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DENDROCLIMATOLOGY OF A MID-ELEVATION FOREST IN PAKISTAN

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Abstract

The study aims for the exploration of dendroclimatological history from Himalayan fir (*Abies pindrow* Royle ex D. Don) growing in the mid elevation zone of Pakistan. Temperature and precipitation are the main limiting factors for tree growth in the region, of which precipitation dominates as the area is moist temperate in nature. As the lower and mid elevations experience a greater degree of human interference, tree-ring records only 148 years old spanning from 1870-2016 AD obtained. The average mean sensitivity of *Abies pindrow* is 0.280 and average auto-correlation is 0.757. Tree-ring widths correlate with precipitation, which was best suited for reconstruction of past climate. Linear correlation between tree-ring chronology and precipitation is significantly ($p<0.05$) positive with May-June precipitation showing the highest correlation with growth of *Abies pindrow*. Gradually changing climate has produced significant changes between past and current climatic conditions, as evidenced from tree rings of Himalayan fir.

Key words: Climatic variabilities, Precipitation, Tree growth, Himalayas, Climatic history.

Introduction

Changes in global weather patterns are a principle feature of interest for the exploration of climatic history from different regions of earth. Information about past climatic events can be helpful to analyze changes in climate and its impact on the globe. Mountainous areas and higher elevation areas are potentially useful in producing climatic signals as the radial growth rings from trees from this region serve as proxies for climatic modeling. Predictions of future climate are achievable when a clear instrumental record of a particular area as well as past information are available. The longer the past information, the farther could be the prediction, a hypothesis by Winston Churchill in 1942 best fitted in dendroclimatology (Fritts, 1991). Hence, by using past information, ecologists study current and future climate and its impacts on natural systems (Fitzpatrick & Dunn, 2019). Time is a transgressive phenomenon that governs transition in climate (Fritts, 1991). Climate has a range of long-term trends to short-term variability when climatic response is checked over multiple time scales. However, variabilities could be studied over a short-term scale or intermediate time scale while many studies have been done on longer time scales, which is suggested to be most reliable (Hecht, 1985).

Causes of climatic variability can be simulated by revealing paleoclimatic records for the anticipation of past climatic conditions (Roibu *et al*., 2020; Coker *et al*., 2019; Hecht, 1985; Schlesinger & Mitchell, 1987; Wood, 1988a & b). A well-reconstructed model of climatic changes of the past can extend our knowledge of past events. It could be at a long scale, *i.e.,* comprised of centennial past records, or it may provide information on short-term scale, *i.e.,* over a period of past several decades. There is another criterion developed of modern period, *i.e.,* past records over a time scale of centuries. An old-growth forest potentially responds with strong climatic signals due to the patterns in tree rings over a long time period (Fritts *et al*., 1991). In addition to biota, wildlife, civilization and other transitional events related to that particular area, historical records of climate lead to a fundamental appreciation to unveil climatic variability (IPCC., 2014; Texeira *et al*., 2012).

Fluctuations in climate strongly influence temperature and moisture fluxes, which are the main drivers of interannual variability in growth rings (Ahlström *et al*., 2015). This interannual variability is a predictor of frequently changing climate in an ecosystem. The predictions include a combination of meteorological and tree-ring data with the knowledge of vegetation (Zscheischier *et al*., 2016). The modern period focuses on rapidly changing environments and for this purpose short-term variability plays an important role to produce interannual description of climate. Interannual variabilities act as predictors that demonstrate rapid changes in growing season, mean annual or monthly temperature and precipitation in the region (Barr *et al*., 2007; Stoy *et al*., 2006).

Asia has the largest mountain ranges on earth, but there is a lack of tree-ring representation from Central Asian region (Esper *et al*., 2001). Central Asia could contribute considerable information as the region constitutes the great Himalaya, Hindukush and Korakuram. The Himalayan mountains lie in an interesting zone of increasing human population at lower elevation in Pakistan. Human activities are major causes of changing climate, hence dendroclimatology studies could present evidence of extreme climate regimes from this region (Rao *et al*., 2018; Ahmed *et al*., 2012).

This paper contributes to the climatic studies from mid elevations (2072 to 2672 m) of Himalayas in Pakistan. The area is known as Ayubia, a popular natural tourism destination in Pakistan. The area consists of an old growth forest of mixed stands of *Pinus wallichiana, Abies pindrow,* and *Cedrus deodara* (Ahmed, 1986). Due to expansion of human population near these forests, changes in climate and plant populations have been observed (Khan, 2021; Khan *et al*., 2018a; Siddiqui, 2011). Our aim is to examine the growth-climate relationship of a conifer species, *Abies pindrow* Royle, inhabiting in the forest, which would help in reconstructing past climate.

Climate of Murree-Ayubia: Ayubia lies in Khyber Pukhtoonkhuwa (KPK) province of Pakistan (Fig. 1). The longitude is 073°23'59.5" E, the latitude is 34°01'73.0" N, and the elevation is 2672 m above sea level. At ~2000 m elevation, a forest of conifers, specifically fir (*Abies pindrow*), exists with trees on the order of 100+ years of age (Khan *et al.,* 2020). Slopes are extreme 31° - 35°) and mostly north-facing. Soils are predominantly sandy clay, well moistened, and rich in organic matter (Khan *et al*., 2018b; Siddiqui, 2011).

Murree is generally a warm and temperate region. Rains occur more in summer than winter (Fig. 2). The annual mean temperature of the area is 12.7°C while mean annual precipitation is 1440 mm, which makes the region moist temperate in nature. The hottest month is June, the wettest months are July and August, and the driest month is November (Fig. 2).

Materials and Method

Dendrochronology sampling in this forest took place in 2017. Using Swedish increment borers, core samples were taken from five different forest stands. Two cores per tree were collected from opposite sides of each tree, as is customary (Stokes & Smiley, 1968). Cores were stored in straws and transported to the lab for processing.

Tree cores were processed for dendrochronological analysis following standard procedure (Phipps, 1985). They were air dried, mounted into protective sticks, sanded with successively finer abrasives in order to create a smooth surface to see the growth rings clearly (Phipps, 1985). Ring growth was crossdated (Yamaguchi, 1991), and ring widths were measured to ± 0.01 mm using Tellervo (Brewer, 2014). Crossdating and measurement accuracy were checked using COFECHA (Holmes, 1983), which cross-correlates segments of series against each other to assess the strength of their matching. Dating and measurement errors were checked by re-consulting the samples and measurement values (Cook, 1985).

Upon confirming correct dating of growth rings, a standard chronology was constructed. Ring-width series were detrended using the conservative modified-negative exponential model or a straight line as a default option (Fritts *et al*., 1969). Index series were calculated by dividing ring widths by the fit lines, yielding stationary series that were averaged together into a site chronology (Cook, 1985).

For examining growth-climate relationships, climate data was retrieved from Department of Meteorology, Pakistan. Dendroclimatic modeling started by correlating the tree-ring chronology with monthly climate data for the common period of overlap, 1987–2016 (Blasing *et al*., 1984). Based on strengths of monthly correlations, various seasons of climate were also considered (Meko, 1981). Upon deriving the strongest possible model of climate with the tree-ring chronology, a regression model was run to establish a quantitative model between tree growth and climate (Elshorbagy *et al*., 2016). Significance of coefficients, strength of shared variance, PRESS R-sq value (Michaelsen *et al*., 1987), and model residuals were assessed as measures of model strength.

Upon evaluating the final dendroclimatic model for the full length of the tree-ring chronology, the reconstructed climate variable was analyzed for frequency of extreme events and low-frequency (decadal) departures.

Fig. 1. Map of Murree-Ayubia showing location in Pakistan.

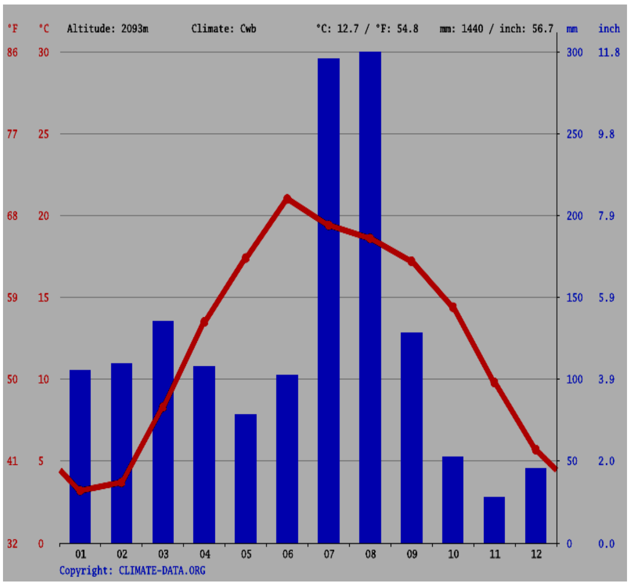

Fig. 2. Mean monthly average temperature and precipitation in Murree-Ayubia.

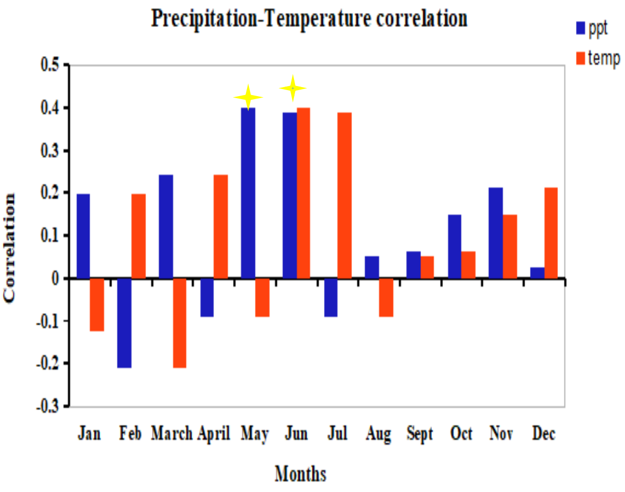

Fig. 3. Temperature-precipitation correlations *Abies pindrow* growth rings.

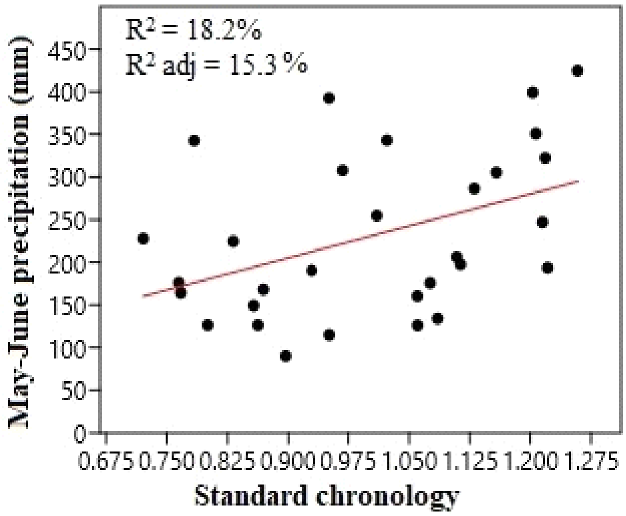

Fig. 4. Bivariate scatter plot between chronologies and season (precipitation).

Results and Discussions

Trees of *Abies pindrow* reached as old as 148 years at this site (Ayubia), though the average age of trees sampled was 83 years (Table 1). Average mean sensitivity was 0.280 and average autocorrelation was 0.757. Crossdating was evident but quantitatively weak, with an average correlation between trees and the chronology of +0.444 (Table 1) with EPS value greater than 0.85.

Table 1. Chronology values from ARSTAN output.

Summary statistics	
Number of dated series	28
Master series 1870-2017	148 years
Total rings in all series	2333
Total dated rings checked	2313
Series intercorrelation	0.444
Average mean sensitivity	0.280
Segments, possible problems	6
Mean length of series	83
Mean auto-correlation	0.757
Express Population Signal	> 0.85

Table 2. Bivariate linear model statistics from May-June and tree-ring chronology.

Regression statistics	
R^2 value	15.3%
Press R^2 value	6.4%
Correlation coefficient	($p<0.02$)

After preliminary assessment (Fig. 3), a season of precipitation from May–June was calculated and found to be the climate variable strongly positively associated (r = +0.40) with the growth of tree-ring chronology (Fig. 4). Therefore, May-June precipitation was reconstructed using the tree-ring chronology. A linear model was estimated, with a significant coefficient ($p<0.02$), an adjusted R-sq of 15.3%, and a PRESS R-sq of 6.4% (Table 2). While not overly strong, this model was the strongest one for this site and is biologically logical (increased moisture availability leads to increased ring growth). Model residuals were acceptable in showing no relationship with the predicted values (Fig. 5).

The reconstruction of May-June precipitation at this site shows typical climate patterns (Fig. 6). High-frequency variation is as expected, some decadal-scale departures are shown, e.g., a dry period in the 1980s and a wet period in the 2000s. Other departures are evident earlier on, though the sample depth of the chronology weakens going back in time by 1940.

A continuous wavelet transformation model is applied for analyzing the temporal seasonal variation on an annual basis. For this purpose, we divided the predefined reconstructed chronology over the period from 1870-2016 into 50-year segments (Fig. 7a, b, and c). Highest signal strength was occurred from 1870-1920 AD segment (Fig. 7a) that have produced weak correlations ($p<0.02$) but continuity throughout the whole period in between 2-3.5 years scale. Stronger signals were observed from 1932-1970 AD with some discontinuity at the scale of 1.5-2.5 years and 4-4.5 years indicating the interruptions in rainfall pattern (Fig. 7b). Low frequency bands were mostly observed in the third segment (Fig. 7c). High signal strength occurred in 1993-2007 AD at the scale of 1.8-2.5 years. This demonstrates the wettest periods in the past years while fewer low frequency bands of dry period spotted from the wavelet spectrum at few places. Cumulatively, the area preserves adequate precipitation level at present, but the signals show a gradual decrease in precipitation flux through time (Fig. 7, Table 3).

Discussion

The changing dynamics of climate have emerged on global scale as a consequence of rise in temperature and hydrological gradients. Pakistan experiences large climatic variations within its diverse range of ecological boundaries. The Himalayas share interesting climatic history of gradients over last several decades. The spatial shifting in rainfall pattern predominantly indicates the differential fluctuations in climate of the region (Rodo, 2003). However, summer monsoonal rains might be critical for climatic analysis (Sheppard & Wiedenhoeft, 2007). Salma *et al*., (2012) found rainfall changes in Pakistan in the past years based on data analysis from 30 different weather stations in the country. Himalayan regions have higher rainfall than other northern areas and adjacent mountain ranges like Hindukush and Korakorum (Ahmed, 1986). Although the region possessed high precipitation, the lesser Himalayas showed a slightly decreased level of precipitation in recent time (Rao *et al*., 2018). A remarkable decrease in precipitation intensity occurred from 1976-1990 AD but this rainfall level was negligibly greater than rainfall in 1991-2005 (Salma *et al*., 2012). The time periods indicate a gradual lowering of precipitation that has started from lower regions. While collecting the facts for lowering in rainfall pattern, the socioeconomic importance of the region of population and livestock propagation cannot be ignored, might be a reason for the rise in temperature and fall in precipitation (Yadav *et al.,* 2016). As agricultural industries, livestock and other related factors rely on summer rainfall (Zafar *et al.,* 2015; Yadav*,* 2011; Sheppard & Wiedenhoeft, 2007; Cox, 1988). The ring-width patterns and reconstructed model of current study indicates a slight drop in precipitation after year 2000. Conifers in the region generally show positive correlations with June-August precipitation (Ahmed *et al*., 2011) whereas in our study the rainfall of June period shifted into July-August period. Weak sensitivity recorded from the same area along with significant rainfall regimes from 1980 to 2000 whereas our study points for the change of trend from 1975.

Table 3. Determination of dry and low precipitation years at an interval of 50 years time scale.

Time scale (50 year interval)	Wet period	Dry period
1870-1920	1870-1883, 1884-1920	1880-1888, 1896-1919
1921-1970	1933-1970	1921-1924
1971-2016	1991-2007	1971-1978, 1987-1990, 2002-2006, 2008-2011, 2012-2015

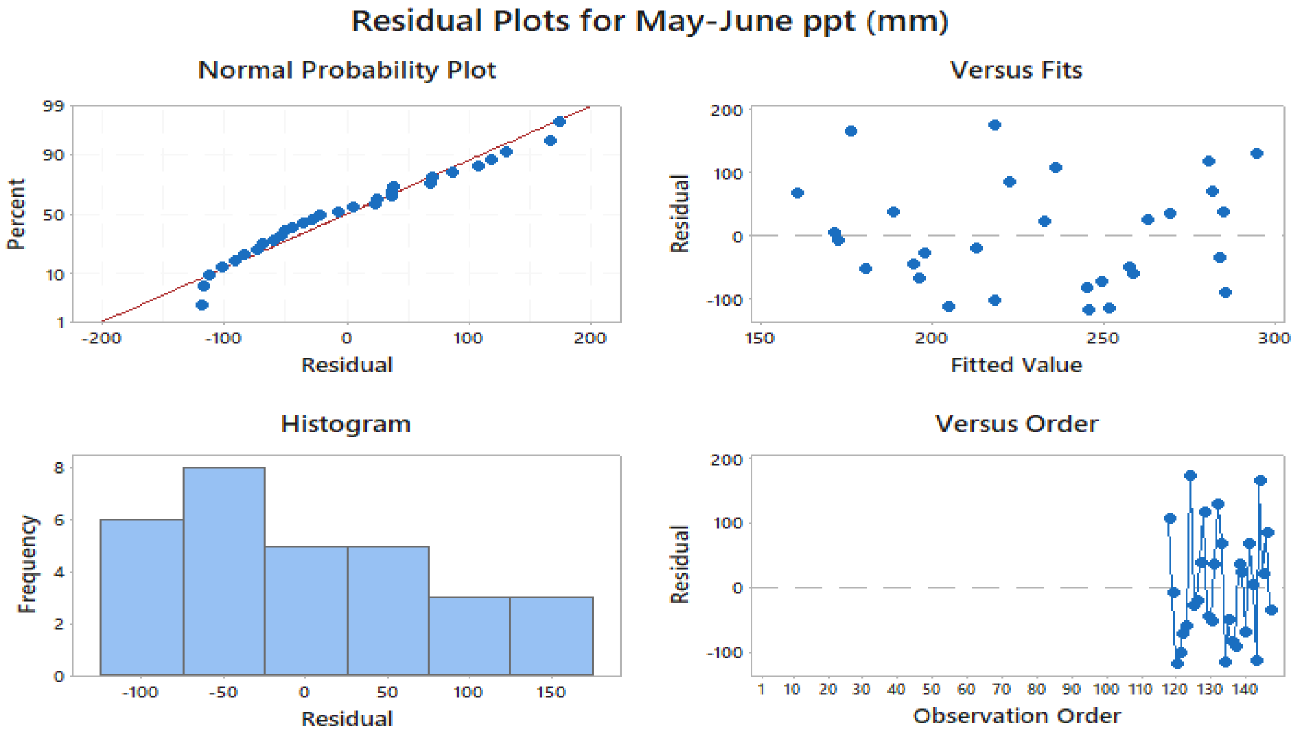

Fig. 5. Residual plots for May-June precipitation (mm).

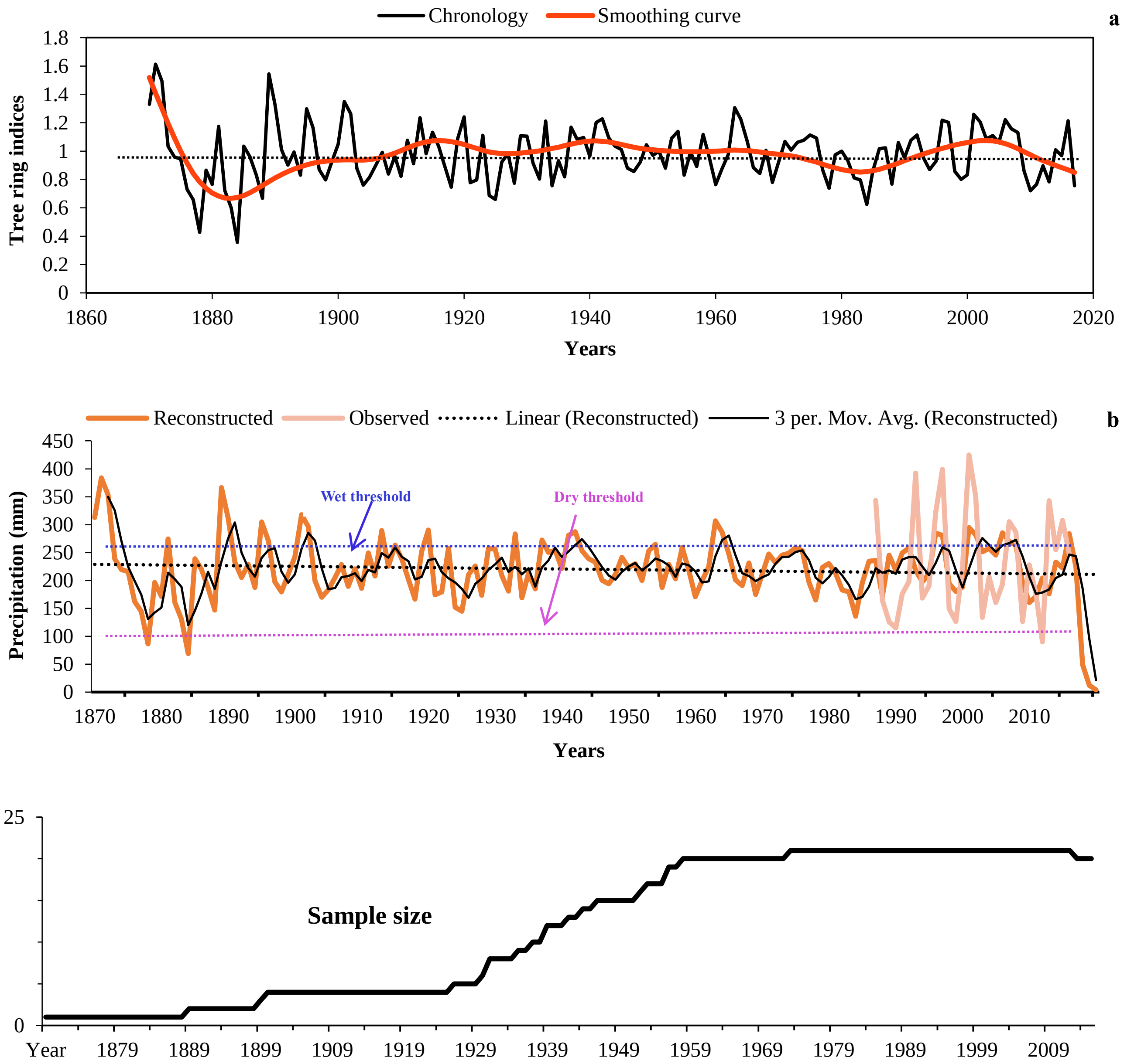

Fig. 6. Ring-width pattern of *Abies pindrow* from 1870-2016 AD. Fig. 6a presents ring width indices. Fig. 6b. presents climatic reconstruction of May-June precipitation.

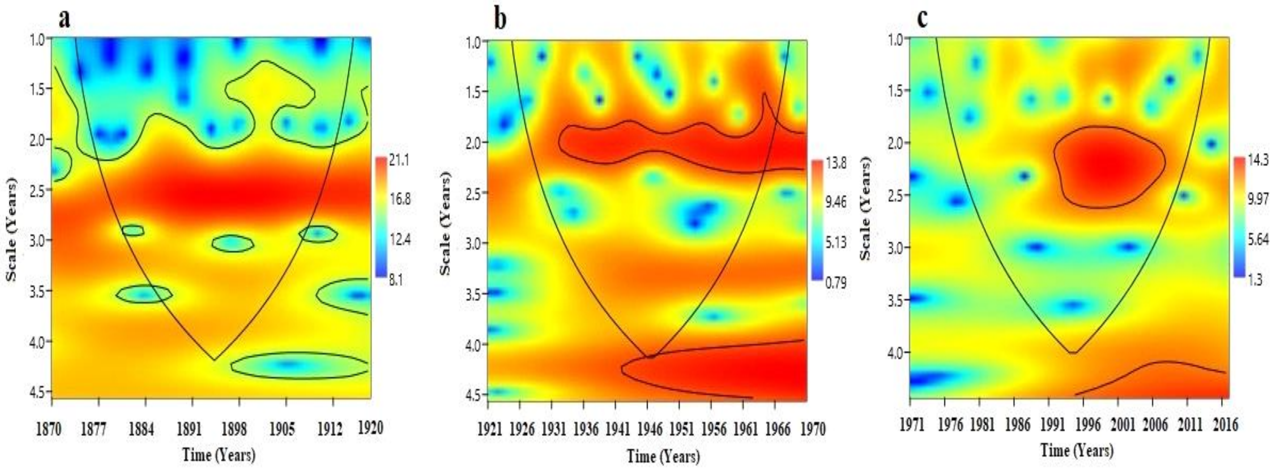

Fig. 7. Annual summer precipitation correlations at 50 years interval from 1870-2016AD.

The lower regions of Himalayas are advantageous for human population, as a resourceful habitat with moderate climatic conditions. The past decades since 1980 have seen a remarkable increase in disturbance in this area that has caused dramatic fluctuations in climatic yearly trends (Gaire *et al.,* 2017; Yadav *et al.,* 2016). It is important to study short-term variability in tree growth as it leads as it reveals the actual climate change that has short-term frequencies over inter-annual scale (Kumar *et al*., 2019).

The amount of precipitation per day was evaluated in Hindukush-Korakorum-Himalayan regions by collecting climatic data from different grid stations in the country as well as by using different gauges and instruments for rainfall measurements to make a reliable precipitation assessment (Palazzi *et al*., 2012). Hydrological investigations showed initiation of monsoon season from May to June that reached its peak with highest precipitation in July and lowered down in August during 1950 to 2009, this pattern was common in Himalayas (Pallazi *et al*., 2012). While Tredyte *et al*., (2006) showed the late 1800s to early periods of 1900s for the extreme rainfall in the summer season which has gradually decreased on a yearly basis after 1960s in Himalayas. However, short-term variabilities can be explained by the help of climatic signals transmitted over smaller time periods. In this regard, continuous wavelet transformation (CWT) is a robust tool that determines temporal variabilities (Torrence & Compo, 1998). This kind of spectral analysis is considered useful for examination of non-stationary processes like climatic fluctuations (Jemai *et al*., 2017; Torrence & Compo, 1998). By utilizing reconstruction model and CWT, our study shows a slight decrease in rainfall pattern and fluctuations in tree growth per year. This indicates an inter-annual variability in the seasonal pattern on short term scale and hindering the stability of regional climate. Pallazi *et al*., (2012) presented Himalayas precipitation status with a comparative summer precipitation pattern along with other ecologically and climatically important regions (Hindukush-Korakorum) showing the Himalayas as the wettest region in the country and holds a geographically important position to set up climatic stability.

Conclusion

The Himalayas are experiencing rapid climatic fluctuations due to extreme anthropogenic influence in the area, the inter-annual variability as a function of changing environment claims rapidly changing climatic conditions. The climate is slowly evolving towards drought as the temperature is rising and rainfall pattern is dropping downwards. In order to explore the basis of climatic fluctuations in a region, dendroclimatology provides a deeper insight for the explanation of consequences. Tree rings are the tools for extraction of climatic proxies that is the most reliable natural data to study. Current findings conclude a sharp decrease in wet seasonal duration and lowering in rainfall pattern that would be responsible for changing in the diversity and ecological systems in the region.

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References

Ahlström, A., M.R. Raupach, G. Schurgers, B. Smith, A. Arneth, M. Jung, M. Reichstein, J.G. Canadell, P. Friedlingstein, A.K. Jain, E. Kato, B. Poulter, S. Sitch, B.D. Stocker, N. Viovy, Y.P. Wang, A. Wiltshire, S. Zaehle and N. Zeng. 2015. Carbon cycle. The dominant role of semi-arid ecosystems in the trend and variability of the land CO_2 sink. *Science*, 348: 895-899.doi:10.1126/science.aaa1668

Ahmed, M. 1986. Vegetation of some foothills of Himalayan range of Pakistan. *Pak. J. Bot*., 18: 261-269.

Ahmed, M., J. Palmer, N. Khan, M. Wahab, P. Fenwick, J. Esper and E. Cook. 2011. The dendroclimatic potential of conifers from northern Pakistan. *Dendrochronologia*, 29(2): 77-88.

Ahmed, M., N. Khan, M. Wahab, M.U. Zafar and J. Palmer. 2012. Climate growth correlation of tree species in the Indus Basin of the Karakorum Range, North Pakistan. Int. Assoc. Wood Anat. *IAWA J*., 33(1): 51-56.

Anonymous. 2014. Synthesis Report. Contribution of working groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. Geneva.

Barr, A.G., D.Y. Hollinger and A.D. Richardson. 2007. CO2 flux measurement uncertainty estimates for NACP. Eos Trans. AGU, 90, Fall Meet. Suppl., Abstract B54A-04.

Blasing, T.J., A.M. Solomon and D.N. Duvick. 1984. Response functions revisited. *Tree-Ring Bull*., 44: 37-43.

Brewer, P. 2014. Data management in dendroarchaeology using Tellervo. *Radiocarbon*, 56(4): 79-83.

Coker, T.L.R., J. Rozsypálek, A. Edwards, T.P. Harwood, L. Butfoy and R.J.A. Buggs. 2019. Estimating mortality rates of European ash (*Fraxinus excelsior*) under the ash dieback (*Hymenoscyphus fraxineus*) epidemic. *Plants, People, Planet.*, 1: 48-58.

Cook, E.R. 1985. A time series analysis approach to tree ring standardization. (Theses). University of Arizona. https://ltrr.arizona.edu/content/time-series-analysis-approach-tree-ring-standardization.

Cox, J.R. 1988. Seasonal burning and mowing impacts on Sporobolus wrightii grasslands. *J. Rang. Manag*., 41(1): 12-15.

Elshorbagy, A., T. Wagener, S. Razavi and D. Sauchyn. 2016. Correlation and causation in tree-ring-based reconstruction of paleohydrology in cold semiarid regions. *Water. Res. Res*., 52: 7053-7069.

Esper, J., K. Treydte, H. Gartner and B. Neuwirth. 2001. A tree-ring reconstruction of climatic extreme years since AD 1427 for western central Asia. *Palaeobot*., 50: 141-152.

Fitzpatrick, M.C. and R.R. Dunn. 2019. Contemporary climatic analogs for 540 North American urban areas in the late 21st century. *Nat. Com*., 10(1): 614.

Fritts, H.C. 1991. Reconstructing large-scale climatic patterns from tree-ring data. University of Arizona Press, Tucson.

Fritts, H.C., E.A. Vaganov, I.V. Sviderskaya and A.V. Shashkin. 1991. Climatic variation and tree ring structure in conifers: empirical and mechanistic models of tree ring width, number of cells, cell size, cell-wall thickness and wood density. *Clim. Res*., 1: 97-116.

Fritts, H.C., J.E. Mosimann and C.P. Bottorf. 1969. A revised computer program for standardized tree-ring series. *Tree-Ring Bull*., 29: 15-20.

Gaire, N.P., D.R. Bhuju, M. Koirala, S.K. Shah, M. Carrer and R. Timilsena. 2017. Tree-ring based spring precipitation reconstruction in western Nepal Himalaya since AD 1840. *Dendrochronologia,* 42: 21-30.

Hecht, A.D., ed. 1985. Paleoclimatic analysis and modeling. New York: John Wiley and Sons.

Holmes, R.L. 1983. Computer-assisted quality control in tree-ring dating and measurement. *Tree-Ring Bull*., 43: 69-78.

IPCC. Climate Change. 2014. Synthesis Report. Contribution of working groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. Geneva.

Jemai, S., M. Ellouze and A. Habib. 2017. Variability of precipitation in arid climates using the wavelet approach: Case study of watershed of Gabes in south-east Tunisia. *Atmosphere*, 8: 178-194.

Khan, A. 2021. Seedling diversity and spatial distribution of some conifers and associated tree species under highly disturbed western Himalayan regions of Pakistan. *J. F. Sci.,* 67(4): 175-184. https://doi.org/10.17221/138/2020-JFS

Khan, A., M. Ahmed, A. Khan and F. Ahmed. 2020. Dynamics of highly disturbed pine species around Murree hills of Pakistan; A preliminary study. *Pak. J. Agri. Sci.,* 57(6): 1597-1606.

Khan, A., M. Ahmed, A. Khan and M.F. Siddiqui. 2018a. Ring width characteristics of 4 pine tree species from highly disturbed areas around Murree, Pakistan. *Pak. J. Bot*., 50(6): 2331-2337.

Khan, A., M. Ahmed, A. Khan, F. Ahmed and M.F. Siddiqui. 2018b. Quantitative description and future trends of highly disturbed forest around Murree Hills. *FUUAST J. Biol*., 8(2): 169-191.

Kumar, M., S.H. Singh, R. Pandey, M.P. Singh, N.H. Ravindranath and N. Kalra. 2019. Assessing vulnerability of forest ecosystem in the Indian Western Himalayan region using trends of net primary productivity. *Biod. & Cons*., 28: 2163-2182. https://doi.org/10.1007/s10531-018-1663-2

Meko, D.M. 1981. Applications of Box-Jenkins methods of time series analysis to the reconstruction of drought from tree rings. Ph.D. Dissertation, University of Arizona, Tucson.

Michaelsen, J., L. Haston and F.W. Davis. 1987. 400 years of central California precipitation variability reconstructed from tree-rings. *Water Res. Bull*., 23: 809-818.

Palazzi, E., J von Hardenberg and A. Provenzale. 2012. Precipitation in the Hindu-Kush Korakorum Himalaya: Observations and future scenarios. *J. Geophy. Res*.: *Atmosphere*, 118: 85-100.

Phipps, R.L. 1985. Collecting, preparing, cross-dating, and measuring tree increment cores. *US Geological Survey Water Resources Investigations Report*, 85-4148. 48pp.

Rao, M.P., E.R. Cook, B.I. Cook, J.G. Palmer, M. Uriarte and N. Devineni. 2018. Six centuries of upper indus basin streamflow variability and its climatic drivers. *Water Res. Res*., 54(8): 5687-5701.

Rodo, X. 2003. Global climate current research and uncertainties in the climate system. *University of Barcelona Climate Research Group Baldiri Rexac*, 4-6, Torre D 08032 Barcelona Spain, 3-6.

Roibu, C.C., V. Sfecla, A. Mursa, M. Ionita, V. Nagavciuc, F. Chiriloaei, I. Lesan and I. Popa. 2020. The climate response of tree-ring width components of Ash (*Fraxinus excelsior* L.) and common Oak (*Quercus robus* L.) from Eastern Europe. *For.,* 11: 600.

Salma, S., S. Rehman and M.A. Shah. 2012. Rainfall trends in different climate zones of Pakistan. *Pak. J. Met*., 9(17): 37-47.

Schlesinger, M.E. and J.F.B. Mitchell. 1987. Climate model simulations of the equilibrium climatic response to increased carbon dioxide. *Rev. Geophy.*, 25: 760-798.

Sheppard, P.R. and A. Wiedenhoeft. 2007. An advancement in removing extraneous color from wood for low-magnification reflected-light image analysis of conifer tree rings. *Wood & Fiber Sci*., 39(1): 173-183.

Siddiqui, M.F. 2011. Community structure and dynamics of conifer forests of moist temperate areas of Himalayan range of Pakistan. Doctoral dissertation, Department of Botany, Federal Urdu University of Arts Sciences and Technology Karachi.

Stokes, M.A. and T.L. Smiley. 1968. An introduction to tree-ring dating. Chicago: University of Chicago Press.

Stoy, P.C., G.G. Katul, M.B.S. Siqueira, J.Y. Juang, K.A. Novick, J.M. Uebelherr and R. Oren. 2006. An evaluation of models for partitioning eddy covariance-measured net ecosystem exchange into photosynthesis and respiration. *Agr. Forest Meteorol.*, 141: 2-18.

Texeira, M., G. Baldi and J. Paruelo. 2012. An exploration of direct and indirect drivers of herbivore reproductive performance in arid and semi arid rangelands by means of structural equations models. *J. Arid. Agric. Env.,* 81: 26-34.

Torrence, C. and G.P. Compo. 1998. A practical guide to wavelet analysis. *Bull. Amer. Meteorol. Soc.*, 79: 61-78.

Treydte, K.S., G.H. Schleser, G. Helle, D.C. Frank, M. Winiger, G.H. Haug and J. Esper. 2006. The twentieth century was the wettest period in northern Pakistan over the past millennium. *Nature*, 440(27): 1179-1182.

Wood, F.B. 1988a. Global alpine glacier trends, 1960s-1980s. *Arctic & Alpine Res*., 20: 404-413.

Wood, F.B. 1988b. The need for systems research on global climate change. *Sys. Res*., 5: 225-240.

Yadav, A.K., A. Brauning, A. Singh and R.R. Yadav. 2016. Boreal spring precipitation variability in the cold arid western Himalaya during the last millenium, regional linkages and socio-economic implications. *Qua. Sci. Rev.,* 144: 28-43.

Yadav, R.R. 2011. Long-term hydroclimatic variability in monsoon shadow zone of western Himalaya, India. *Clim. Dyn.*, 36: 1453–1462.

Yamaguchi, D.K. 1991. A simple method for cross-dating increment cores from living trees. *Can. J. For. Res*., 21: 414-416.

Zafar, M.U., M. Ahmed, M.P. Rao, B.M. Buckley, N. Khan, M. Wahab and J. Palmer. 2015. Karakorum temperature out of phase with hemispheric trends for the past five centuries. *Clim. Dyn*, 46: 1943-1952.

Zscheischler, J., S. Fatichi, S. Wolf, P.D. Blanken,, G. Bohrer, K. Clark, A.R. Desai, D. Hollinge, T. Keenan, K.A. Novick and S.I. Seneviratne. 2016. Short-term favorable weather conditions are an important control of interannual variability in carbon and water fluxes. *J. Geophy. Res. Biogeosci*., 121(8): 2186-2198.

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