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Research Article

Integrating radial growth response of Himalayan cedar to climate change in the mountainous region of Shogran Valley, Pakistan

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Abstract

Himalayan mountainous region is ecologically sensitive to climate change where forest ecosystems face monsoon climate and information is well recorded in tree rings. Tree growth is highly influenced by climate and its response is inconsistent, varying geographically with different forest composition and different tree species. Assessment of the growth response of trees has important implications for forest dynamics and sustainable forest management. Wood samples of Himalayan cedar (*Cedrus deodara* (Roxb. ex D.Don) were obtained from coniferous forest (Shogran Valley, Pakistan) by following standard dendrochronological techniques. Ring width characteristics of samples were studied and their regression analysis between DBH (diameter at breast height) vs age and DBH vs growth rate showed significant correlation ($R^2 = 0.5275$, $R^2 = 0.0449$ respectively). Statistical Quality of cross dating and accuracy of tree-ring measurements showed mean sensitivity values of 0.272 and autocorrelation values of 0.699. These values specified the good potential of the samples for dendroclimatological studies. Based on earlywood, latewood and total ring widths, chronologies were developed, analyzed and correlated with climate factors using standard dendrochronological software. The statistics of this chronology (1815-2021) with standard deviation of 0.408, 0.146, 0.161 and autocorrelation of 0.691, 0.576, 0.575 with mean sensitivity values of 0.273, 0.348, 0.279 respectively revealed the dendroclimatic potential of the species. Temperature and precipitations had strong influence upon ring widths. This dendrochronological analysis can be used for paleoclimate studies of the region which will improve our understanding of forest management and growth responses of tree species under climate change.

Keywords: *Cedrus deodara*; climate; dendroclimatology; response function; tree-rings

Introduction

Study of chronological sequences of annual growth rings and their characteristics is known as dendrochronology. Variations in environment and its effects on tree growth can be examined by studying annual growth rings of gymnosperm tree species which are formed by the seasonal activity of vascular cambium

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(Fritts, 1976; Speer, 2010). This ring width variation is best studied in coniferous forests of cold zone floras (Schweingruber, 2007). Climatic histories of these areas can be documented through dendrochronology (Martinelli, 2004; Buntgen *et al*., 2005). With the help of numerical methods tree ring records provide relationship of tree growth and climatic variables (Speer, 2010). Global fluctuations of climatic parameters pose serious influences on forest dynamics and its distribution (Boisvenue and Running, 2006). This calibrated data can be used for reconstructions of the past climatic events/episodes (Liang *et al*., 2009; Shao *et al*., 2010; Zhang *et al*., 2019). Tree ring width has been widely used in research on climate change response for a long time. Tree ring width is formed as a result of combined biological and external environmental factors. It not only records the past events but can also be used to determine future patterns of tree growth in context of climate change (Liu *et al*., 2017).

Species specific response of trees to climate is useful to evaluate the response of forest growth to these exogenous climatic parameters. Due to the presence of a range of tree species and difference in their physiological characters, forest growth becomes a complex of the multi-species growth behavior (Yu *et al*., 2011). Since Pakistan has a wide range of climatic and soil conditions, it possesses various forest types. Conifers mixed with broadleaf species and Oaks constitute the Himalayan moist temperate forest regions. These forests are, with 12 °C mean annual temperature and 650-1500 mm mean annual precipitation, evergreen having good canopy cover. Grass vegetation covers the soil of open patches. Dominant conifer species are kail (*Pinus wallichiana*), spruce (*Picea smithiana*), fir/partal (*Abies pindrow*) and barmi (*Taxus baccata*) along with patches of *Cedrus deodara*.

In conifers, earlywood part of tree rings is formed by cell division in the beginning of growth season having thin cell wall, large size and light color. Latewood part is formed by cell division in late growth season and is characterized by smaller, thick walled and darker cells. Earlywood and latewood formation is influenced by seasonal variations in climate. Because of sensitivity of earlywood and latewood towards various climatic factors, dendrochonologists are interested in reconstruction of past climate based on earlywood and latewood parts of annual ring (Peng *et al*., 2022).

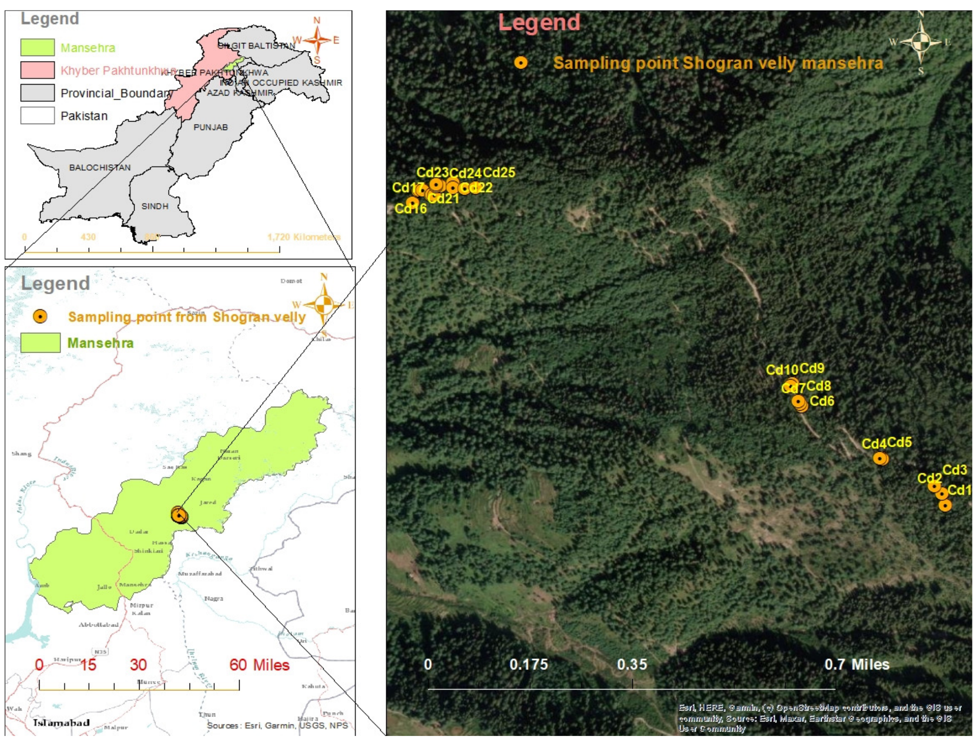
The Himalayan-Karakoram-Hindukush region is highly diversified and complex mountain system. However, little is known about environmental change especially quantitative and spatiotemporal precipitation distribution which provides critical input for hydro-climate assessment (Dahri *et al*., 2016). This dry temperate Himalayan Forest is located at elevation between 1700-3300 m above the sea level. Global surface temperature and precipitation change regime especially global monsoon precipitation, water cycle and severity of dry and wet events have significant contribution on growth and development processes of natural forest plant species (Gauli *et al*., 2022). The climate variation over the time and its impacts on natural protected areas are important to understand conservation, management and restoration strategies of different forest regions in these mountain ranges. Forest ecosystems have been severely threatened in context of worldwide warming, intensity, frequency, maximum weather events period and abnormal climate occurrence in recent years. Therefore, it is important to study climatic variations in these areas and their response relationship in order to explore tree growth strategies, management and protection measures under future climate change (Wu *et al*., 2023; Tayyab *et al*., 2023).

Himalayan cedar (*Cedrus deodara* (Roxb. ex D.Don) is a light demanding conifer species that grow slowly and has a lengthy rotational period (Sajad and Ahmed, 2021). It is a significant species of conifers and has been designated as Pakistan's National Tree. Various studies confirmed that this species can aid in the climatic researches in the areas of Himalayas (Yadav *et al*., 2000; Singh and Yadav, 2007; Singh *et al*., 2009). *C. deodara* shows positive tree-ring features and has good response to climate which makes it highly recommended for climatic experiments (Khan *et al*., 2013). The current study was conducted with following objectives (1) Determination of the age and growth rate of *C. deodara* and the relationship of growth parameters across the study site (2) To develop standardized growth chronologies of *C. deodara* (3) To determine climate growth relationships through response function analysis between tree increment growth and climatic variables. (4) To assess the potential of tree-ring chronology of *C. deodara* for past climatic reconstruction over the study region.

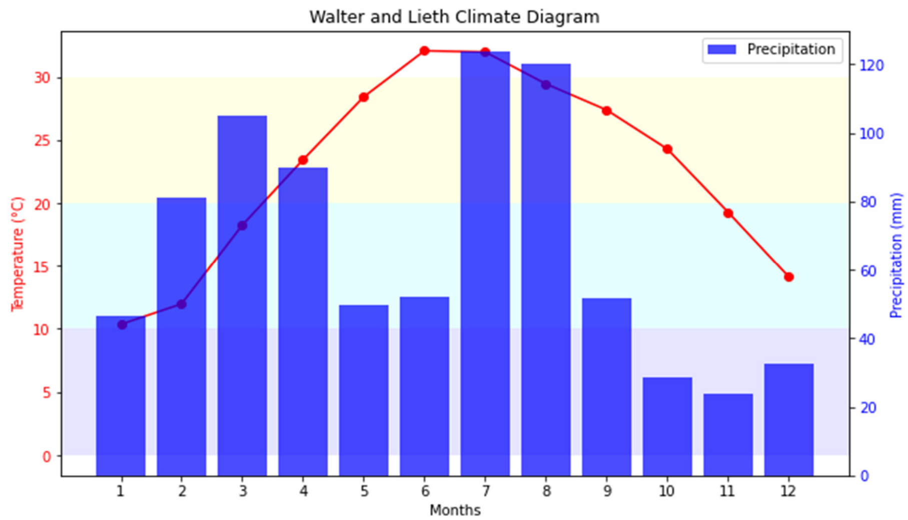
Materials and Methods

Site description

Shogran Valley is located in District Mansehra of Khyber Pakhtunkhwa. It is the North-West part of Pakistan (Figure 1A). This valley is on the western end of Himalayan Range close to Hindukush and Karakoram mountains from West and North, respectively. It covers a total area of 945.47 km^2 (Ahmad *et al.*, 2011; Ummara *et al.*, 2015). At 2362 m above sea level, Shogran is a proper hill station in the Kaghan Valley. It is located between 34°40′ SN latitude and 73°30′ WE longitudinal. Important minerals in the soil of Shogran Valley are dolomite, limestone, quartzite etc. Physical features of the valley include flat ground and hilly terrain. With 2500 mm annual rainfall this valley comes under the category of moist temperate region (Matin *et al.*, 2001). The highest mean temperature is 32.1 °C during June, and the lowest -12.7 °C during January. It is distinguished by the existence of a diverse range of conifer species. The pictorial representation of average monthly temperature, precipitation and their trend analysis is described for the period of 1982-2021 (Figure 1B and 2 A-E). The climate data for study site was obtained from NASA Langley Research Center (LaRC) POWER Project funded through the NASA Earth Science/Applied Science Program (https://power.larc.nasa.gov/).

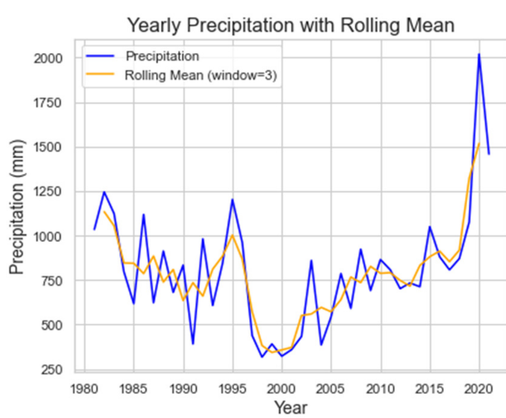


A)



B)

Figure 1. Geographic location map of sampling site in the mountainous area of Shogran Valley (Siri Paye), Pakistan (A); Climograph of average monthly temperature and precipitation (1982-2021). The left y-axis shows temperature (°C), and the right y-axis shows precipitation (mm). The x-axis shows the months. The red curve shows the temperature, and the blue vertical bars show the precipitation (B)



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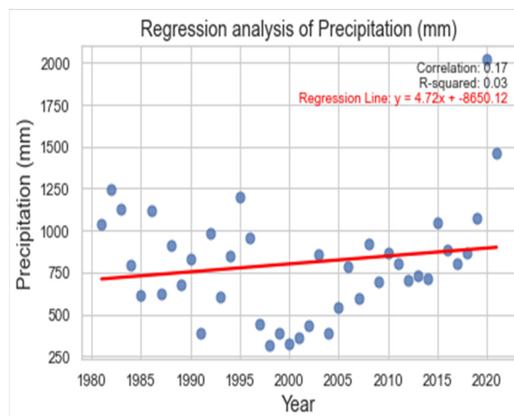

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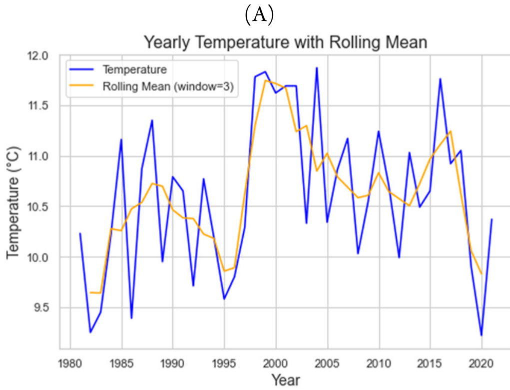
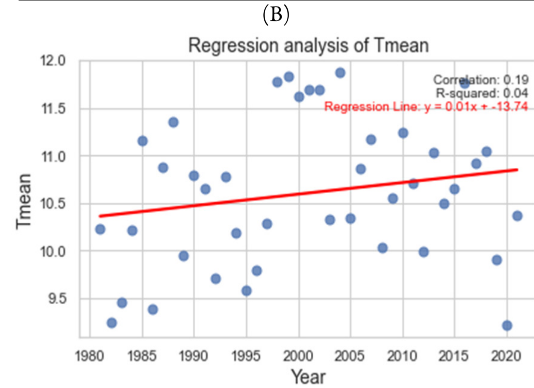
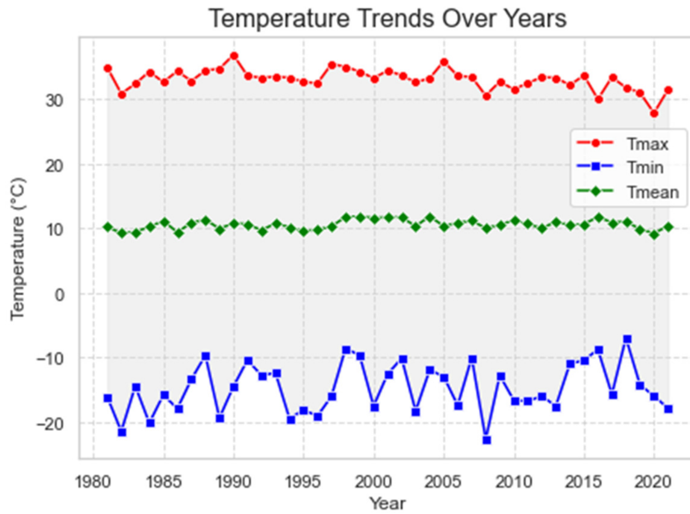


(C)



(D)



(E)

Figure 2. Precipitation and Temperature distribution (A, C); Trend analysis (B, D); and changes in temperature during the study period (1982-2021): maximum (Tmax), minimum (Tmin) and mean (Tmean) temperatures (E)

Tree-ring sample collection and processing

Sampling of undisturbed and unevenly-aged trees of *C. deodara* was performed in 2021 along Siri Paye track in Shogran Valley (Figure 1). 25 healthy trees were selected and cored at the height of 1.3 m above root collar. Two increment cores opposite to each other were taken from each tree. Selected cores were preserved in plastic straws having core codes written on them (Wahab *et al*., 2008; Ahmed, 2014). After air drying in the laboratory the cores were mounted on grooved wooden frames. Samples were polished after treating with sand papers of progressively finer grain size up to 400 grits (Stokes and Smiley, 1996; Arnot, 2008). All the core samples were visually cross dated and measured in Velmex Measuring System (TA4021H1) with connection of the Voortech's Measure J2X software (Hart and Grissino-Mayer, 2008).

Development of tree growth chronologies

The accuracy of the ring width measurements (msmt) and cross dating was checked by COFECHA software. By running this program we checked the credibility of our data for further use. It identified the flagged rings, sensitivity of the samples, correlation values with master and autocorrelation of all the series (Grissino-Mayer, 2001). After checking the accuracy of ring width measurements, we applied broad range of standardization techniques through ARSTAN computer program. By using this software signal of interest was enhanced and noise (non-climatic signals) was removed through negative exponential curve fitting method and standardized ring width, earlywood and latewood chronologies were developed (Cook, 1985; Bunn, 2010).

Results

Dendrometric characteristics of the samples

Relationship between growth rate and age of *C. deodara* from Shogran was assessed. Mean average growth rate, DBH (diameter at breast height) and estimated age of the samples are given in the Table 1 A-C. Maximum growth rate of 0.39 cm/year with 68 cm DBH and 205 years of age was observed in Cd21 sample. Minimum growth rate of 0.09 cm/year with 91 cm DBH and 110 years of estimated age was observed in Cd1 sample. This sample also showed lowest age. Maximum mean estimated age of 400 years was shown by Cd3 sample with 0.20 cm/year growth rate having 129 cm DBH. This tree sample also observed the maximum DBH.

Table 1A. Mean growth, early and latewood measurements (±SD) of *Cedrus deodara*

Sample ID	Mean growth	Earlywood (mm) ±SD	Latewood (mm) ±SD	DBH (cm)
Cd 1	0.92	0.52 ±0.91	0.53±0.184	91
Cd 1'	0.89	0.61±0.364	0.54±0.163	
Cd 2	0.98	0.59±0.255	0.6±0.271	68
Cd 2'	1.11	0.59±0.371	0.57±0.373	
Cd 3	1.89	1.08±0.6	0.88±0.306	129
Cd 3'	2.06	1.44±0.823	0.71±0.36	
Cd 4	1	0.59±0.2	0.56±0.171	62
Cd 4'	1.05	0.53±0.217	0.55±0.274	
Cd 5	1.33	0.71±0.334	0.64±0.236	69
Cd 5'	1.27	0.74±0.336	0.72±0.267	
Cd 6	1.68	0.98±0.95	0.77±0.417	82
Cd 6'	1.33	0.73±0.348	0.73±0.312	
Cd 7	1.27	0.76±0.325	0.79±0.361	73
Cd 7'	1.36	0.67±0.652	0.54±0.322	
Cd 8	1.17	0.71±0.376	0.54±0.185	80
Cd 8'	1.17	0.69±0.379	0.71±0.314	
Cd 9	3	2.27±1.622	0.87±0.523	84
Cd 9'	2.48	1.84±1.059	0.66±0.237	
Cd 10	1.91	1.04±0.722	0.94±0.482	76
Cd 10'	2.23	1.33±1.048	1.43±0.858	
Cd 11	3.66	2.62±1.35	1.02±0.337	64
Cd 11'	2.81	2.14±1.014	0.69±0.285	
Cd 12	3.17	2.47±1.515	0.76±0.278	60
Cd 12'	3.09	2.12±1.258	1.01±0.323	
Cd 13	1.76	1±0.597	0.82±0.312	67
Cd 13'	2.02	1.25±0.843	0.9±0.507	
Cd 14	2.94	1.84±0.997	1.14±0.573	79
Cd 14'	2.62	1.81±0.98	0.79±0.348	
Cd 15	2.44	1.91±0.663	1.34±0.836	64
Cd 15'	2.34	1.03±0.516	1.19±0.494	
Cd 16	2.9	1.93±0.996	1.14±0.34	61
Cd 16'	3.25	2.85±1.717	0.62±0.15	
Cd 17	2.22	1.55±0.857	0.65±0.203	66
Cd 17'	2.09	1.46±0.944	0.67±0.266	
Cd 18	2.37	1.31±0.901	1.03±0.724	70
Cd 18'	2.6	1.92±1.434	0.83±0.523	
Cd 19	3.15	1.91±1.373	1.14±0.738	70
Cd 19'	3.64	2.99±1.681	0.82±0.268	

Cd 20	3.43	2.51±1.142	0.97±0.371	62
Cd 20'	3.2	2.22±1.26	0.92±0.357	
Cd 21	2.73	1.82±1.145	0.98±0.429	68
Cd 21'	4.81	3.93±1.891	0.93±0.29	
Cd 22	3.54	1.95±1.64	1.37±1.033	84
Cd 22'	3.56	2.05±0.905	1.46±0.765	
Cd 23	3.45	2.71±1.961	0.73±0.203	77
Cd 23'	3.66	2.74±1.391	0.98±0.485	
Cd 24	2.58	1.65±0.895	1.02±0.635	58
Cd 24'	2.99	1.72±0.896	1.19±0.736	
Cd 25	2.39	1.48±0.856	1.09±0.474	69
Cd 25'	2.45	1.63±1.1	0.98±0.442	

On the basis of tree ring counts of 50 series (sample cores), the age of the samples was evaluated and their grouping into 10 different age classes was created having class interval of 20 by using the frequency distribution methodology. Thus, this ungrouped data was generated having minimum age of 38 years and maximum age of 207 years. This showed the mixed type of forest stand having young to mature tree samples of the selected species. The detail of frequency distribution of sample trees with respect to different age classes is given in Table 1B.

Table 1B. Age frequency classes of sampled trees

Age group (years)	Frequency (No. of trees in age class)
20-40	1
41-60	13
61-80	16
81-100	5
101-120	4
121-140	2
141-160	3
161-180	2
181-200	2
201-220	2

Table 1C. Characteristics of tree samples of Himalayan cedar

Species	*C. deodara*	
Age (years)	Min	38
	Max	207
Growth (cm)	Min	0.09
	Max	0.39
DBH (cm)	Min	58
	Max	129
Earlywood	Min	0.52
	Max	3.93
Latewood	Min	0.53
	Max	1.46
No. of trees	25	
No. of core samples	50	

linear regression equation/R^2	age/DBH	y=0.2002x+31.152, 0.53
	growth/DBH	y=-32.673x+81.24, 0.04
	earlywood/growth	y=1.1398x+0.556, 0.92
	latewood/growth	y=2.1897x+0.4685, 0.33

Regression analysis between Age/Growth rate and DBH was performed. Age and DBH was found to be positively correlated, while correlation between DBH and growth rate was not strong. Regression values of DBH and age were $R^2 = 0.5275$ and $y = 0.20002x + 31.1515$, while values of DBH and growth rate were $R^2 = 0.0449$ and $y = -32.6725x + 81.2398$. Pictorial representation of the correlation analysis is given in the Figure 3 (A and B). The correlation of seasonal parts of wood was also studied. Earlywood showed strongly positive correlation ($R^2 = 0.9212$) while it was not significant in latewood part ($R^2 = 0.3294$) (Figure 3 C-D).

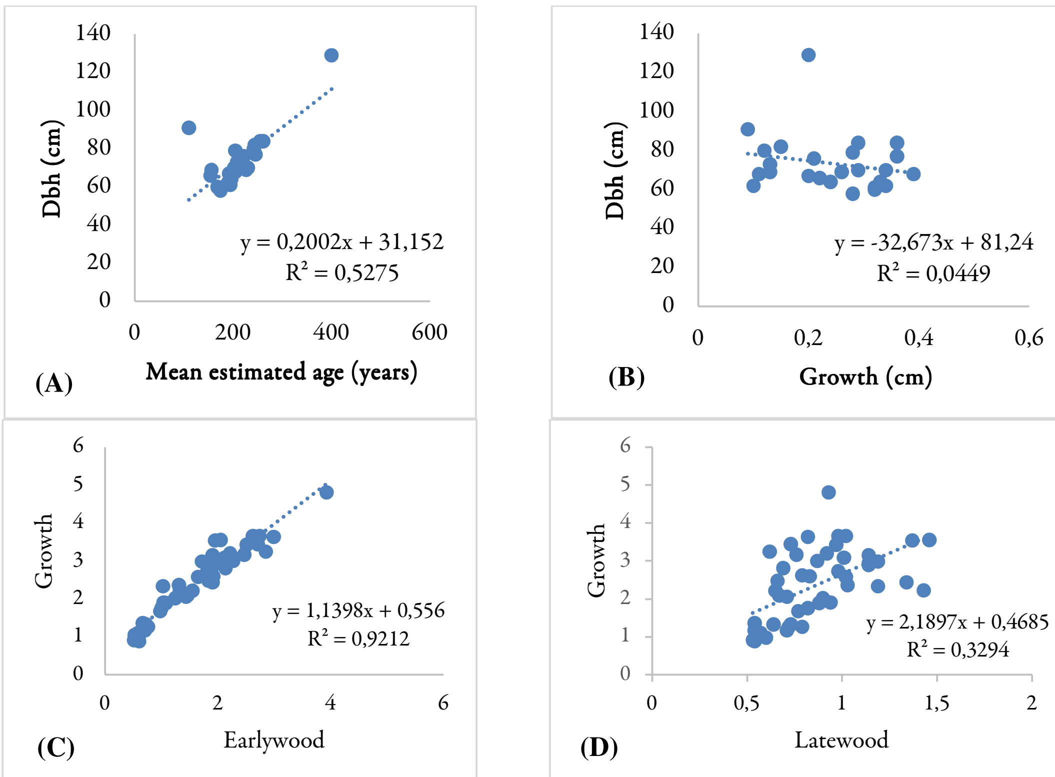


Figure 3. (A-D). Regression analysis of different tree growth parameters

Statistical characteristics

After ring width analysis of the increment cores of the *C. deodara*, they were subjected to a range of statistical tools and methods. Mean measurement (msmt) is the ring width of increment cores. Mean sensitivity is the measure of variations in ring widths under the influence of climatic variables. The values of mean sensitivity determine the potential of samples for dendrochronological analysis. Higher the sensitivity higher will be the potential. Samples with too many complacent rings are not suitable for analysis. Maximum mean msmt values were observed in Cd21 with 3.83 mm/ring and mean sensitivity values of 0.276 which is close to the default values for sensitivity (0.3-0.8). Average mean sensitivity value of the all samples was 0.272. Measurement of the influence of previous year's growth on current year is known as autocorrelation. Autocorrelation values of the *C. deodara* were found to be 0.699.

Interactive detrending and chronology development

For standardization of the measurements, ARSTAN (autoregressive standardization) computer programme was used to remove the non-climatic or noise effects from the measurements. To model biological growth trends between the series of measurements detrending of series was performed. Four different chronologies were formed naming raw, standard, residual and arstan chronologies (Figure 4 A and B). Mean tree ring measurements without standardization were presented as raw chronology. Biweight robust estimates were performed to standardize it. This function of the programme was used to remove the endogenous disturbance and to enhance the common signals of the chronology measurement. Pooled auto regression or persistence modeling was performed to point out sustained or consistent periods among tree ring series which are due to same site or same species facing same exogenous conditions. Statistical values of the chronologies are given in the Table 2.

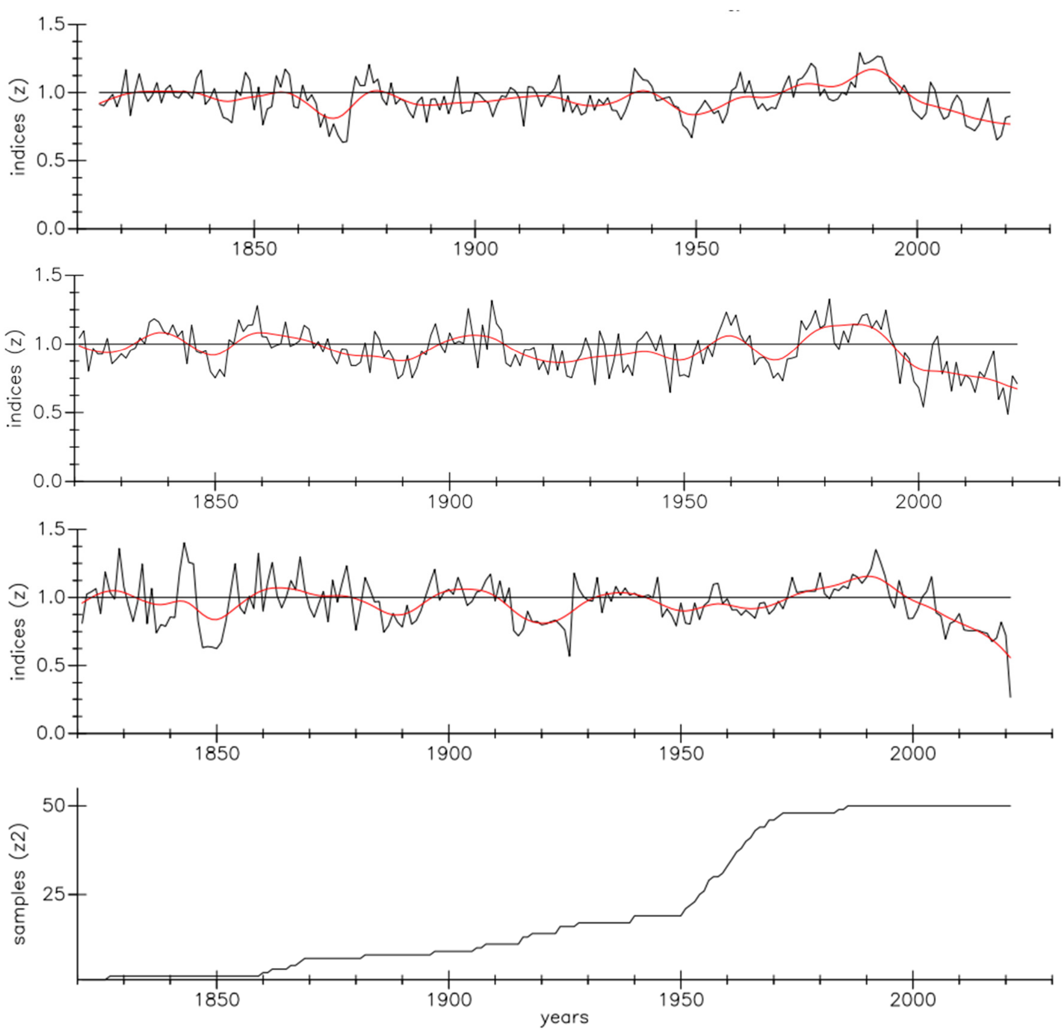


Figure 4. (A, B, C). Standard chronology of *C. deodara* tree ring width, earlywood and latewood with sample depth

Table 2. Descriptive statistics of ring width, earlywood and latewood chronology of *C. deodara*

Parameters	Ring width chronology	Earlywood chronology	Latewood chronology
Life span	1815-2021 AD		
Mean index	0.976	0.958	0.968
Standard deviation	0.408	0.146	0.161
Serial correlation	0.626	0.386	0.422
Mean sensitivity	0.273	0.348	0.279
Autocorrelation	0.691	0.576	0.575
Skewness coefficient	1.362	-0.175	-0.010
Kurtosis coefficient	6.323	3.122	4.274

Climate-growth relationship

Moving correlation and bootstrapped response function analysis of this Himalayan Cedar (*C. deodara*) was carried out to investigate climate and tree ring growth relationship. It was observed to be vary over the period of time. The Precipitation and temperature variation during the period 1982-2021 was observed as shown in Figure 2 (A-E).

Tree-ring growth was significant positively correlated with winter months $T_{max.}$ (current January, February) and was strongly correlated with September and it was observed to be consistently increasing up to 2021 while pre-monsoon months response function analysis was performed between tree ring width chronologies and climate variables (Max temperature, Min temperature, precipitation), and observed to be negatively correlated for period (1983-2012) and correlation coefficient was found to be -0.4. Current May $T_{max.}$ was not significant consistently up to year 2019 (correlation coefficient, 0.1-0.2). $T_{min.}$ was highly negatively correlated with pre-monsoon months (March, April, May) for the period (1982-2006) to (1993-2017) and correlation coefficient value was consistently decreasing (<-0.4) while it was positively correlated for current colder months. Similar pattern was observed in current/previous September month. Precipitation was observed to be strongly positive for March during 1982-2012 period and not much significant in late summer and fall months (current May, July, August, September and previous August & October). The positive influence of June precipitation disappeared while it became prominent in case of September, precipitation in the previous growth periods (Figure 6 a-c).

Response function analysis

Response analysis of *C. deodara* tree-ring width was performed using earlywood, latewood, average annual temperature (T_{max}, T_{min}, T_{mean}) precipitation (Table 3). It can be concluded from Table 3 that tree-ring width was highly significantly correlated with earlywood and latewood along with their strong pairwise correlations. Latewood also correlated statistically significant with T_{mean} with correlation coefficient of 0.385. Bootstrapped response analysis of monthly minimum and maximum temperatures and precipitation indicated the response to trees growth and highlighted their coefficients of correlation (Figure 5 a-c).

Table 3. Correlation coefficients between tree ring width and climate factors

Index	G	E	L	T_{max}	T_{min}	T_{mean}	P
G	1	0.966***	0.562***	-0.278	0.238	0.303	-0.086
E	0.966***	1	0.410**	-0.270	0.240	0.224	-0.076
L	0.562***	0.410**	1	-0.160	0.146	0.385*	-0.179
T_{max}	-0.278	-0.270	-0.160	1	0.156	0.257	-0.602***
T_{min}	0.238	0.240	0.146	0.156	1	0.587***	-0.361*
T_{mean}	0.303	0.224	0.385*	0.257	0.587***	1	-0.690***
P	-0.086	-0.076	-0.179	-0.602***	-0.361	-0.690***	1

G is tree-ring width of *C. deodara*; E and L means earlywood and latewood respectively; T_{max} , T_{min} and T_{mean} are annual maximum, minimum and mean temperature respectively; P is average annual precipitation;. No asterisk: p-value >=0.05 (not statistically significant), one asterisk (*): 0.01 <= p-value < 0.05 (statistically significant), two asterisks (**): 0.001 <= p-value < 0.01 (highly statistically significant), three asterisks (***): p-value < 0.001 (very highly significant)

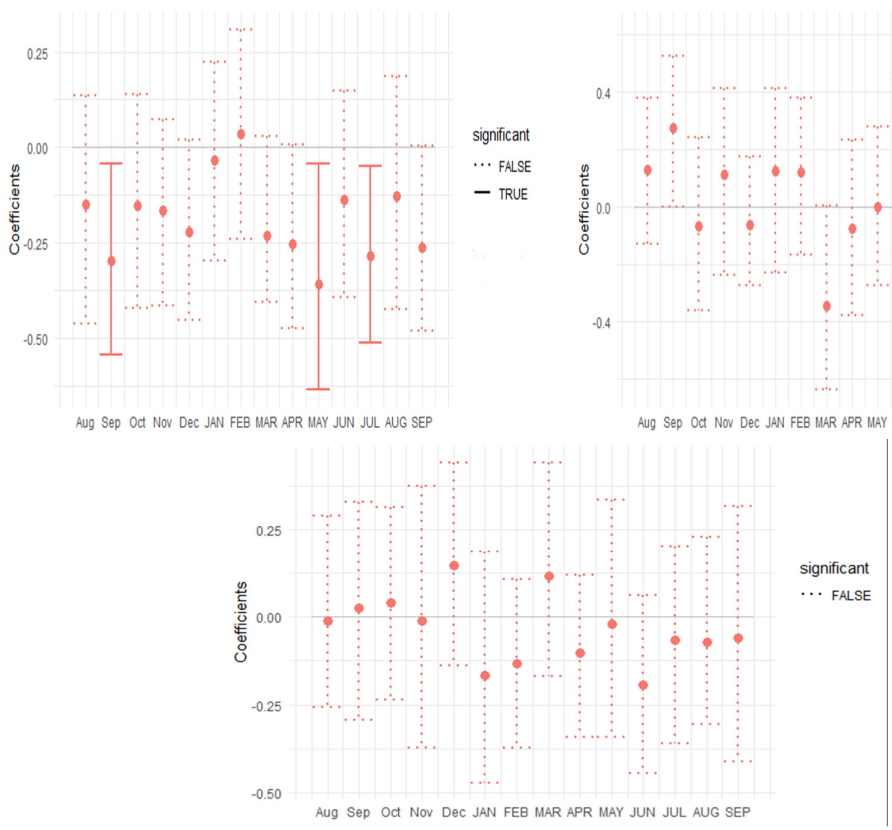


Figure 5. Bootstrapped response function analysis of tree ring width and climate variables (T_{min}, T_{max}, Precipitation) for the period 1982-2021 from previous August to current September (left to right)

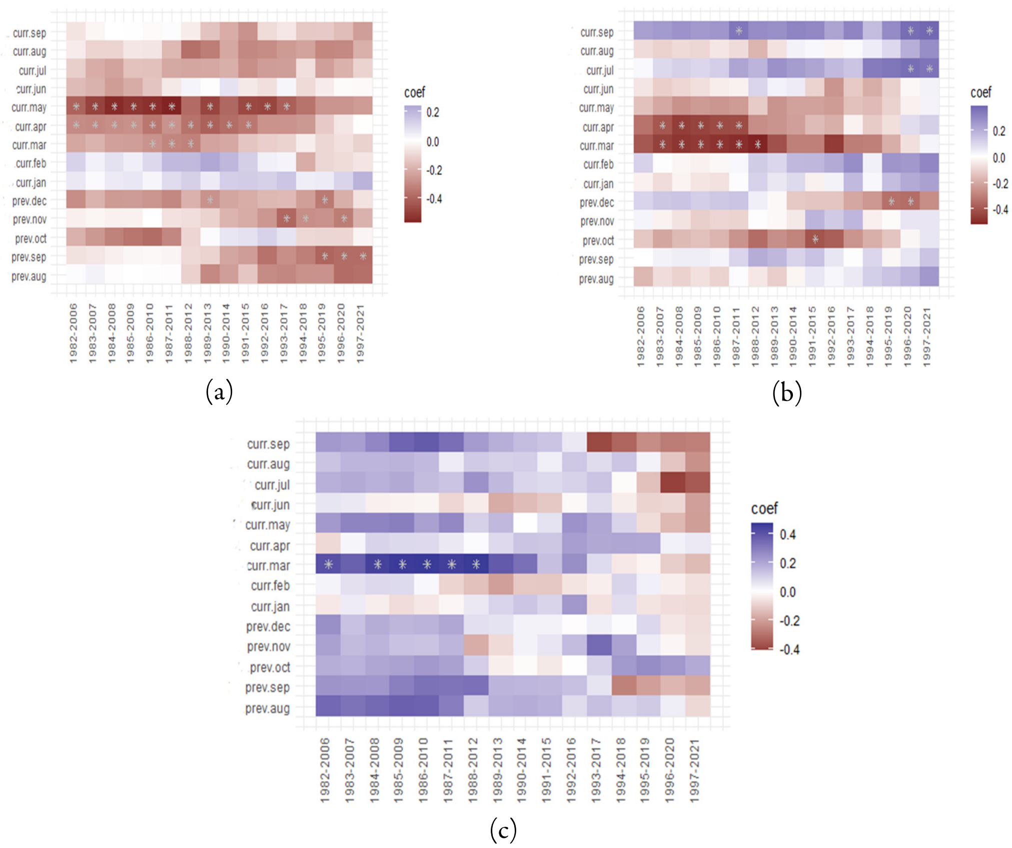


Figure 6. Climate growth response of *C. deodara* with Min Temp. (a), Max Temp. (b) and Precipitation (c). Color code represents the correlation coefficient while white asterisks represent the significance of correlation ($p < 0.05$)

Seasonal correlation

Earlywood is an early season part of annual growth ring and positively correlated with T_{max} for February and its correlation coefficient value was decreased in monsoon months (March, Apr. May). Similarly, T_{min} had positive correlation with current February and negative for current March, April, May its value was -0.2 in previous growth periods and decreasing gradually towards recent years. Latewood is a later season part of annual growth ring and its T_{max} correlation was perceived to be positive for colder months and negative for pre-monsoon months. T_{max} was also remained positive for late summer months for previous years while it became non-significant for current years. T_{min} had highly negative correlation with early season months (March, April, May) while remained non-significant in June, July, August in previous years and became significant for current years. September month had no positive influence during whole period.

Precipitation relationship with earlywood was found to be negatively correlated with colder months and positive for current March month while responded not positively in late growing months and even remained non-significant for current April, May, June months. Latewood response was remained positive in March and for late growth season and negative for summer months (April, May June). It had negative correlation with colder months (January and February) (Figure 7 a-f).

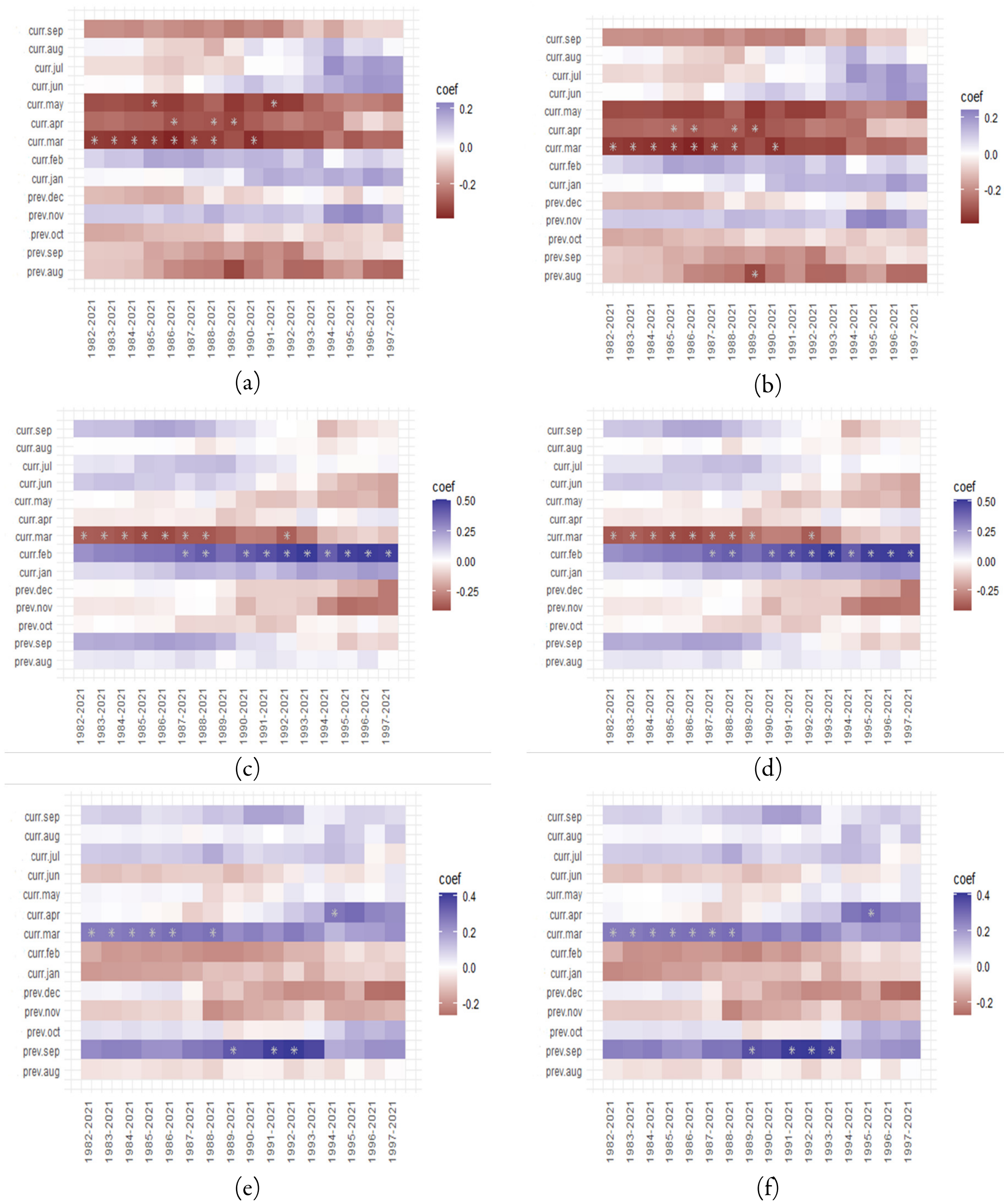


Figure 7. Climate growth response of earlywood and latewood with Min Temp. (a, b), Max Temp. (c, d) and Precipitation (e, f)

The results were interpreted statistically and explored the dendroclimatic potential with 0.273, 0.408, 0.691 mean sensitivity, standard deviation and autocorrelation respectively of samples and inferred with best possible growth response of the trees from this moist temperate region. The investigation was completed to determine the past climatic changes as well as to possible future climate changes for forest management purposes.

Discussion

The current study aimed to find the dendrochronological potentiality of *C. deodara*. It is native to the Himalayan Ranges of Pakistan along the different altitudinal gradients from moist to dry temperate regions (Rahman *et al*., 2022). To find out the effects of environmental variables on the tree rings of *C. deodara*, (Khan *et al*., 2013) prepared ring chronologies of this conifer from Hindukush range. They traced out the climatic signals from tree ring chronologies and concluded that this conifer species has good potential for future paleoclimatic reconstructions. (Sajad and Ahmed, 2021) found strong correlation between DBH and age in tree ring chronologies of *C. deodara* from Kumrat. Dhayani *et al*. (2022) demonstrated growth response of *C. deodara* in its different age groups from young to old. Old age stands in their collection also reflected strong correlation between age and DBH. Ring width measurements were verified by COFECHA programme for dendrochronological applications. Maximum mean ring width observed was 3.83 mm and minimum were 0.52 mm. Mean sensitivity which indicates the climatic influence on tree rings and range from 0.202 to 0.238 which indicates that samples have good potential for further dendroclimatic analysis after (Speer, 2010). Autocorrelation values of *C. deodara* from Shogran ranges in between 0.497 to 0.841 indicating persistent signals among the samples (Wahab, 2011; Rafique *et al*., 2023).

Noise (non-climatic variations) among the measurements was removed by ARSTAN software (Cook, 1985). Standardized form of ring widths is presented in different pictorial views in figure 4 and statistical values are given in the Table 2. Distinct narrow and wide rings in the chronology showed ring width variations due to climatic factors like temperature and precipitation, indicating the congruous signals in the chronologies that would be valuable for climatic reconstructions (Khan *et al*., 2008; Muhammad *et al*., 2019; Muhammad *et al*., 2021). Statistical values (Mean index; 0.976, 0.958, 0.968, standard deviation; 0.408, 0.146, 0.161, serial correlation; 0.626, 0.386, 0.422, mean sensitivity; 0.273, 0.348, 0.279, autocorrelation; 0.691, 0.576, 0.575, skewness coefficient; 1.362, -0.175, -0.010, kurtosis coefficient; 6.323, 3.122, 4.274 respectively) of the chronologies indicated that *C. deodara* from the selected site has good potential to use for paleoclimatic reconstructions (Ahmad and Zafar, 2014). Interactive detrending of the master series at Negative Exponential Curve Fitting and Hugershoff Curve provides an insight to the potentiality of the samples for more understanding (Bunn, 2010).

Gymnosperm species especially conifers of Himalayan Range are the major source of tree-ring chronologies for dendrochronological studies (Muhammad *et al*., 2019; Muhammad *et al*., 2021, Ali *et al*., 2022). These species are preferred for climate growth relationships and past climate reconstructions longer than instrumental data (Gautam *et al*., 2020). Shogran is anthropogenically undisturbed area and has a wide range of conifer trees including *C. deodara*. Mean sensitivity, autocorrelation and pooled autoregressive modeling of the samples collected from the study site showed climatic signaling in tree-ring chronologies. The potential of *C. deodara* from selected site indicated that this species can be used for future climate reconstructions.

The climate variability of this large mountainous region provides an opportunity to understand climatic response of conifer species by the development of tree ring chronologies (Muhammad *et al*., 2019; Ali *et al*., 2022). The involvement of this tree species with different ecological requirements captures in detail the dominant climate variability and these changes attribute to climatic warming. Climate warming may put at risk the biodiversity of this region due to warm season controlled by temperature and precipitation after (Tayyab *et al*., 2023).

The climate variation is not homogenous in all types of ecosystems around the world, recent research shows that drought conditions and other physiological responses affected significantly the forest ecosystem, species composition, ecological gradients and dominant climatic condition. It has been confirmed that growth of conifer species is correlated with different environmental variables. Previous studies from different regions have attributed in increase in the frequency, loss of forest productivity, insect outbreak, species composition variation and other negative anthropogenic impacts on the ecosystem, to the influence of climate change. The mean ring width and all statistical values after analysis suggested an environmental signal. All the trees growing in the forest faced the microclimatic conditions, altitude and soil either in mixed or in stands nearby.

Both response analysis and moving correlations confirmed that climate-growth relationship was species specific but variable and inconsistent over time. The growth of species was stimulated by high temperatures in winter months, such positive correlation between growth and winter temperature has been reported in several other studies. High precipitation had a higher impact on Himalayan cedar growth.

All trees were cross dated successfully by standards dendrochronological techniques. Cross dating of samples confirmed the annual growth structure rather arbitrary structural features of xylem. RWI chronology characterized with common environmental signal, as shown by statistical values (Table 2). The chronology signals reported in this study are similar magnitude to previously reported species (Bräuning *et al*., 2009; Battipaglia *et al*., 2015; Chen *et al*., 2015; Locosselli *et al*., 2016). However, our chronology is not suitable for longer paleoclimate reconstruction. In order to improve and cross the threshold level, older trees could be added to the chronology.

Tree growth was influenced by temperature throughout growing season. Due to higher evapotranspiration, early and late growth response to temperatures was observed. At the end of dry season, environment becomes extremely dry with low moisture content, high vapour pressure deficit (VPD) and low relative humidity. The increase in temperature during the time period further increases water stress which might limit tree growth (Feeley *et al*., 2007). Negative relationship between tree growth and temperatures (1982-2006) were reported for many forest sites (Dong *et al*., 2012; Locosselli *et al*., 2016; Tai *et al*., 2017; Tai and Sugimoto, 2018).

All the physiological processes (temperature, air water potential, evapotranspiration and respiration) affected the tree ring growth in respective seasons. Also, higher vapour pressure deficit increases evapotranspiration, creating drier environment, especially during monsoon season (Galbraith *et al*., 2010; Choat *et al*., 2012). Thus, with increase in VPD, radial growth of *C. deodara* declined in early growth season. Correlation between tree growth and precipitation was also found to be significant. Soils are moisture saturated at the end of monsoon season. Cedar trees prefer well drained soils and can't withstand anoxic root conditions (Orwa *et al*., 2009). However, these findings are dissimilar to previously reported dry and boreal forests (Fichtler *et al*., 2004; Ram *et al*., 2008). The current study signifies the dendrochronological potential of *C. deodara* from Shogran Valley. The developed tree-ring chronologies will be substantially helpful in understanding growth variability of a wide range of forest trees. The study also highlights the impacts of seasonal environmental conditions on *C. deodara*, demonstrating its possible growth trends in contexts of global climate change.

Conclusions

From the above-mentioned results, it is evident that growth is extravagant during the months of March, April and May. Precipitation relationship with earlywood was found to be negatively correlated with colder months and positive for current March month while responded not positively in late growing months and even remained non-significant for current April, May, June months. Latewood response was remained positive in March and for late growth season and negative for summer months (April, May June). It had negative correlation with colder months (January and February). Exploration of the dendrochronological potentiality from Shogran Valley divulges the climatic signaling in tree ring series of *C. deodara*. Correlation and regression analysis showed good relationship between age, growth and DBH. The maximum age of trees was found to be 207 years and minimum was 38 years while maximum DBH was observed to be 129 cm and minimum was observed to be 58 cm. Mean sensitivity of samples and their autocorrelation manifest that this tree species can be used for future climatic reconstructions. Response Function Analysis broaden the canvas of tree ring applications to forest management, drought severity assessment, analysis of precipitation and temperature fluctuations and seismological records. Trend analysis of climatic variables showed statistically significant with mean, minimum and maximum temperatures. Under the climate change scenario, forests make an important contribution to mitigate the resultant harmful impacts. This study highlighted the effects of climatic variability upon tree growth of species, improving our understanding of past climatic changes in this forest. Furthermore, performing reconstruction of these climatic parameters would be helpful for forest management practices especially in the context of climate change in future.

Authors' Contributions

Conceptualization, SM, ZK; Data curation, HN, MT; Software, AA; Investigation, MT, HN; Supervision, SM; Writing—original draft, MT AA; Writing—review and editing, TK, MH, MB; Formal analysis, MT, HN; Methodology, MJTK. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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