan. Some extremely dry events of the spruce-dominated area (e.g. 1774–1775, 1885–1886, 1917–1919, 1974–1976) also found in the western Tien Shan.

Further west, the study showed that tree-ring widths of juniper trees of northern Tajikistan were also sensitive to $P_{\text{August}}-C_{\text{July}}$ drought variations (Chen et al. 2016). The period 1850 to 2005 appears to coincide with similar dry/wet periods in Tien Shan. In particular, juniper and spruce series both show an upward trend at the period 1987–2015, suggesting a consistent wetting trend in Central Asia. However, some

divergences existing in the tree-ring records from spruce-dominated and juniper-dominated areas during 1565–1850 that is supposed to be associated to small scale climate variations.

10.4.2 Current and Historical Drought Perspectives

The wetting trend since 1980s has raised the concerns about water resource variation and possible future climate change of Central Asia (Shi et al. 2007). Understandably, this consistently wetting trend, especially in lowland areas, is of advantage to social and economic development and ecology of Central Asia. Nevertheless, the drought risk reduction strategies are still prominent topics for Central Asian countries. The comprehensive drought information from the SPEI reconstruction reveals the natural drought variations of northwestern Kyrgyzstan over the past centuries. For example, the 1970s drought likely included the driest years of the last 451 years, but the drought periods (e.g., 1710s and 1870s) in the pre-instrumental period were probably drier than any in the instrumental SPEI record (Table 10.2). Similar to recent wet period with wet years (e.g., 1993 and 2015), many wet periods and years found in the 451-year chronology, but there are few wet periods lasted more than 40 years in the past 451 years. Therefore, the recent wet period and how to deal with the possible dry period are need to further study.

In history, irrigated agriculture which relies on water resources was always the basic social economical engine in Central Asia (McKinney 2004; Clarke et al. 2005). Since Naryn River is an important water resource for the Fergana Basin, which is the most densely populated area in Central Asia, fluctuations in drought and streamflow can have serious geopolitical consequences (White et al. 2014; Duishonakunov et al. 2014). Correlations of our SPEI reconstruction with annual and highest monthly streamflow series of Naryn River, calculated over the 1951–1995 common period are 0.60 and 0.64 ($p < 0.01$), respectively (Fig. 10.9). This significant positive correlation supports the linkage of regional drought variation with streamflow and agricultural production. Meanwhile, many severe drought events lasted a long time (Fig. 10.8) and have had more profound impacts on the peoples of central Asia over the past several centuries. From the historical perspective, some drought periods in northwestern Kyrgyzstan correspond well with the historical events of Central Asia. During the prolonged drought period 1695–1719, the national strength of Bukhara Khanate was weaken consistently, and led to the division of the khanate (Roudik 2007). The 1876–1878 drought events and the dry period 1870–1888 from our SPEI reconstruction matches the turbulent period 1865–1877. During this period, the Tsarist Russian conquest of Central Asia was completed (Soucek 2000; Kharin 2002; Kilavuz 2007), and the bad climate weaken the resistance of the Feudal khanates, which were mainly agricultural and accelerated the conquest process, and many local inhabitants left the Fergana Basin for China, and led to the war in Xinjiang (Kim 2004). The 1917–1918 drought events from our SPEI reconstruction correspond to the dry decade 1910s which some official documents of local government report low pre-

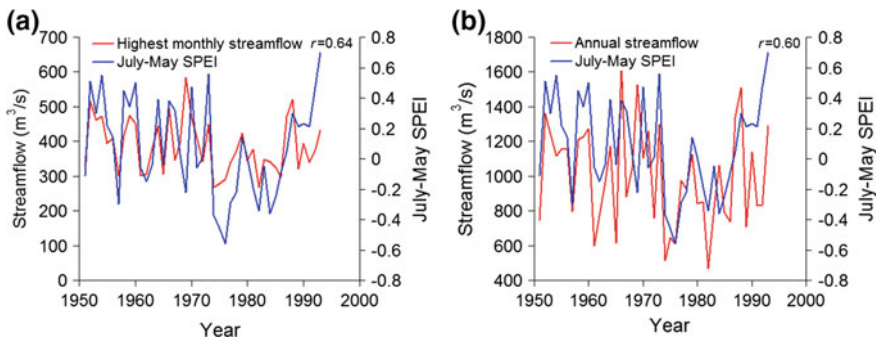


Fig. 10.9 **a** Comparison of the highest monthly streamflow and reconstructed $P_{\text{July-C}_{\text{May}}}$ SPEI for northwestern Kyrgyzstan from 1951 to 1995. **b** Comparison of annual streamflow and reconstructed $P_{\text{July-C}_{\text{May}}}$ SPEI for t northwestern Kyrgyzstan from 1951 to 1995

precipitation and bad agricultural yields (Allworth 1994; Esper et al. 2001; Chen et al. 2013). The feudal khanates at the lower reaches eventually perished, and began to sovietize Central Asia. Before the disintegration of the former Soviet Union, the study region experienced a dry period since 1970s (Lamb 2002).

10.5 Conclusions

We developed the standard and residual chronologies from the low-elevation juniper forest of northwestern Kyrgyzstan, where previously drought reconstruction were missing. Standard and residual chronologies are both sensitive to regional drought variation. Based on standard chronology, a SPEI reconstruction was developed over the past 451 years. Spatial correlation fields revealed that our SPEI reconstruction can represent regional moisture variability over northwestern Kyrgyzstan. Comparison with the drought reconstruction from the spruce-dominated area of eastern Tien Shan shows high coherency. The SPEI reconstruction also shows a strong positive response to streamflow variation of Naryn River, and reveals that some significant drought events are linked with regime change and catastrophic historical during the past 451 year. The spatiotemporal divergence of drought variation between spruce-dominated and juniper-dominated areas was also found, and may reflect the impacts of regional climate features.

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