Dendroclimatic analysis of Western Himalayan tree growth in India

The various mountain ranges of the Western Himalaya have a high topography barrier on the surface of the earth, which plays an important role in limiting monsoon circulation in the Asian region. Particularly, in the Himalaya, tropical, subtropical, temperate and Mediterranean influences interact with each other, causing vast differences in climate fluctuation within short distances. Precipitation shows high variability due to diverse mountainous regions. In contrast, temperature shows strong spatial coherence[1].

To understand climate variability/change in the Western Himalaya over the past few centuries, several studies were carried out using tree rings as high-resolution proxy records with respect to climate fluctuations[1–5]. They have shown that tree-ring records of the Himalaya are important to reconstruct past climate before instrumental records for understanding the natural and anthropogenic climate change. Ram and Borgaonkar[6] have shown the strong relationship of tree growth with multiple climatic parameters and have discussed the role of climatic parameters in tree growth processes.

However, most of the tree-ring chronologies of the diverse Himalayan mountain ranges are focused on rainfall and temperature to understand the longer climatic variations. In the present study, an effort has been made to improve our understanding on tree growth–climate relationship in complex geological features and to observe the influences of several meteorological parameters on tree growth processes in which some of the parameters are not measurable using instruments but only obtained through computation.

For the present study, Bhairoghati tree-ring data near the Gangotri region was used with a variation in climate (Figure 1), which is located about 100 km away in the southeast of Shimla, Himachal Pradesh[7]. Tree-ring dating was verified using the program COFECHA[8]. The mean correlation coefficients (0.67) showed good cross-matching in ring-width measurements and revealed strong common forcing of climate on tree growth.

To produce signal-free functions in the chronology, RCS_Sig_Free software was used[9,10]. Tree-ring width was aligned to the age of biological. The obtained series were averaged using the biweight robust mean method to compute site chronology of *Cedrus deodara* extending from 1738 to 2004, based on 22 series (Figure 2), which is found reliable to dendroclimatic analysis[11].

To analyze the relationship between tree growth and climate, I used the grid point (31°.25, 78°.25E) climatic data of monthly mean temperature (TM), precipitation (PPT) and vapour pressure (VP) as a continuous record for the period 1901–2017 from climatic research unit (CRU)[12] (Figure 1). In addition, moisture index (MI) and potential evapotranspiration (PET) for the corresponding months were computed using the methods of Thornthwaite[13] and Ram *et al.*[14], to understand the influence of climate on tree growth in combination with several meteorological parameters.

Figure 3 shows the monthly variations in precipitation, temperature, vapour pressure and potential evapotranspiration near the sampling areas. June is the hottest month (17.6°C) and January the coldest (2.2°C) over the region. July receives the highest rainfall (241.5 mm). The monsoon season (June and July) contributes around 70% of annual rainfall (Figure 3).

To analyse tree growth–climate relationship, correlation analysis of tree growth with TM, VP, PET, PPT and MI was performed during 1901–2004 using DENDROCLIM2002 (ref. 15). Monthly mean TM, VP, PET, PPT and MI values were used with chronology, from the previous year's to the current year's October[16]. TM, VP and PET showed significant positive association for tree growth during the previous year's November, December and the

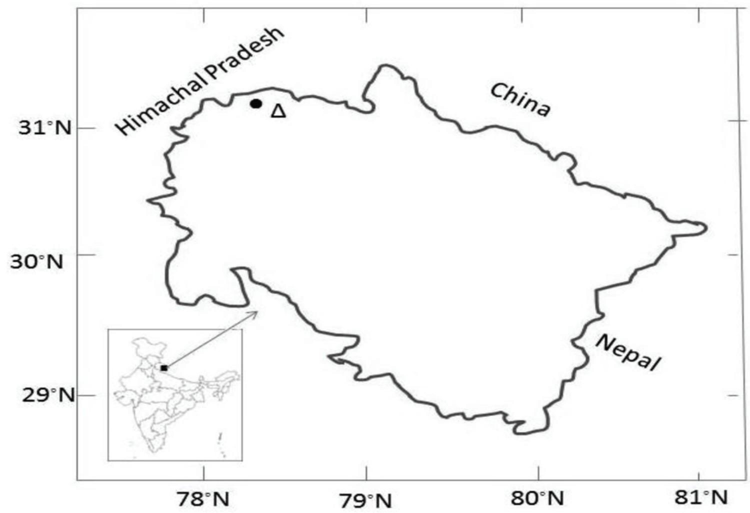

Figure 1. Map showing the location of the sampling site. △: Tree ring-width; ●: grid point climate data.

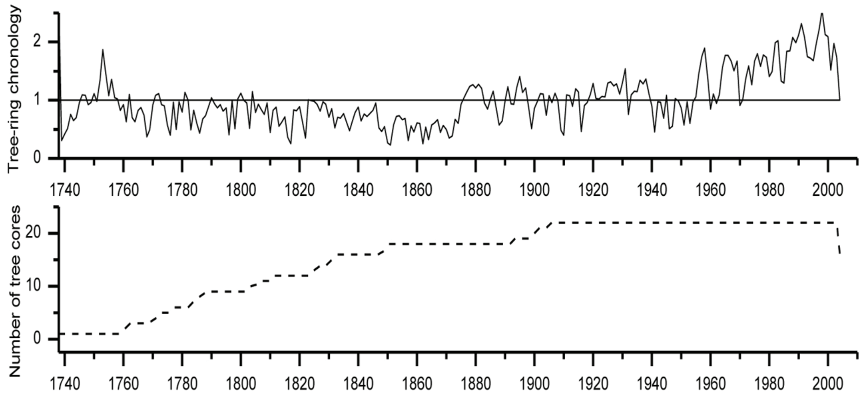

Figure 2. Tree-ring chronology from Bhairoghati, Western Himalaya, India along with tree cores sample during 1738–2004.

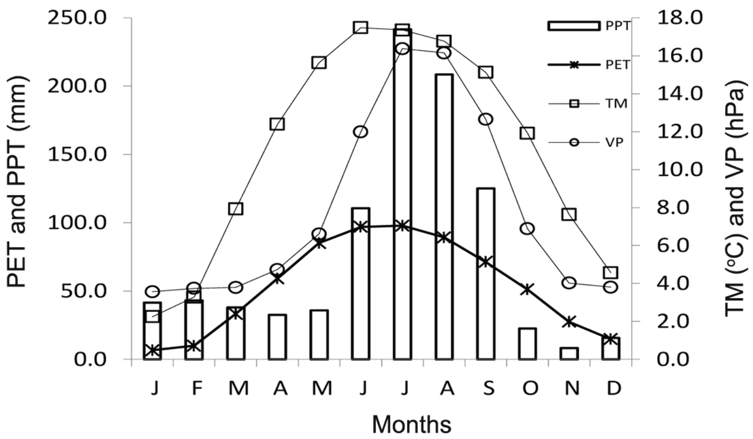

Figure 3. Average monthly temperature (TM), precipitation (PPT), vapour pressure (VP) and potential evapotranspiration (PET) during 1901–2017.

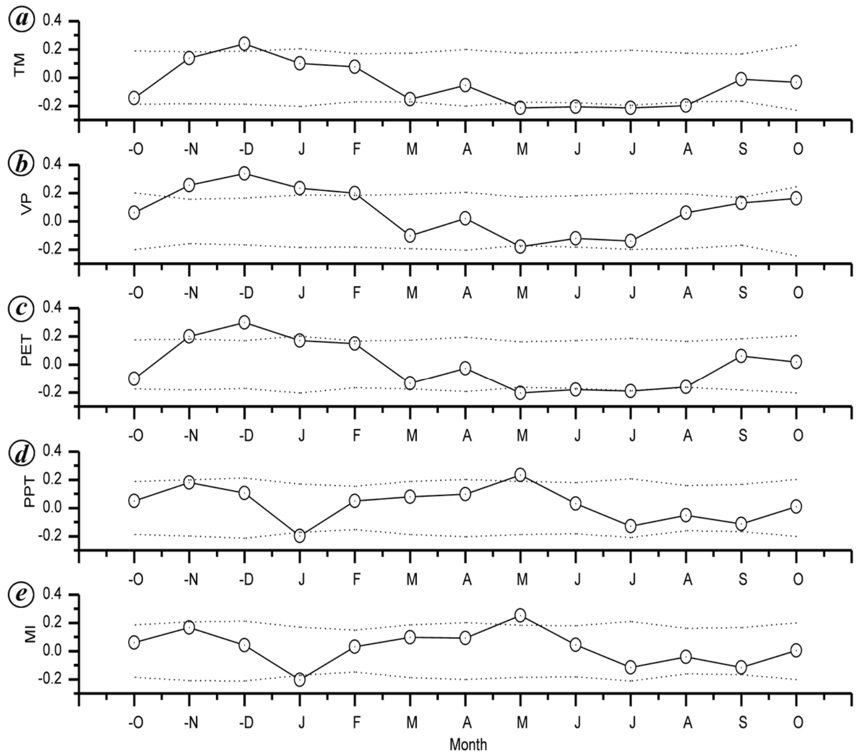

Figure 4. Correlation of chronology using (***a***) TM, (***b***) VP, (***c***) PET, (***d***) PPT and (***e***) moisture index (MI). Dotted lines show the significance level at 5%.

current year's January and February. PET and TM during January and February were barely significant, but showed a negative relationship with tree growth (Figure 4). The results indicate that increasing trends in TM, VP and PET during winter months (November–February) over the region may trigger early snowmelt, which in turn increases the available soil moisture and has been responsible for surge in the growth of trees during the 20th century through the influence on soil moisture and photosynthesis[17]. A similar type of trend in tree growth has been reported by Singh and Yadav[18]. In temperate regions, the persistence of low temperature for a longer term during winter months at high elevations may be detrimental to photosynthesis and respiration, which caused the slow growth prior to the 1950s, reflecting very cool conditions as evidenced by Tranquillini[19]. So, increasing TM, VP and PET over the region might increase the water movement rapidly into a tree, resulting in stomata exposed as evidenced[2,17,19–21]. So, dendroclimatic analysis of trees close to existing glaciers may provide valuable information on climate change over the region during the recent past.

A significant negative association of tree-ring chronology with TM, VP and PET during summer (May–August) showed that increasing TM, VP and PET over the region may increase evapotranspiration, resulting in insufficient moisture for tree growth, which might harm the trees during their growing season. Similar observations have been reported in earlier studies over the Western Himalaya[6,7]. VP showed a slightly week relationship with tree growth, but was poorly significant during June to August.

The existence of significant association of single tree growth with various meteorological parameters encourages developing a long tree-ring chronology with higher replication of tree cores collected at distinct locations, which may provide valuable information on climate fluctuations for better understanding the past environment conditions. This study may prove useful in forest management, water resources and hydrology.

1. Yadav, R. R., Park, W.-K. and Bhattacharyya, A., *Holocene*, 1999, **9**, 85–90.
2. Ram, S., *Quaternary Int*., 2012, **254**, 152–158.
3. Cook, E. R., Anchukaitis, K. J., Buckley, B. M., D'Arrigo, R. D., Jacoby, G. C. and Wright, W. E., *Science*, 2010, **328**, 486–489.
4. Yadav, R. R., Park, W. K., Singh, J. and Dubey, B., *Geophys. Res. Lett*., 2004, **31**, L17201; doi:10.1029/2004GL020201.
5. Singh, J., Yadav, R. R. and Wilmking, M., *Climate Dyn*., 2009; doi:10:1007/s00382-09-0528-5.
6. Ram, S. and Borgaonkar, H. P., *Dendrochronologia*, 2014, **32**, 32–38.
7. Borgaonkar, H. P., Ram, S. and Sikder, A. B., *Dendrochronologia*, 2009, **27**, 59–69.
8. Holmes, R. L., *Tree-Ring Bull*., 1983, **44**, 69–75.
9. Cook, E. R., Krusic, P. J., Holmes, R. H. and Peters, K., Program ARSTAN Ver.44a. 2011; www.ldeo.columbia.edu/tree-ring-laboratory
10. Melvin, T. M. and Briffia, K. R., *Dendrochronologia*, 2008, **26**, 71–86.
11. Wigley, T. M. L., Briffa, K. R. and Jones, P. D., *J. Climate Appl. Meteorol*., 1984, **23**, 201–213.
12. Ian, H., Jones, P. D., Osborn, T. J. and Lister, D. H., *Int. J. Climatol*., 2014, **34**, 623–642.
13. Thornthwaite, C. W., *Geogr. Rev*., 1948, **38**, 55–94.
14. Ram, S., Borgaonkar, H. P. and Sikder, A. B., *J. Earth Syst. Sci.*, 2008, **117(**5), 637–645.
15. Biondi, F. and Waikul, K., *Comput. Geosci*., 2004, **30**, 303–311.
16. Ram, S. and Borgaonkar, H. P., *Curr. Sci*., 2017, **112**(12), 2453–2455.
17. Fritts, H. C., *Tree-Rings and Climate*, Academic Press, London, UK, 1976.
18. Singh, J. and Yadav, R. R., *Curr. Sci*., 2000, **79**, 1598–1601.
19. Tranquillini, W., *Annu. Rev. Plant Physiol*., 1964, **15**, 345–362.
20. Ram, S. and Borgaonkar, H. P., *Curr. Sci*., 2013, **105**(2), 225–231.
21. Ram, S., Ph.D. thesis, Banaras Hindu University, Varanasi, 2021.

ACKNOWLEDGEMENTS. I thank the Director, Indian Institute of Tropical Meteorology, (IITM), Pune and R. Krishnan (Centre for Climate Change Research, IITM, Pune) for their continuous support and encouragement. I also thank the Forest Department of Uttarakhand for support; Dr H. P. Borgaonkar for help with the data and climatic research unit for making the climatic data available.

Received 17 January 2022; accepted 3 February 2022

SOMARU RAM

Indian Institute of Tropical Meteorology, Pune 411 008, India
e-mail: somaru@tropmet.res.in