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Climatic response of *'Cedrus deodara'* tree-ring width records from Jangla region of western Himalaya in India: A case study

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ABSTRACT

Cedrus deodara tree ring-width index chronology from Jangla of western Himalaya, showed significant positive relationship with Palmer drought severity Index (PDSI) and cloud cover, and negative relationship with vapor pressure, mean, maximum and minimum temperatures during spring season (March to May). The relationship indicates that rising vapor pressure/temperatures over the region might be linked with low moisture availability due to high transpiration and evaporation which caused insufficient moisture supply at root zone of the trees, thus showing adverse impact on tree growth during growing season. Moreover, the significant positive association of tree growth with the cloud cover and PDSI, showed that increasing/ decreasing CLD during growing season, might preserve the high and low moisture availability at trees root, that works as a booster to tree growth and plays the vital role in limiting of tree growth in western Himalaya. The Correlation analysis of CLD with PDSI (moisture availability) for the period 1901-2002 during spring season (March to May) indicates statistically strong correlation (r = 0.30) which is significant at 0.01% level.

Keywords: Tree ring-width, Temperatures, Percentage cloud cover, Vapor pressure, Western Himalaya.

INTRODUCTION

Tree ring-width chronological studies over western Himalaya, have been carried out by many researchers in relation to climate variability/change over south Asia (Borgaonkar et al., 1999; Bhattacharyya et al., 2006; Yadav, 2009; Yadav and Singh, 2002; Yadav et al., 2004, 2009; Singh and Yadav, 2005). They showed that tree growth is influenced by rainfall and temperature during spring season and have also shown the reliability of tree ring–width chronologies to predict the climate for several centuries back. Moreover, tree width index chronologies from high altitude sites of the western Himalaya, has also been carried out in relation to climate variability/change (Yadav et al., 2004; Singh and Yadav, 2000; Borgaonkar et al., 2009; Ram and Borgaonkar, 2013). They showed that the rising trend in tree growth might be associated with warm winter temperature, caused by sharp increase of greenhouse gases during recent few decades. Further, Borgaonkar et al., (2009) showed that the released and suppressed tree growth near snow line is linked with negative and positive snow mass balance respectively over western Himalaya.

Furthermore, the latest studies done based on tree ring width records over the Himalaya, indicated a strong significant relationship with PDSI (Cook et al., 2010; Ram, 2012, 2018; Ram and Borgaonkar, 2013, 2014 a, b, 2016, 2017). They showed the direct linkage of tree growth to the availability of moisture supply at the root zone of the trees. Also, they indicated that tree ring-width records can be gainfully utilised in predicting meteorological parameters, other than rainfall and temperature. In the present study, an attempt has been made to carry out the relationship between tree growths and several climatic variables near the sampling area to see the impact of climates on the tree growth variations in western Himalaya.

METHODOLOGY

Tree ring-width data

Cedrus deodara tree ring-width records from the Jangla region of western Himalaya, was taken from International tree-ring data bank (http://www.ncdc.noaa.gov./paleo/treering.html), to investigate the tree growth-climate relationship (Figure 1). Total of 40 tree core samples from 20 trees, were included in present study. Details about site information and tree core samples are given in previous studies (Ram et al., 2017; Ahmed et al., 2013; Borgaonkar et al., 2009). The COFECHA program (Holmes, 1983) was used to check missing and datings errors of ring-width measurement. The inter-correlation coefficients (0.637) among the trees core samples, indicated the coherency and excellent match of the ring width patterns. It strongly suggests the common climate forcing in tree ring-width records.

To develop mean tree ring width chronology with multi-decadal variations, regional curve standardization (RCS) technique was used in preparation of chronology to keep maximum low frequency signal in detrended series, due to decreasing of trees cores samples backward in chronology, which has been found suitable in climate study. Therefore, a regional curve standardization (RCS) option in

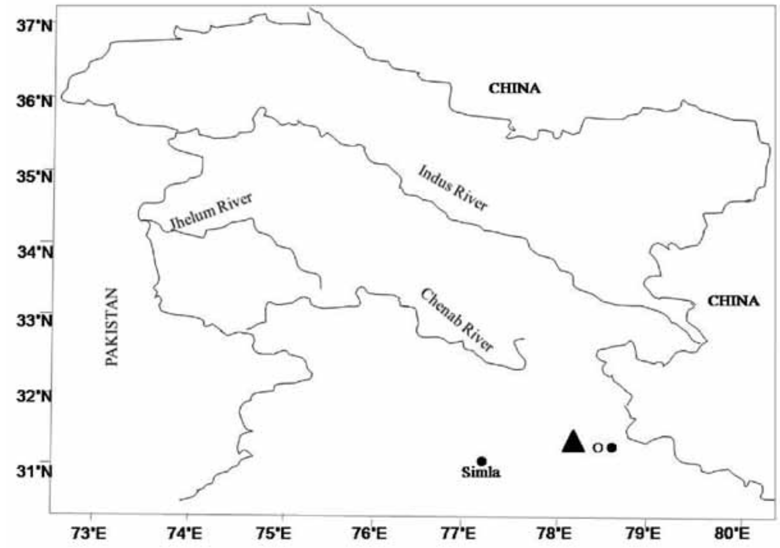

Figure 1. Study area showing tree ring site; ▲: tree-ring site, ○: grid point climatic data; ●:PDSI

ARSTAN program (Cook, 1985), with 50 year window of 25 year overlaps, was selected to compute running expressed population signal and common variance (Mitchell, 1967; Briffa et al., 1992; Esper et al., 2003; Yadav et al., 2009). The resultant indices were pre-whitened individually, using the autoregressing model. All indices were then averaged to prepare the mean site chronology, using the biweight robust mean value function to remove the influence of the outliers (Cook and Kairiukstis, 1990). The chronology showed low growth in early part of the chronology, as compared to later period during recent few decades (Figure 2), which indicates cool anomalies during early period that is consistent with Little Ice Age (LIA), as evidenced by Yadav (2009).

However, In case of abrupt changes in chronology around from 1875, the reasons for which are not too well known, but it is felt that abrupt change in tree growths around 1875, might be associated with large-scale land transformation and disturbance in natural resources which is attributed to anthropogenic forcing of the climate (Tian et al., 2014; Yadav et al., 2004). During 1880-2010, over the Indian region, there has been a significant alteration in the land use and land cover (LULC), including loss of the forests, and rapid urbanization (Tian et al.2014), which might have enhanced the trees growth, especially after deforestation due to the released effect resulting from by the lack of competition. This may be one of the possible reasons, which could cause the trees to change its behavior.

In addition to this, the analysis of surface air temperature data over the region indicates significance increasing trend during the last century (Kothawale, et al., 2016; Singh et al., 2004, 2009; Borgaonkar et al., 2009). Bhattacharyya et al. (2007) indicated that 20th century was the warmest during the past 1000 years, with AD 1989-98 the warmest decade. So, the abrupt changes in tree growth might as well be associated with global warming (Yadav et al., 2004; Singh and Yadav, 2000). The increased temperature at high altitude might increase the ability of trees root to absorb water and nutrients from the soil; resulting stomata unclosed and released trees growth as evidenced by Tranquillini, (1964) and Korner (1998).

Climate data

Due to limitations of observed climatic variables and sparse meteorological stations in and around the sampling area, the precipitation, monthly mean, maximum and minimum temperatures, vapor pressure and percentage of cloud cover data of grid box (31.25°N; 78.25°E) nearer to sampling sites were used for the period 1901-2002, from Climate Research Unit (Mitchell and Jones, 2005). In addition to this, PDSI (31.25°N, 78.75°E) for the period 1901-2002 was used for better understanding tree growth-climate relationship over the region (Dai et al., 2004) (Figure 1). Climate statistics in and around the sampling areas has been shown in Table 1.

RESULTS

Climatic data

Mean monthly variations of precipitation (PPT), mean (Tm), maximum (Tmax) and minimum temperature (Tmin), vapor pressure (VP) and percentage of cloud (CLD) were shown in Figure 3. June is the hottest months by 17.4°C and July wettest with 230.9 mm precipitation over the region (Figure 3). Maximum CLD and VP (pressure of water vapor constituent of the atmosphere) occurs during July to August, because of availability of sufficient precipitation in the month of July (Figure 3). High and

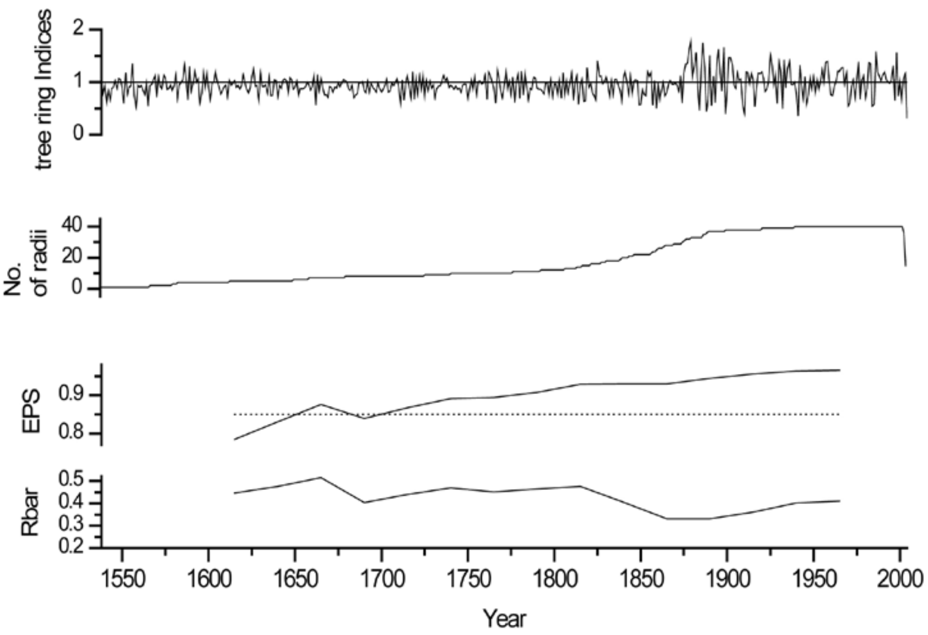

Figure 2. Residual tree ring-width chronology along with no. of radii, running EPS, and Rbar. Dashed lines are the threshold (0.85) values of EPS (Wigley et al., 1984).

Table 1. Mean ($\overline{X}$), standard deviation (SD) and trend/year (Trd) of the various climatic parameters during 1901-2002 ([a]significant at 5%; [b]significant at 1% level; [c]significant at 0.1% level; 1: January; 2: February; 3: March; 4: April; 5: May; 6: June; 7: July; 8: August; 9: September; 10: October; 11: November; 12: December)

Parameters		1	2	3	4	5	6	7	8	9	10	11	12
PPT (mm)	$\overline{X}$	37.8	40.8	34.2	29.7	39.5	115.0	230.9	215.0	121.0	21.4	10.8	14.5
	SD	27.6	29.8	25.8	22.4	29.8	81.7	103.5	83.1	75.8	21.5	16.1	15.3
	Trd	-.04	.04	.09	.02	.07	-.01	-.07	-.36	-.17	0.0	0.0	-.01
Tm (°C)	$\overline{X}$	1.9	3.2	7.5	12.1	15.3	17.4	17.3	16.7	15.1	11.7	7.6	4.4
	SD	1.5	1.5	1.6	1.4	1.2	1.0	0.6	0.5	0.7	0.9	1.1	1.2
	Trd	0.0	.01[c]	.01[c]	.01[a]	0.0	0.0	0.0	0.0	0.0	0.0	.01[c]	.01[c]
Tmax (°C)	$\overline{X}$	6.6	8.0	12.5	17.3	20.7	22.3	21.3	20.4	19.5	16.8	12.8	9.4
	SD	1.5	1.6	1.6	1.5	1.3	1.1	0.7	0.6	0.7	0.9	1.1	1.3
	Trd	0.0	.01[c]	.01[b]	.01[a]	0.0	0.0	0.0	0.0	0.0	0.0	.01[c]	.01[c]
Tmin (°C)	$\overline{X}$	-2.7	-1.6	2.5	6.9	10.0	12.5	13.3	13.0	10.8	6.6	2.3	-0.6
	SD	1.6	1.5	1.6	1.5	1.2	1.0	0.7	0.6	0.8	0.9	1.2	1.2
	Trd	0.0	.01[c]	.01[c]	.01[a]	0.0	0.0	0.0	0.0	0.0	0.0	.01[c]	.01[c]
VP (hpa)	$\overline{X}$	3.4	3.7	3.5	4.5	6.1	11.6	15.8	15.9	12.2	6.6	3.9	3.6
	SD	0.5	0.5	0.6	0.6	0.7	0.8	0.6	0.4	0.5	0.4	0.3	0.4
	Trd	0.0	.003[a]	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	.002[a]	.005[c]
CLD (%)	$\overline{X}$	44.1	43.6	45.7	39.0	43.7	49.8	60.4	60.0	43.2	27.3	23.6	36.5
	SD	3.9	4.4	4.7	5.0	4.4	4.7	3.6	3.4	5.0	5.6	6.3	4.7
	Trd	0.0	.01	.03[a]	.02	.04[c]	.04[b]	.02[a]	0.0	.01	.05[c]	.04[a]	.02

low VP depends on availability of moisture of the region, in which precipitation distribution across the country has significant role in modulating the soil moisture.

Mean ($\overline{X}$), standard deviation (SD) and trends/year (Trd) of the various climatic parameters was shown in Table 1. In case of temperatures and VP, significant increasing trends

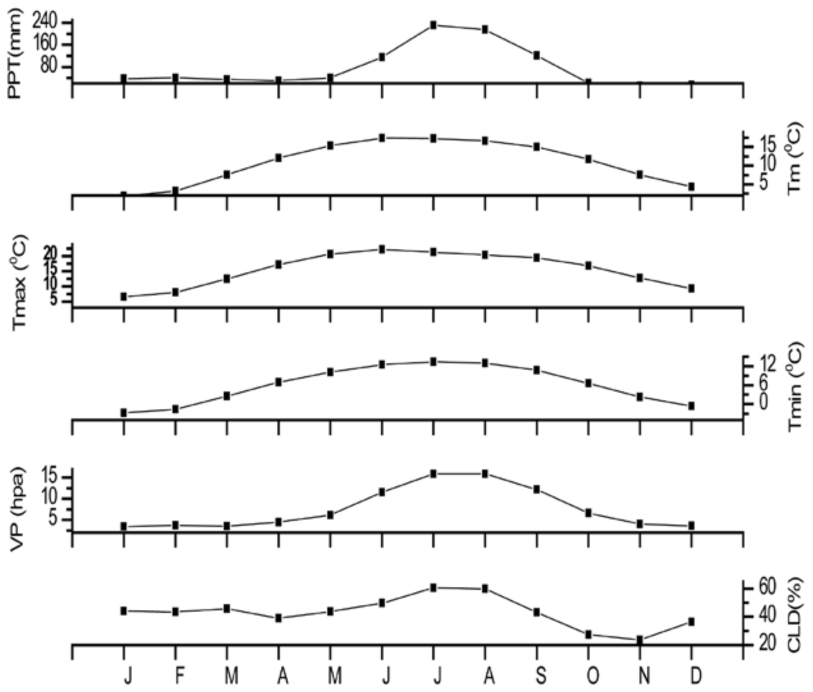

Figure 3. Averaged monthly variation of precipitation (PPT), mean (Tm), maximum (Tmax) and minimum temperature (Tmin), and cloud cover (CLD) in and around the sampling site during 1901-2002.

were observed during February, March, April, November and December. But, VP (which depends on moisture availability) appears trendless during the months of March and April (Table1). In case of CLD, significant increasing trend was found during March, May, June, July, October and November (Table 1). It means that increases in CLD during March to May, would reduce the insufficient moisture stress conditions over the region. Correlation analysis of CLD with PDSI (which describes the moisture availability) for the period 1901-2002, indicates strong correlation (r = 0.30) during spring season, which is statistically significant at 0.01% level, which represents the climatic condition in and around the sampling areas.

Tree-ring chronology

Residual tree ring-width index chronology for the period 1538-2004 along with no. of radii, Expressed population signal (EPS), and common variance (Rbar), were shown in Figure 2. The Dashed line is the threshold values of EPS (Wigley et al., 1984). After 1715, Rbar ranges within 0.33 to 0.47 (Figure 2) and; the EPS ranges within 0.87 to 0.97, which shows the reliability and stability for climatic reconstruction (Wigley et al., 1984).

Tree growth-climate relationship

The correlation analysis between residual ring-width index chronology and multiple climatic variables (PDSI, PPT, Tm, Tmax, Tmin, VP, and CLD) has been carried out over the western Himalaya during 1901-2002. We considered a 13-month dendroclimatic window, starting from previous year October (ending of growing season) to current year October (ceasing of growing season), to understand the impact of climatic conditions on tree growth during current and prior year growing season of the trees. Dashed lines in the figure are significant at 5% level (Figures 4a-g). Figure 5 showed the 31-year sliding correlation analysis between chronology and various climatic parameters.

DISCUSSION AND CONCLUSIONS

The PDSI from previous year of November to current year May, showed significant influence on the trees growth over the region. Particularly, the relationship of tree growth with PDSI is higher during March to May than other months. July to August PDSI also indicates positive relationship, but barely significant with chronology. In case of PPT, only previous year November, December and current year March reveal significant relationship (Figure 4b) whereas PDSI is well associated with tree growth as compared to PPT (Figure 4a). The relationship showed that moisture availability prior to starting of growing season, woks as booster to the following year growth of the trees as supported by the finding of Fritts (1976) and Ram and Borgaobkar (2014a). Pant and Borgaonkar (1983) have also shown that the preserved moisture during dry season, have significant role during subsequent year growing season of the trees.

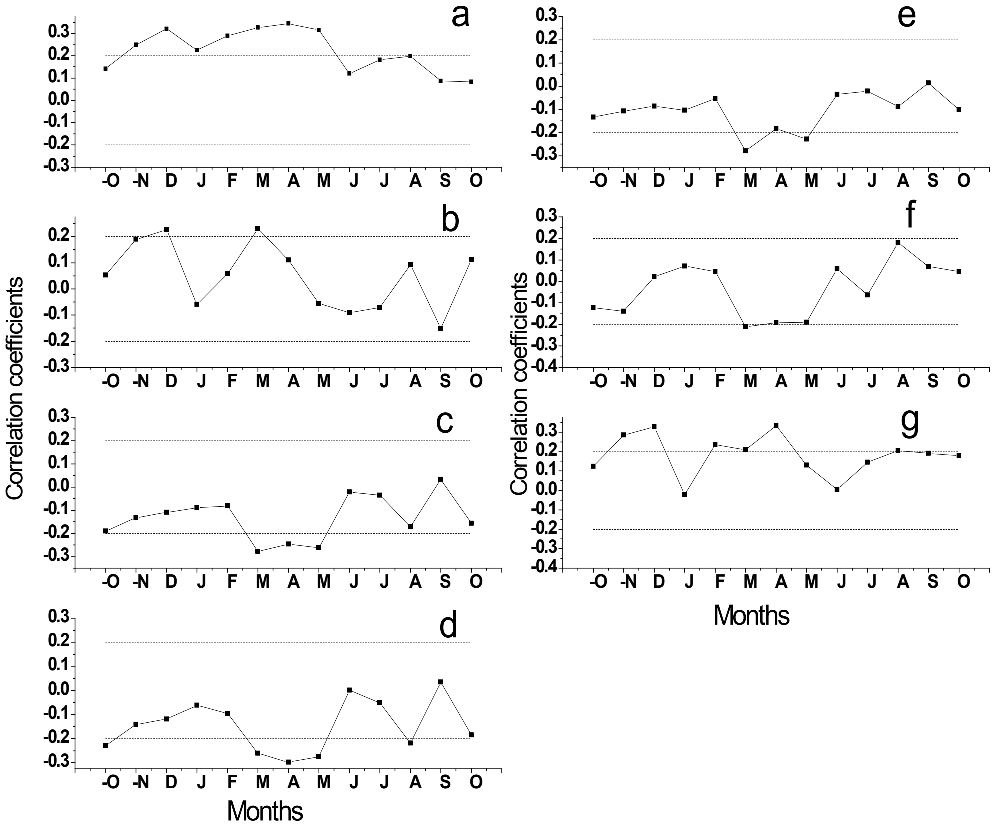

Figure 4. Correlation coefficients between chronology and PDSI (a), PPT (b), mean (c), maximum (d) and minimum temperature (e), vapor pressure (f), and cloud cover (g). Dashed lines are significant at 5% level.

Tm, Tmax and Tmin and VP during March to May, are not observed conducive in favor of tree growth, because of negative relationship with trees growth (Figures 4c-f). Increasing temperatures and VP may accelerate the potential evapotranspiration and reducing the moisture availability at the root zone of the trees (Ram and Borgaobkar, 2014a). Higher temperatures and VP above the normal during March to May, can cause the severe moisture stress condition over the region, which is not favorable for the tree growth (Figures 4c-f), as evidenced by Ram and Borgaonkar (2014a)

In case of cloud cover, the CLD during prior year November and December and current February, March and April indicates, significant positive association with ring-width index chronology (Figure 4g). The relationship showed that the increased CLD reduces the rising of temperatures due to reflectivity of incoming short wave radiation, i.e., reduction in solar radiation which preserve the soil moisture availability at the root of the trees. Thus, the CLD during dry season and summer would reduce the potential evapotranspiration which leads to maintain the moisture in developing of annual ring-width patterns.

Based on the results given by various monthly climatic variables to tree growth, the spring season is formed through March to May. The significant correlation coefficients between tree ring chronology and PDSI, PPT, Tm, Tmax and Tmin, VP, and CLD are 0.40, 0.13, -0.36, -0.40, -0.31, -0.23, and 0.26 respectively, which are significant at .01%, .01%, 0.1%, 5%, 1%, and 1% level respectively, except PPT. all climatic parameters are found statistically significant with chronology. It showed that seasonal climate is more responsible than a single month as evidenced by Ram and Borgaonkar (2014a) and Cook et al. (1999).

However, to see the long-term temporal stability between chronology and different climatic parameters (PDSI, PPT, Tm, Tmax and Tmin, VP, and CLD) during spring season, the 31-year sliding correlation analysis was performed during the common period 1901-2002 (Figure 5a-g). There is constantly significant relationship between chronology and PDSI from 1925 onwards (Figure 5a). However, the relationship during recent few decades is slightly weak as compared to early period, but correlation coefficients showed the constantly significant (at 5% level) (Figure 5a). The possible causes for change in the relationship are not well known, but soil deterioration due to reduction of forest cover might reduce the soil water infiltration and enhance the surface water runoff

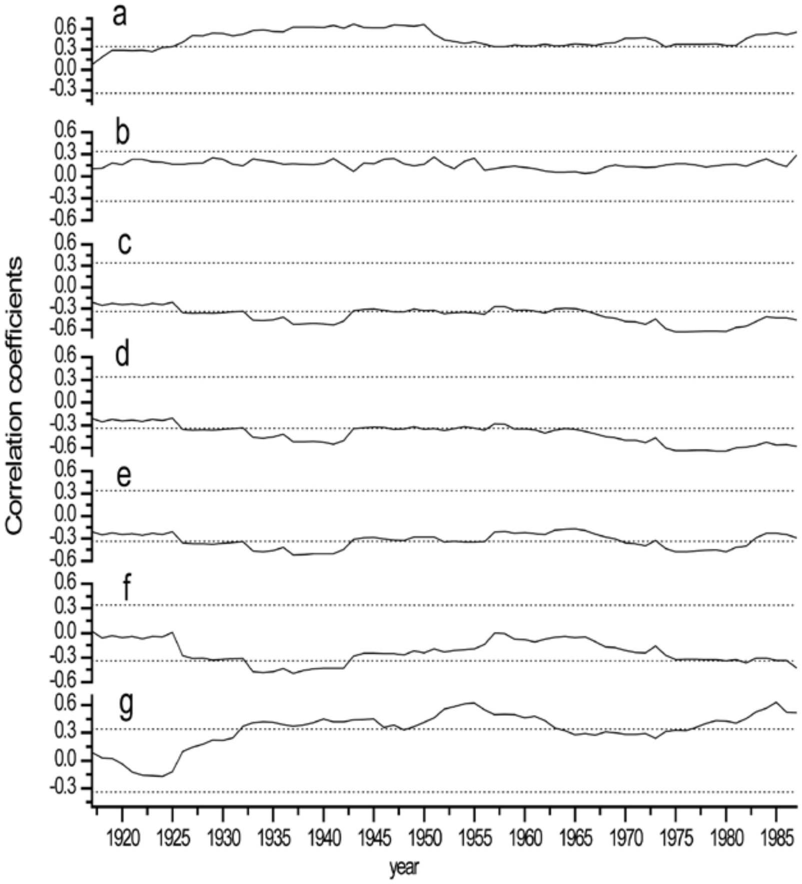

Figure 5. A 31- year sliding correlation analysis between chronology and PDSI (a), PPT (b), mean (c), maximum (d) and minimum temperature (e), vapor pressure (f) and cloud cover (g). Dashed lines are significant at 5% level.

over the region, which caused insufficient moisture in recent decades. In addition, the disturbance in natural resources over the region may be one of the possible reasons which may alter the tree growth - climate relationship as supported by Yadav (2009). Ram and Borgaonkar (2013, 2014a) also showed weak relationship between soil moisture and tree growth over the western Himalaya during recent few decades.

In case of PPT, there is no significant relationship (Figure 5b). It showed that the availability of the moisture during spring season and winter plays the vital role in developing of annual ring-width patterns as evidenced by Ram and Borgaonkar (2013, 2014a, b). In case of temperatures, around 1925 onwards, Tm, Tmax and Tmin indicate constantly significant negative relationship (Figures 5c-e). However, Tmin showed slightly weak correlations during 1943-1951, 1957-1969 and 1983-1987, but showed negative phase (Figure 5e); overall, the increasing trends of Tm, Tmax and Tmin temperature over the region (Table 1) may increase the potential evapotranspiration, which results insufficient soil moisture, causing moisture stress condition at root zone of the trees growth during spring season.

In case of the VP, The chronology indicates the significant correlation coefficients during 1933 to 1942 and 1975-1987 (Figure 5f). And, the remaining periods indicate somewhat similar pattern like temperatures but it is not significant. The reason for weak correlation coefficients between tree ring-width index chronology and VP is likely due to lack of trend in VP during spring season (Table 1). It showed that high and low VP depends on availability of soil moisture of the region as evidenced by Ram and Borgaonkar (2014a). However, on an average, it is observed that increasing temperatures and VP over the region may create severe moisture stress conditions due to high potential evapotranspiration, which turns to low soil moisture availability for trees growth (Ram and Borgaonkar, 2014a).

In case of CLD, there are consistently significant relationships between tree growth and CLD from 1932 onwards, except 1965-1975, but indicated barely significant at 5% level (Figure 5g). Williams et al. (2008) have also shown that the effect of CLD on tree growth, tree ring-width may vary depending on the type of cloud, the time of day and year. The significant association showed that the significant increasing trends of CLD during spring season might preserve moisture by reducing the rising temperatures (Table 1). It showed that increasing/decreasing CLD over the region could be associated with increasing/decreasing moisture supply of the region, which would be useful during and subsequent year growing season of the trees.

The present analysis showed that CLD, VP, and drought index are found equally important in trees growth process. These climatic variables may explain the growth variation beyond the influence of precipitation and temperature. This result may give better idea to reconcile the complication in understanding of tree growth - climate relationship over the region. Also, it will help to know the climate which is more effective in tree growth variations across western Himalaya, and thereby, improvements can be made for better understanding of the long-term climate variability/change on local and regional scale, by using good network of tree ring chronologies from Himalaya.

However, this study is based on a single site tree ring–width data which motivate us to prepare the longer tree ring chronology with good replication of trees cores samples of earlier period to monitor the drought history on decadal to intra decadal scale. This type of research work can be more useful for the societal point of view, forest management, extremely wet and dry periods, water resources, and hydroclimatic variations. Thus, long-term proxy record of the climate, other than the precipitation and temperature from different location of south Asia, may provide better information to understand climate variability/change on local and regional scale during the past several centuries and millennia, as drought index has significant role in controlling of annual ring-width patterns over the region.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

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