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Climate of the Past Discussions

# A 424-year tree-ring based PDSI reconstruction of *Cedrus deodara* D. Don from Chitral HinduKush Range of Pakistan: linkages to the ocean oscillations

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**Abstract.** Currently, the rate of global warming has led to persistent drought patterns. It is considered to be the preliminary reason affecting socio-economic development under the background of dynamic forecasting of water supply and forest ecosystems in West Asia. However, long-term climate records in the semi-arid Chitral mountains of northern Pakistan are seriously lacking. Therefore, we developed a new tree-ring width chronology of *Cedrus deodara*

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spanning the period of 1537-2017. We reconstructed the March-August Palmer Drought Sensitivity Index (PDSI) for the past 424 years back to A.D. 1593. Our reconstruction was featured with nine dry and eight wet periods 1593-1598, 1602-1608, 1631-1645, 1647-1660, 1756-1765, 1785-1800, 1870-1878, 1917-1923, 1981-1995, and 1663-1675, 1687-1708, 1771-1773, 1806-1814, 1844-1852, 1932-1935, 1965-1969 and 1996-2003, respectively. This reconstruction is consistent with other dendroclimatic reconstructions in west Asia, confirming its reliability. The analysis of the Multi-Taper Method and wavelet analysis revealed drought variability at periodicities of 2.1-2.4, 3.3, 6, 16.8, and 34-38 years. The drought patterns could be linked to the broad-scale atmospheric-oceanic variability such as El Niño-Southern Oscillation (ENSO), Atlantic Multi-decadal Oscillation (AMO) and solar activity. In terms of current climate conditions, our findings have important implications for developing drought-resistant policies in communities on the fringes of Hindu Kush mountain Ranges in northern Pakistan.

**Keywords:** Tree rings, Growth-climate response, Drought variability, ENSO, dendroclimatology, the broad-scale atmospheric-oceanic variability

## 1. Introduction

Numerous studies have shown that the intensity and frequency of drought events have increased due to rapid climate warming (Stocker et al., 2013; IPCC, 2013). The apparent drought has had serious adverse effects on social, natural, and economic systems (Ficklin et al., 2015; Yu et al., 2018; Yao et al., 2015). Global drought is considered to be the most destructive climate disaster that has caused billions of dollars in worldwide loss (Zhu et al., 2009; Seneviratne et al., 2012). The accelerated rate of warming changes the regional hydrological regimes, leading to an unsustainable water supply (Hellmann et al., 2016; Wang et al., 2017). It is not only critical for

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agricultural production, but also leads to forest mortality, vegetation loss (Martínez-Vilalta and Lloret, 2016), increases risk of wildfires (Turner et al. 2015; Abatzoglou and Williams 2016), and affects social stability and well-being of the people. The degradation of grassland and loss of livestock caused by drought will eventually affect the lifestyle of nomadic peoples, especially in high-altitude forested areas (Shi et al., 2019; Pepin et al., 2015; Wu et al., 2015). In high altitude, arid and semi-arid areas, forest growth is sensitive to climate change, so there is a need to understand more about the long-term drought regimes of the past.

Northern Pakistan belongs to the Indus civilization and occupies an important position in the history of drought-related culture. In addition, Pakistan has a semi-arid climate, and its agriculture economy is most vulnerable to drought (Kazmi et al., 2015; Miyan, 2015). The prolonged drought from 1998 to 2002 reduced the production from 80% to 60% (Ahmad et al., 2004). Trees in the Chitral, Hindu-Kush Himalayan (HKH), northern Pakistan are important for climate reconstruction because of their distinct and complex topography, high altitudes, inadequate availability of metrological record, shadow precipitation (out of summer monsoon reach), and unique precipitation seasonality (Khan et al., 2010). Meanwhile, a large hydroelectric reservoir in Pakistan, such as Tarbela Dam, is built on the Upper Indus River (UIB), which receives water in the form of melting glaciers from HKH (Rao et al., 2018; Rashid et al., 2018). In addition, the Chitral forest, an essential archive of dendroclimatic research, has been heavily felled. According to the Pakistani Government, only 4% of the country is still forested, compared with 2% reported by the Food and Agriculture Organization. In northern Pakistan, there is little research on the dendroclimatology (Treydte et al. 2006), and instrumental climate records are inadequate in terms of quality and longevity. Climate reconstruction is urgently needed in northern Pakistan in order to understand long-term climate change, expand climate record, develop forest management strategies, and understand the impact of past climate change. Researchers used multiple proxies, including ice cores, speleothems, lake sediments, and historical documents and tree rings to reconstruct past short-term or long-term climate change. Among them, tree growth is susceptible to evapotranspiration, soil and air temperature, air humidity, and soil moisture (Paudel and Vetaas, 2014). Therefore, the study of tree rings is highly recommended for dendroclimatic studies.

Meanwhile, tree rings were widely used in long-term paleoclimatic reconstructions and forecasting future climate because of their accurate dating, high resolution, wide distribution, easy access, long time series, and abundant environmental information recorded (Zhang et al., 2016; Chen et al., 2019; Shi et al., 2018; Klippel et al., 2017; Esper et al., 2016)

The intensity and frequency of the drought trend are very complex in HKH, and there is no manifest measuring tool to compute how long the drought period might persist. Climate uncertainty complicates the situation, for example, whether the drought trend is increasing or decreasing (Chen et al. 2019). Most studies believe that the wetting trend in HKH is going to increase in current decades (Treydte et al. 2006). However, some extreme drought events in the region are very severe and persistent (Gaire et al., 2017). Little work had been done to examine the linkages of the drought trend and driving forces (Gaire et al., 2017; Cook et al., 2003). The Palmer drought sensitivity index (PDSI) is a preferred index for reconstructing past climate records (Ficklin et al. 2015; Schrier et al 2013). PDSI has been widely used in the world, including Australia (O'Donnell et al., 2018), New Zealand (Palmer et al., 2015), Africa, Europe, and Asia (Cook et al., 2015; Ficklin et al., 2015, Tejedor et al., 2017; Steinschneider et al., 2018). In the United States, federal and state agencies also use PDSI for water resources management (Werick et al., 1994)

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In this study, we collected drought-sensitive tree-ring cores of *Cedrus deodar* from the upper and lower Chitral, Hindu-Kush Himalayan (HKH) region of Pakistan. These tree rings have a good potential for dendroclimatic study (Yadav, 2013). Then, March-August PDSI was reconstructed for the past 400 years to examine the climatic variability and driving forces. To verify its reliability, we compared our reconstructed PDSI with other available paleoclimatic records near our research area. The intensity and drought mechanism in this area were also discussed. This will be the first time that the drought index has been reconstructed in northern Pakistan and is considered to be a baseline for more tree-ring reconstruction in Pakistan.

## 2 Material and Methods

### 2.1 Study area

We conducted our research in the Chitral, Hindu-Kush (HK) Mountains of northern Pakistan (35.36° N, 71.48° E, Fig. 1). Northern Pakistan is a subtropical monsoon climate. Summer is dry and hot, spring is wet and warm, and in some high altitudes it snows all the year round. March is the wettest month (with an average precipitation of 107 mm), while July or August is the driest (with an average precipitation of 6.3 mm). July is the hottest month (mean monthly temperature 36 °C), and January is the coldest (mean monthly temperature -0.8 °C) (Fig. 2). The soil at our sampling sites is acidic, with little variation among stand of forest. Similarly, the soil water holding capacity ranged from 47%±2.4% to 62%±4.6%, while the soil moisture ranged from 28%±0.57% to 57%±0.49% (Khan et al., 2010). Chitral forest is mainly composed of *Cedrus deodara*, *Juglans regia*, *Juniperus excelsa*, *Quercus incana*, *Q. diltata*, *Q. baloot* and *Pinus wallichiana*. *C. deodara* was selected for sampling because of the high dendroclimatic value (Khan et al., 2013).

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Climate data such as monthly precipitation and temperature obtained from the meteorological station of Chitral, northern Pakistan during the period of 1965-2013. PDSI downloaded from the datasets of nearest grid point ($35.36^{\circ}$ N, $71.48^{\circ}$ E) through Climatic Research Unit (CRU TS.3.22, $0.5^{\circ}$ latitude × $0.5^{\circ}$ longitude). The most common reliable period spanning from 1960-2016 was used (http://climexp.knmi.nl/) for dendroclimatic studies (Harris et al., 2014; Yadav et al., 2014; Shekhar, 2014).

## 2.2 Tree rings collection and chronology development

Tree-ring cores collected in Chitral forest from *Cedrus deodar* trees, located in northern area of Pakistan. To maintain the maximum climatic signals contained in tree rings, undisturbed open canopy trees were selected. One core per tree at breast height (~1.3 m above ground) was sampled using a 5.15 mm diameter increment borer (Haglöf Sweden, Langsele, Sweden). In addition, several ring width series were also downloaded from the International Tree-Ring Data Bank from Bumburet forest and Zairat forest (https://www.ncdc.noaa.gov/paleo-search/) collected in 2006 (Fig. 1).

All tree-ring samples were first glued than progressively mounted, dried, and polished according to a set procedure (Fritts, 1976; Cook and Kairiukstis, 1990). The preceding calendar year was assigned and properly cross-dated. False rings were identified by Skeleton-plot and crossdated as mentioned in Stokes and Smiley (1968).

The cores were measured using the semi-automatic Velmex measuring system (Velmex, Inc., Bloomfield, NY, USA) with an accuracy of 0.001 mm. The COFECHA program was then used to check the accuracy of cross-dating and measurement (Holmes, 1983). All false one has been modified and the cores that didn't match the master chronology were not used to develop

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tree-ring chronology. For quality checks, the COFECHA 2002 program was used. (Holmes, 1998). The synthesized tree-ring width chronology (Fig. 3) was built by the program R (Zang and Franco, 2015). To preserve climate signals and avoid noise, appropriate detrending was introduced. Biological trends of tree growth associated with tree age were conservatively detrended by fitting negative exponential curves or linear lines (Fritts, 1976). The tree-ring chronology was truncated where the expressed population signal (EPS) was large than 0.85, which is a generally accepted standard for more reliable and potential climate signal results (Wigley et al., 1984; Cook and Kairiukstis, 1990). The mean correlation between trees (Rbar), means sensitivity (MS) and EPS were calculated to evaluate the quality of chronology (Fritts, 1976). Higher mean sensitivity and EPS were considered to be strong response to climate change (Cook and Kairiukstis, 1990).

**2.3 Statistical analysis**

Correlation analysis was conducted between tree-ring indexes (TRI) and monthly temperature, precipitation, and PDSI (from previous June to current September, collected from the nearby stations or downloaded from KNMI). The March-August PDSI was reconstructed according to the relationship between TRI and climate variables. To test the validity and reliability of our model, reconstruction was checked by the split-period calibration/verification methods subjected to different statistical parameters, including reduction of error (RE), coefficient of efficiency (CE), Pearson correlation coefficient ($r$), R-square ($R^2$), product mean test (PMT), sign test (ST) and Durban-Watson test (DWT) (Fritts, 1976). PMT is used to test the level of consistency between the actual and estimated values, taking into account signs and magnitudes of departures from the calibration average (Fritts, 1976). ST expresses the coherence between reconstructed and instrumental climate data by calculating the number of coherence and

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incoherence, which is often used in previous studies (Fritts, 1976; Cook et al., 2010). DWT is used to calculate first-order autocorrelation or linear trend in regression residuals (Cook and Pederson, 2011; Wiles et al., 2014). The RE and CE larger than zero were considered skill (Fritts, 1976; Cook and Kairiukstis, 1990).

We defined the dry or wet years of our reconstruction with the PDSI value greater than or less than the mean ±1 standard deviation. We assessed the dry and wet periods for many years based on strength and intensity.

Although there were a few reconstructions in our study area, we still compared our reconstruction with other available drought reconstructions near the study area (Treydte et al., 2006). The Multi-taper Method (MTM) was used for spectral analysis, and the Wavelet analysis was used to determine the statistical significance of band-limited signals embedded in red noise by providing very high-resolution spectral estimates that eventually give best possible option against leakage. To identify the local climate change cycle, background spectrum was used (Mann and Lees, 1996).

## 3 Results

### 3.1 Main climate limiting factors for *Cedrus deodar*

The statistical parameters of the tree-ring chronologies, including MS (0.16), Rbar (0.59), and EPS (0.94) indicated that there were enough common signals in our sampled cores, and our chronology is suitable for dendroclimatic study. According to the threshold of EPS (5 trees or EPS > 0.85), the 1593-2016 was selected as the reconstruction period to truncate the period 1537-1593 of the chronology (Fig. 3).

https://doi.org/10.5194/cp-2019-62
Preprint. Discussion started: 14 August 2019
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The TRI was significantly positively correlated with monthly PDSI ($p < 0.01$) (Fig. 4a). While it was positively correlated with precipitation in the previous October and the current February-May and significantly negatively correlated ($p < 0.001$) with precipitation in the previous September. TRI was significantly positively ($p < 0.001$) with the minimum temperature in the previous September, December, and the current year January and February (Fig.4b). Similarly, TRI was significantly negatively ($p < 0.001$) correlated with the mean maximum temperature in the previous January, October, December and the current February, March, May, and June, and significantly positively correlated with the mean maximum temperature in September.

**3.2 Reconstruction of the past drought variation in northern Pakistan**

Based on the above correlation analysis results, the March-August PDSI was the most suitable for seasonal prediction and reconstruction. The linear regression model between TRI and mean March-August PDSI for the calibration period from 1960 to 2016 was significant ($F$=52.3, $p$ <0.001, adjusted $R^2 = 0.47$, $r$ =0.69). The regression model was:

$$Y = 5.1879x - 5.676$$

Where $Y$ is the mean March-August PDSI and $x$ is the tree-ring index.

The split calibration-verification test showed that the variance explained was higher during the two calibration periods (1960-1988 and 1989-2016). Statistics of $R$, $R^2$, ST, and PMT are all significant at $p$ <0.05, indicating that the model was reliable (Table 1). In addition, the most rigorous RE and CE tests in the verification period were all positive. For the calibration period (1960-2016), the reconstruction accounted for 39.2% of the scPDSI variation (37.6 after accounting for the loss of degrees of freedom). These results made the model more obvious and robust in scPDSI reconstruction.

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The instrumental and reconstructed scPDSIs of the Hindu Kush Mountains had similar trends and parallel calibrations during short- and long-time scales in the 20$^{th}$ century (Fig 5). However, the reconstructed scPDSI did not fully capture the magnitude of extremely dry or wet conditions.

### 3.2 The drought regime in the Chitral Mountain, northern Pakistan for the past 424 years

Fig. 5 showed the dry and wet years of the past 424 years (1593-2016) in the Chitral Mountain in northern Pakistan. The dry periods were recorded in 1593-1598, 1602-1608, 1631-1645, 1647-1660, 1756-1765, 1785-1800, 1870-1878, 1917-1923, and 1981-1995. Similarly, the wet periods were recorded in 1663-1675, 1687-1708, 1771-1173, 1806-1814, 1844-1852, 1932-1935, 1965-1969, and 1996-2003. Spectral analysis showed that the historical PDSI changes in the Hindukush Mountains showing several significant (95% or 99% confidence level) with periods at 33-38 (99%), 16.8 (99%), 2-3 (99%) years, corresponding to significant periodic peaks (Fig. 7)

## 4 Discussion

### 4.1 Drought variation in Chitral HinduKush Range of Pakistan

The growth-climate relationship revealed the positive and negative influence of precipitation and summer temperature on growth. It means that water availability (PDSI) is the main limiting factor affecting the growth of *C. deodara*. Singh et al. (2006) reported that the previous October precipitation limited the growth of *C. deodara*, while Ahmed et al. (2011) found no such effect. Except for last August, November, and current September, maximum temperature has a negative impact on the growth of *C. deodara*, while the minimum temperature

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does not. These results suggest that moisture conditions in April-July are critical to the growth of *C. deodar* in the study area (Hussain et al., 2007; Khan et al., 2013; Borgaonkar et al., 1996). Remarkably, Chitral does not receive monsoon rains. That's why it is hard to understand how trees respond to different moisture trends.

Here we developed a 467-year (1550-2017) of tree ring chronology of *C. deodara*, and reconstructed the 424-year (1593-2016) drought variability of the Chitral Hindukush Range in northern Pakistan. The point years, 2002, 2001, 2000, 1999, 1985, 1971, 1962, 1952, 1945, 1921, 1917, 1902 and 1892, were recorded in our tree-ring record. Among them, 2001, 1999, 1952, and 1921 were identified by previous studies (Khan et al., 2013; Ahmed et al., 2010; Zafar et al., 2010; Esper and Genrt, 2001; Esper et al., 2001; 2002, Ahmed et al., 2009b, 2010a, 2010b; Khan et al., 2008; He et al., 2018). Sigdel and Ikeda (2010) reported that droughts occurred in 1974, 1977, 1985, 1993, and the winter of 2001 and the summers of 1977, 1982, 1991, and 1992. Our PDSI reconstruction fully captured the widespread drought in Pakistan, Afghanistan, and Tajikistan in 1970-1971 (Yu et al., 2014). The above drought has disrupted the people's daily life, leading to food and water shortages and livestock losses in high altitude areas (Yadav et al., 2017; Yadav and Bhutiyani, 2013; Yadav, 2011). This drought may also be due to the failure of Western disturbance precipitation (Hoerling et al., 2003).

The results were compared with adjacent studies for validation and reliability. Our reconstruction captured a range of climate changes mentioned in other studies (Gaire et al., 2018; Chen et al. 2019; Yu et al., 2014, Ahmad et al., 2004). Our dry periods (1981-1987, 1870-1875 to 1761-1764) were consistent with the results of Chen et al. (2019). The dry period 1645-1631 also reported in tree-ring based drought variability of Silk Road (Yu et al., 2014). Most notably, three mega drought events in Asian history (Gaire et al., 2018; Yadav, 2013; Panthi et al., 2017),

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Preprint. Discussion started: 14 August 2019
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namely, the Strange Parallels drought (1756-1768), the East India drought (1790-1796) and late Victorian Great Drought (1876 to 1878) was clearly recorded in our reconstructed PDSI. Based on the above results, drought changes in Northern Pakistan and central Himalayas are closely related to large-scale ocean-atmospheric circulation and synchronous in western Asia (Gaire et al., 2018). The driest period of 1917-1921 of our reconstruction, followed by another dry period 1784-1802, coincided with the eruption of Laki volcano (Iceland) in 1783. This could mean that widespread drought on the continent could be linked to volcanic eruptions (Chen et al., 2019). Interestingly, the wet period of 1995-2016 were very consistent with those of Yadav et al. (2017). These results suggested that the long-term continuous wets in 31 years of the past 576 years (1984-2014) may have increased the mass of glaciers in the northwest Himalaya and Karakoram (Cannon et al., 2014; Garg et al., 2014). The devastating floods of July 2010 was also captured by our reconstruction, affecting about a fifth of Pakistan (20 million peoples) (Yaqub et al., 2015). Therefore, we speculate that the size of the Hindukush glacier and the mass of glaciers near to our study areas will continue to increase if it continues to get wet.

**4.2 The linkage of drought variation with the ocean oscillations**

The results of wavelet and MTM analysis indicated that the low and high-frequency periods of drought in northern Pakistan may teleconnect with the large-scale climate oscillation. The high frequency of drought cycle (2.1-3.3 years) may be associated with the El Niño-Southern Oscillation (ENSO) (Van Oldenborgh and Burgers, 2005). The middle-frequency cycle (16 years) may be related to the solar cycle, which is similar with other studies in South Asia (Shekhar et al., 2018; Chen et al., 2019; Panthi et al., 2017). Solar activity may affect climate fluctuations in the Chitral, Hindukush ranges, northern Pakistan (Gaire et al., 2017). The low-frequency (36-38 years) may be caused by the Atlantic Multi-decadal Oscillation (AMO), which

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Preprint. Discussion started: 14 August 2019
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is the anomalies of sea surface temperatures (SST) in the North Atlantic basin. Dimri (2006) found that the precipitation surplus in winter from 1958 to 1997 was related to the significant heat loss in the northern Arabian Sea, mainly due to intensification of water vapor flow in the west and the enhancement of evaporation. As a result, large-scale changes in Atlantic temperature could also regulate western Asia's climate. Our result was supported by other dendroclimatic studies (Chen et al., 2019; Sano et al., 2005). The AMO pattern is robust throughout the study area. Precipitation in Mediterranean, Black sea (Alena et al., 2019; Hatwar et al., 2005), and parts of northern Pakistan showed an upward trend from 1980 to 2010, but the precipitation in the Chitral Mountains received from Winter Indian Monsoon (WID) (December-March) and the rainy shadow in summer (Khan et al., 2013). Predicting different climate cycle patterns is not easy. In addition, the flow of UIB depends on changes in the Ablation air mass (Rao et al., 2018; Rashid et al., 2018), so small changes in the Ablation mass may eventually lead to changes in water quality and quantity. The UIB is considered as a water tower in the plain (Immerzeel et al., 2010), so the Hindukush Mountains are particularly important for extending the proxy network and identifying glacier expansion.

Our drought reconstruction is very consistent with the point years and drought events recorded in other documents or proxy reconstruction. Due to reconstruction indices, species, geographical differences and other reasons, it is not completely consistent with the whole period. The drought regimes in Hindukush ranges in northern Pakistan may be linked to regional, local, and global climate change. In addition, we only studied the response of *C. deodara* to different climate change in the Chitral region, northern Pakistan. Therefore, we suggest further dendroclimatic network studies in different areas and species.

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## 5 Conclusion

Based on the significance of tree-ring width of *C. deodara*, we developed a 467-years chronology (1550-2017). Considering that EPS threshold is greater than 0.85 (> 5 trees), we reconstructed the current March-August PDSI from 1593 to 2016. Our reconstruction captured different drought changes in different time scale in the Chitral, Hindukush Mountain, Pakistan, which falls in the Indus civilization. Several studies have shown that the Indus civilization changed dramatically in history because of its unpleasant climate. Three historic megadrought events, the Strange Parallel Droughts (1756-1768) the East Indian Drought (1790-1796) and late Victorian Great Drought (1876-1878) were captured by our reconstructed PDSI. These large scale and small droughts may be caused by cold or hot weather. Our results are consistent with other dendroclimatic records, which further supports the feasibility of our reconstruction. In addition, due to a different climate change patterns in the region, we suggested to extend the different proxy networks to understand the remote teleconnection across the continent on the multi-decadal to centennial timescales to meet future climate challenges.

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**Data availability**

The reconstructed PDSI can be obtained from the supplementary file of this paper. The tree-ring width used in this paper can be download form the International Tree-ring Data Bank.

**Author contribution**

Xiaochun Wang and Sarir Ahmad initiated this idea. Sarir Ahmad and Sami Ullah collected samples in the field. Liangjun Zhu and Sumaira Yasmeen crossdated and measured the samples. Sarir Ahmad and Xiaochun Wang wrote the manuscript. Liangjun Zhu, Yuandong Zhang, and Zongshan Li revised the manuscript.

**Competing interest**

The authors declare that they have no conflict of interest.

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**Fig captions**

**Fig. 1**. Map of the weather stations (Chitral station) and sampling sites in the Chitral, HinduKush Mountains, Pakistan. The copyright is own to ArcGIS.

**Fig. 2** Monthly maximum, mean, minimum temperature (ºC) and total precipitation (mm) in the Chitral HinduKush, Mountain, Pakistan (1965-2013).

**Fig. 3** The regional tree-ring width chronology from 1550 to 2017. The gray color represents the sample depth.

**Fig. 4** Person correlation coefficients between tree-ring index of *C. deodara* and monthly total precipitation (1965-2013) and scPDSI (1960-2013) (a) and monthly maximum and minimum temperature (1965-2013) (b) from June of the previous year to September of the current year. Significant correlations ($p$<0.05) are denoted by asterisks.

**Fig. 5** The scPDSI reconstruction in the Chitral HinduKush Mountain, Pakistan. (a) Comparison between the reconstructed and actual scPDSI; (b) The variation of annual (black solid line) and 11-year moving average (red bold line) Mar-Aug scPDSI from 1593 to 2016 with mean vale ± one standard deviation (black dash lines).

**Fig. 6** Comparison of our PDSI reconstruction (a) with Treydte et al. (2006) precipitation reconstruction (tree-ring $\sigma^{13}$C) (b) in Pakistan.

**Fig. 7** The MTM spectrum analysis of the reconstructed scPDSI from 1593 to 2016. Red and green line represents the 95% and 99% confidence level, respectively. The figures above the significant line represents the significant periods of drought.

**Fig. 8** (a) Spatial correlation between Actual May-August scPDSI (1901-2017) and Actual May-August reconstructed scPDSI (1901-2017). (b) The wavelet analysis of the reconstructed

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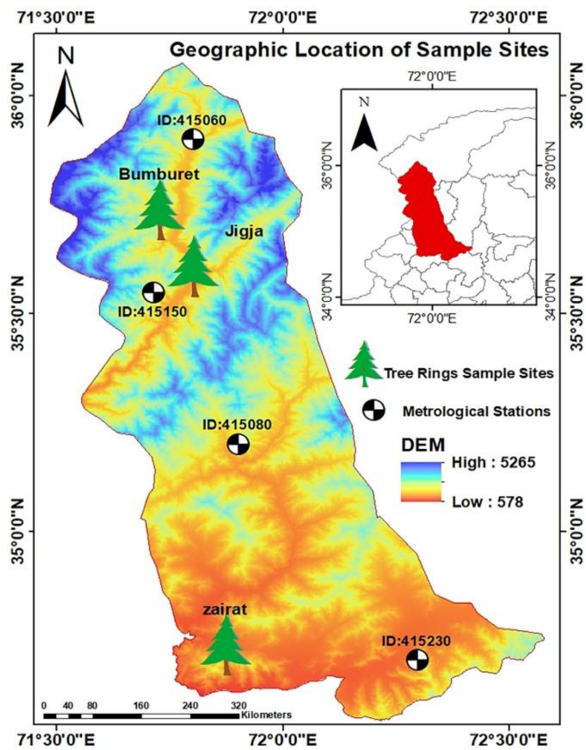
scPDSI in the Chitral HinduKush Ranges, Pakistan. The value for $p$>0.05 were masked out. The copyright is own to KNMI.

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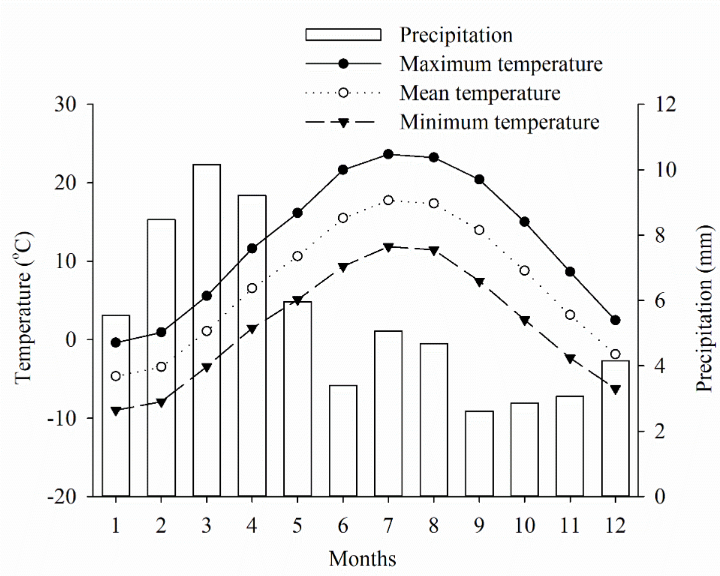


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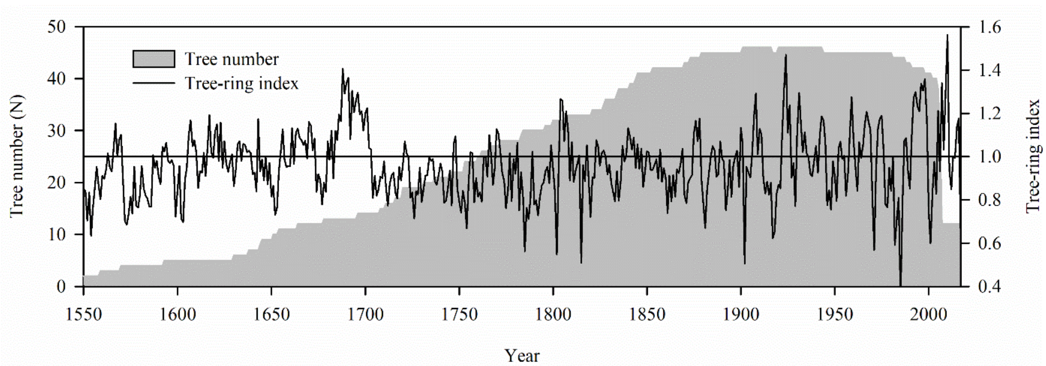


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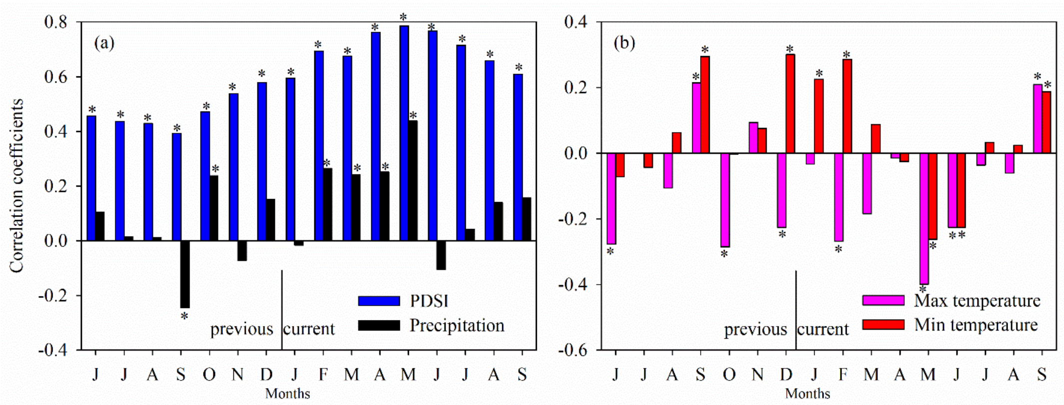


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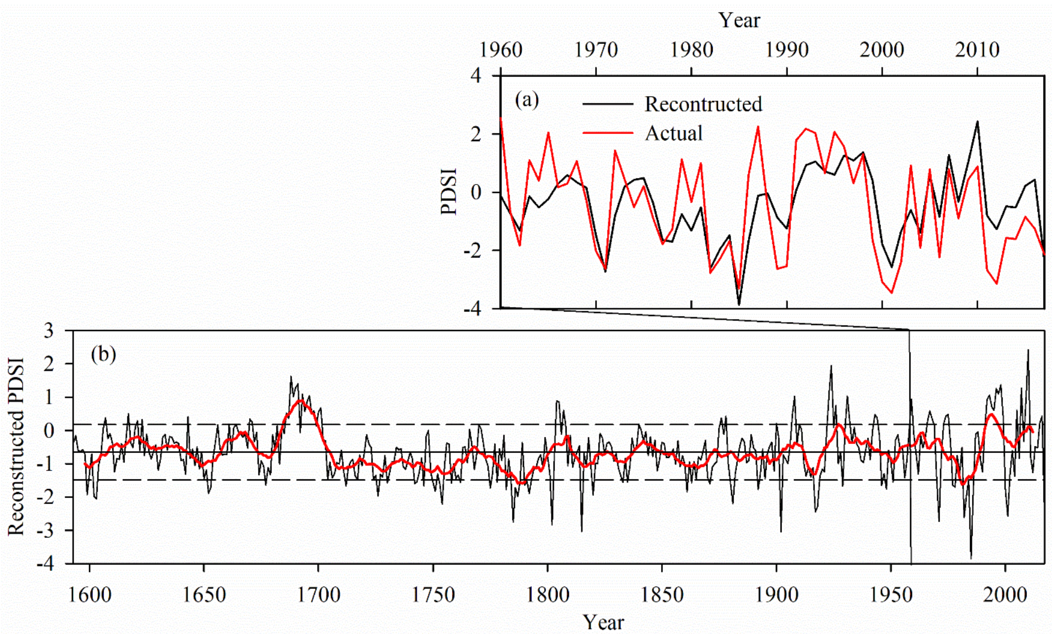


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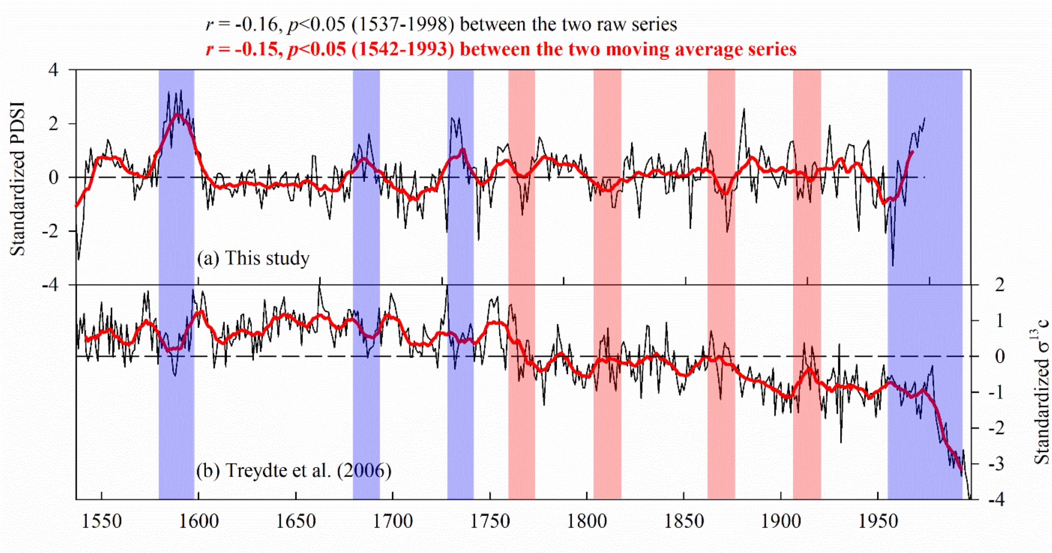


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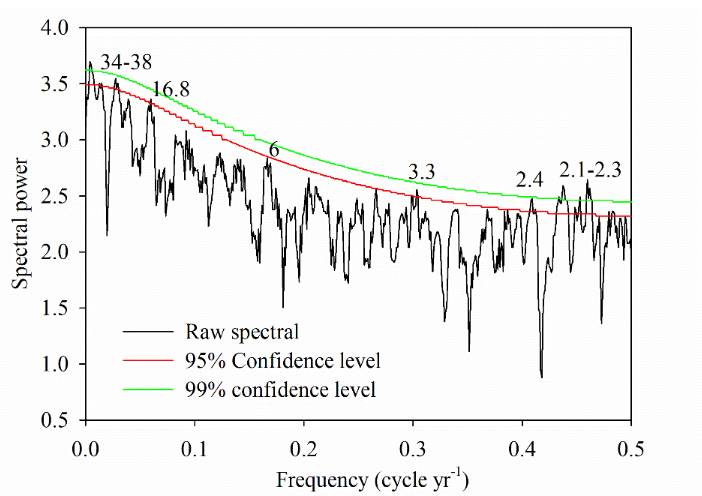

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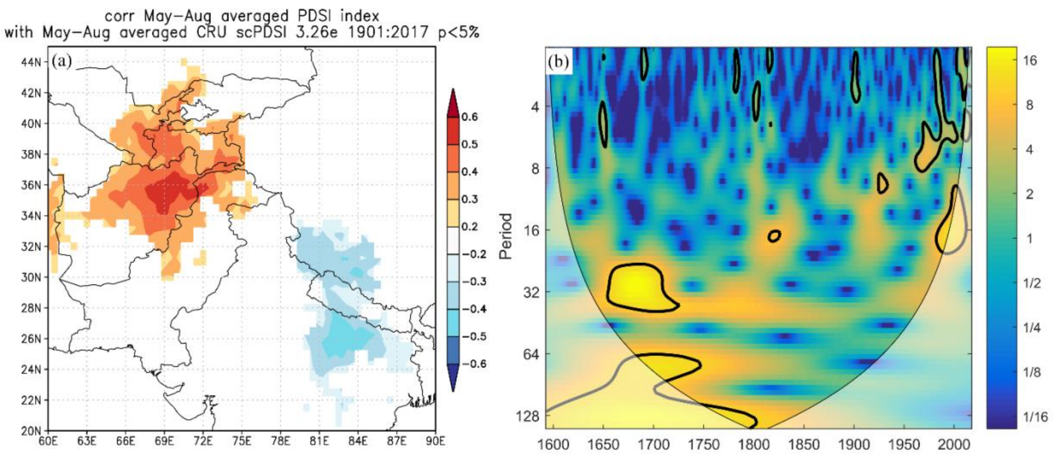


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**Table 1.** Statistics for a split calibration-verification procedure ($p$<0.001)

| Calibrations | $r$ | $R^2$ | Verification | $R^2$ | RE | CE | ST | DW | RMSE | PMT |
|---|---|---|---|---|---|---|---|---|---|---|
| 1960-2016 | 0.71 | 0.51 | - | 0.50 | 0.71 | 0.70 | (41, 15) | 1.0 | 0.33 | 10.0 |
| 1989-2016 | 0.75 | 0.56 | 1960-1988 | 0.55 | 0.61 | 0.62 | (22, 6) | 1.0 | 0.22 | 5.80 |
| 1960-1988 | 0.76 | 0.58 | 1989-2016 | 0.56 | .636 | .623 | (19, 9) | 0.98 | 0.22 | 7.42 |