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Tree ring drought records from Kishtwar, Jammu and Kashmir, northwest Himalaya, India

Vikram Singh [a], Ram R. Yadav [b,*], Anil K. Gupta [b], Bahadur S. Kotlia [c], Jayendra Singh [b], Akhilesh K. Yadava [a], Anoop K. Singh [c], Krishna G. Misra [a]

[a] *Birbal Sahni Institute of Palaeosciences, 53 University Road, Lucknow, India*
[b] *Wadia Institute of Himalayan Geology, Dehradun, India*
[c] *Centre of Advanced Study in Geology, Kumaun University, Nainital, India*

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ABSTRACT

Droughts in semi-arid and arid regions of the northwest Himalaya are very common causing distress to socioeconomic systems. Our understanding on natural variability in droughts in the northwest Himalaya in long-term perspective is limited largely due to paucity of observational and high-resolution proxy records. We developed a 275-years (A.D. 1740–2014) long Standardized Precipitation Index (eight months SPI of May, SPI8-May) reconstruction using ring-width chronology of Himalayan cedar (*Cedrus deodara* (Roxb.) G. Don) from Kishtwar, Jammu and Kashmir in the northwest Himalaya, India. The most conspicuous feature of reconstruction is pluvial 1950s, 1990s and dry 1970s. The wettest phase of 1990s is followed by a distinct drying since 2000s in Kishtwar. The reconstructed SPI8-May series showed very good consistency with tree–ring-based upper Indus basin discharge and gridded summer (June–July–August) PDSI data of the northwest Himalaya–Karakoram region. Such a consistency in SPI8-May, Indus discharge and summer PDSI in westerly dominated region of the Himalaya–Karakoram region underscores potential utility of SPI reconstructions in understanding climate change over the region in long-term perspective.

1. Introduction

Droughts are a frequently occurring phenomenon inflicting serious miseries to human societies almost every year in one or the other region of India (Shewale and Kumar, 2005). In recent years there is a growing concern globally on increase in frequency and intensity of droughts due to precipitation deficits that are amplified by ongoing increase in temperature (Dai, 2013). Deficient summer monsoon rainfall in western and central India consecutively in 2014 and 2015 caused serious water crisis, which worsened in early summer of 2016 and water trains were rushed to meet the civic water demands. Well developed surface transport system and infrastructure in plane areas of the country greatly help in mitigating the vagaries of such devastating droughts. However, coping with droughts in the Himalayan region is challenging as transport of water resources from one place to another, even in short distances, is very difficult due to highly dissected orographic terrains. Droughts occurring even for a short span of time cause drying of streams and aquifers in hilly terrains, which are the main source of water for agriculture and domestic needs. In view of this there is increasing need to understand natural variability in droughts in orography dominated regions of the Himalaya in a long-term perspective. In this line the Monsoon Asia Drought Atlas (MADA) developed by Cook et al. (2010) has shown the strength of tree–ring data networks in developing annually resolved spatial network of summer monsoon droughts in high Asia.

Droughts in the Himalayan region are caused by the reduction in precipitation brought by summer monsoon rains/western disturbances in monsoon/westerly dominated regions. Paucity of weather and high-resolution proxy records in the high elevation Himalayan region limit our understanding on hydroclimatic variability in long-term perspective. Tree rings have been widely used to develop annually resolved drought/hydrological records from

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* Corresponding author.
E-mail addresses: vnegi850@gmail.com (V. Singh), rryadav2000@gmail.com (R.R. Yadav), anil_k_gupta1960@yahoo.co.in (A.K. Gupta), bahadur.kotlia@gmail.com (B.S. Kotlia), singhwihg@gmail.com (J. Singh), akhilesh.k.yadava@gmail.com (A.K. Yadava), anoop1818@gmail.com (A.K. Singh), kgmisrabsip@gmail.com (K.G. Misra).

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semi-arid to arid regions of Asia (Sheppard et al., 2004; Davi et al., 2006; Li et al., 2006, 2007; Liang et al., 2006; Treydte et al., 2006; Yin et al., 2008; Cook et al., 2010, 2013; Shao et al., 2010; Zhang et al., 2011; He et al., 2012; Deng et al., 2013; Fang et al., 2013; Liu et al., 2013; Peng and Liu, 2013; Sun and Liu, 2013; Zhang et al., 2013, 2016; Bao et al., 2015; Yang et al., 2012, 2014a,b). But such studies in the Himalayan region are few and largely restricted to western part of the Himalayan region in Himachal Pradesh and Uttarakhand (Borgaonkar et al., 1996; Yadav, 2009, 2013; Shah et al., 2013; Singh and Yadav, 2013; Yadav et al., 2014, 2015; Misra et al., 2015; Yadava et al., 2016), Nepal Himalaya (Sano et al., 2011; Dawadi et al., 2013), eastern Himalaya (Shekhar and Bhattacharyya, 2015), and Bhutan Himalaya (Sano et al., 2013). Tree–ring studies in Jammu and Kashmir in the northwest Himalaya had a modest beginning in late 1980s with the investigation of ring-width, wood density (Hughes and Davies, 1987; Bhattacharyya et al., 1988) and isotope variations (Ramesh et al., 1985, 1986). The climatic reconstructions were restricted to the valley of Kashmir (Hughes, 1992, 2001; Borgaonkar et al., 1994; Ram, 2012). However, prior to the present study no attempt was made to develop dendroclimatic reconstruction from Jammu region in the northwest Himalaya, India. In the present study the main objectives of our research were i) establish the feasibility of climatic reconstruction especially concerning drought indices and ii) understand spatial patterns and regional hydroclimatic signatures in reconstructed drought indices from Kishtwar.

2. Data and methods

2.1. Tree–ring data

Himalayan cedar (*Cedrus deodara* (Roxb.) G. Don), a valued commercial timber tree in India grows in moist to semi-arid sites in monsoon and monsoon shadow zones of the western Himalaya at altitudes ranging from 1200 to 3300 m asl (Raizada and Sahni, 1960; Champion and Seth, 1968). Though it grows over a wide range of ecological conditions in the western Himalaya, its primary ecological requirements are a good amount of winter snowpack, not too heavy summer monsoon rainfall and well drained soils (Champion and Seth, 1968). The trees on moist sites usually grow faster and attain colossal girth in early age (Gamble, 1902); however, many of the thick trees growing on such sites usually do not attain long age largely due to common wood rot and other fungal/insect borne diseases. Himalayan cedar trees growing on semi-arid sites, where annual increment is low, attain longer ages. Ring-width series of Himalayan cedar (Singh et al., 2004) and other conifer species such as neoza pine (*Pinus gerardiana*) (Singh and Yadav, 2007; Yadava et al., 2016) and Himalayan pencil cedar (*Juniperus polycarpos*) (Yadav et al., 2006; Yadav, 2012) originating from semi-arid ecological settings in the western Himalaya, India have yielded long tree–ring chronologies extending over the last millennium. Thus far, most of the earlier tree–ring studies were restricted to Uttarakhand and Himachal Pradesh regions of the western Himalaya, India. The tree–ring studies of Himalayan cedar from the northwest Himalaya are of only exploratory nature (Bhattacharyya et al., 1988). To expand the tree–ring data network of this species in the Himalayan region we collected increment core samples of Himalayan cedar in July–August 2015 from semi-arid sites in Kishtwar located in the Middle Himalaya (Pir Panjal), Jammu and Kashmir, India (Fig. 1). Prior to our present study Bhattacharyya et al. in mid 1980s had collected Himalayan cedar samples growing in a moisture stressed site at Sashu in Kishtwar (33°20′N and 76°05′E, 1800 m asl) (Bhattacharyya et al., 1988). However, the sample replication in their collection was very low being restricted to 10 increment core samples from 3 trees only. Due to poor replication of tree core samples Bhattacharyya et al. (1988) did not attempt to identify the climate signal in tree–ring chronology. However, strong similarity in ring width pattern noted among trees and also consistency with growth pattern of neoza pine (*Pinus gerardiana*) growing over similar ecological settings in Kishtwar indicated common climate forcing (Bhattacharyya et al., 1988). In this study we present the analyses of increment core samples of Himalayan cedar collected from semi-arid locations in Kishtwar (Fig. 1). The sampling sites exhibited steep rocky slope with very thin soil cover, where trees are liable to suffer from moisture stress.

The growth ring sequences in increment cores were crossdated using conventional skeleton plotting method (Stokes and Smiley, 1968) and ring widths of precisely dated samples measured at 0.01 mm resolution using linear encoder (LINTAB) (Rinntech, Germany) coupled with personal computer. To assess dating quality, program COFECHA (Holmes, 1983) as well as matching of ring width measurement plots (Rinn, 2003) were used. Program COFECHA uses cross-correlation analyses in segmented blocks of individual tree-core measurement series with the master series prepared from all the series used in the analyses. Another important function of program COFECHA lies in assessment of the accuracy of ring-width measurements (Grissino-Mayer, 2001) by locating the 'outlier' ring-width measurements in any given year, which are flagged and listed in the output. These flagged measurements were carefully observed and re-measured to ensure if the original measurements were accurate.

Ring-width measurement series, in addition to climate forcing, are also influenced by various internal factors such as genetic constitution of trees, biological age and external factors like competition among neighboring trees and diseases. In dendroclimatic studies, these non-climatic trends inherent in ring-width measurement series are usually removed by curve fitting and detrending procedures referred as 'standardization' (Fritts, 1976). For standardization of ring-width measurement series we used 'signal-free' (SF) method (Melvin and Briffa, 2008), which is designed to enhance the preservation of common medium-to-low frequency variations ranging from timescales of decades to centuries in tree–ring chronologies. The signal-free method also mitigates the problem of 'trend distortion', which is most prevalent at the ends of the chronologies but can also occur anywhere in a tree–ring series as well, when flexible curve fitting methods are used (Melvin and Briffa, 2008). The signal-free method also has the advantage over conventional tree–ring standardization methods in mitigating the effects of 'segment length curse' (Cook et al., 1995) in preserving variability in excess of the lengths of tree–ring series used in development of the mean chronology. Using the signal-free method we detrended the raw ring-width measurement series of all the samples by applying a cubic smoothing spline (Cook and Peters, 1981) that preserved 50% of the amplitude over a wavelength of 67% of the series length. For standardization of the ring-width measurement series we used the program RCSsigFree_v45 provided by the Tree–Ring Laboratory, Lamont Doherty Earth Observatory (http://www.ldeo.columbia.edu/tree-ring-laboratory/resources/software). To stabilize the variance in heteroscedastic ring-width measurement series before detrending, data adaptive power transformation was applied (Cook and Peters, 1997). After detrending, the individual ring-width measurement series were combined to mean chronology (A.D. 1509–2014; Fig. 2) by calculating biweight robust mean (Cook, 1985). The expressed population signal (EPS) threshold of 0.85, considered to be reasonable for acceptance of chronology quality (Wigley et al., 1984) in

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