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Tree-ring based reconstruction of winter drought since 1767 CE from Uttarkashi, Western Himalaya

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A B S T R A C T

This article presents a reconstruction of winter (November–March) drought by using the Standardized Precipitation Evapotranspiration Index (SPEI) based on the tree-ring width data of *Pinus roxburghii* (Chir pine) growing near Uttarkashi, Garhwal region, western Himalaya. This is based on a significant negative correlation between growth of Chir pine and SPEI of November–March (N-M) months. This relationship might be linked with the low rate of photosynthesis during low or freezing temperature when roots unable to take soil moisture, an analogous to drought situation as in the cold desert. The reconstructed winter SPEI record extends from 1767 to 2013 CE. It explains 30.5% of the variance for the calibration period (1903–2013 CE). The regression model was tested using Correlation Coefficient (r), Coefficient of Determination (R^2), Reduction of Error (RE), Coefficient of efficiency (CE) and Durbin-Watson test (DW). The extended SPEI time series has revealed several intervals of high and low intensity drought since the 17th century. There is also a linkage between (N-M) months SPEI and Western Disturbance (WD). This connection indicates that the WD may have a role in modulating droughts in the Indian region.

1. Introduction

Extreme climatic events like droughts/floods are the greatest challenges in the context of global warming. As per model projections, there would be the more probable incidence of these events in coming years (IPCC, 2013). It is expected with the increase of temperature; the severity of drought conditions would be spreading and accelerate with the drying of the land surface (IPCC, 2013). Moreover, the warmer climates would alter the amount, intensity, frequency and type of precipitation in many parts of the world (De et al., 2005; Goswami et al., 2006; Kumar et al., 2006; Rajeevan et al., 2008; IPCC, 2013). There are extensive studies and methodologies adopted for the management of droughts/flood so that such adverse situation is mitigated judiciously. Recently, the Standardized Precipitation Evapotranspiration Index (SPEI) is also found as one of the promising parameters to analyze and evaluate drought events (Allen et al., 2011; Vicente-Serrano et al., 2012; Abiodun et al., 2013). Based on precipitation and potential evapotranspiration, the SPEI combines the sensitivity of Palmer Drought Severity Index (PDSI) to the changes in evaporation demand with the simple calculations along with Standardized Precipitation Index (SPI) (Vicente-Serrano et al., 2010, 2012). The Standardized Precipitation Evapotranspiration Index (SPEI) is an extension of the widely used Standardized Precipitation Index (SPI) and is better in a way as it takes into account the both precipitation and potential evapotranspiration (PET) in determining the drought. Thus, unlike the SPI, the SPEI captures the main impact of increased temperatures on water demand. Like the SPI, the SPEI can be calculated on a range of timescales from 1 to 48 months. The Global SPEI database offers long-time robust information about the drought conditions at the global scale with a 0.5° spatial resolution (source: http://sac.csic.es/spei/database.html). There are several analyses based on proxy records that could be absolutely dated and annually resolved for the better understanding of temporal changes in the occurrence of drought and flood events for the longer time scale. In this context tree-rings of many trees from several parts of the globe have been used as most excellent proxies for analyzing the droughts, especially from the sites where the tree-growth is limited by variation in the amount of precipitation (Cook et al., 2004, 2007; Touchan et al., 2005, 2008, 2011; Davi et al., 2006; Esper et al., 2007; Woodhouse et al., 2010; Song and Liu, 2011; Burnette and Stahle, 2013; Griffin and Anchukaitis, 2014). There are also a significant progress made

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towards the generation of baseline data of drought/hydrological/climate using the tree ring records from the Himalaya and other mountainous sites of Asia (Bhattacharyya and Chaudhary, 2003; Sheppard et al., 2004; Li et al., 2006, 2007; Liang et al., 2006; Treydte et al., 2006; Cook et al., 2010; Shao et al., 2010; Zhang et al., 2011, 2016; Ram, 2012; Sano et al., 2010, 2012; Yang et al., 2012, 2014; Yadav, 2013; Chaudhary et al., 2013; Shekhar, 2014; Shekhar and Bhattacharyya, 2015). Within these efforts, an important development was recorded in the form of Monsoon Asia Drought Atlas (Cook et al., 2010) that provides a proxy-based gridded spatio-temporal reconstruction of the Palmer drought severity index (PDSI) for the past thousand years. There are also records towards the reconstruction of droughts from the arid north-western part of the Himalayan region. Based on the combined ring-width chronologies of *Cedrus deodara* and *Pinus gerardiana* October–May PDSI has been analyzed for a longer time span (Yadav, 2013). Later, reconstruction of drought variability has been extended spatially to further east from the Kumaun Himalaya, India (Yadav et al., 2015). However, the limited drought reconstructions based on PDSI from the Himalayan region could be either due to the limited gridded PDSI data for the Himalayan region (Dai et al., 2004) or low spatial coverage of tree-ring data network. Recently, further progress witnessed where tree ring chronology is used to reconstruct drought expressed by SPEI in several regions of the Globe (McGuire et al., 2010; Linares and Camarero, 2012; Martin-Benito et al., 2013; Mendivelso et al., 2014; Ma et al., 2015; Zhang et al., 2016). So far one of the longest successful reconstructions of the millennium standardized precipitation–evapotranspiration index (SPEI) from the eastern Qilian Mountains based on tree ring data established the importance of SPEI in analyzing drought variability in longer time scale (Gou et al., 2015).

But from the Himalayan region, no work has been done earlier on this aspect. The present study is a maiden attempt on the reconstruction of SPEI from the Himalayan region using the tree-ring data of chir pine (*Pinus roxburghii*) growing around Uttarkashi, Garhwal, Western Himalaya.

2. Materials and methods

2.1. Sampling site and acquirement of tree ring data

Tree ring samples in the form of cores were collected through increment borer from chir pine trees growing at Uttarkashi, Garhwal region, Western Himalaya (Fig. 1). This site is characterized by the growth of subtropical pine forest where chir pine (*Pinus roxburghii*) are dominant trees growing between elevations 1200–2300 m amsl, are overtopped by Kail pine (*Pinus wallichiana*) and deodar (*Cedrus deodara*) forest at the higher elevations where winter precipitation in the form of snow is high. Tree-ring samples were collected from some selected older chir pine trees from two localities namely Mahidanda (30° 45′ 33.9" N, 78° 25′ 41.2" E; elevation ~2000–2050 m amsl) and Sankuran Dhar (30° 40′ 0.3" N, 78° 28′ 25" E; elevation ~2150 m amsl) of this region. The forests in the both sites are rather open, pure and confine mostly on thin soil cover over base rock. These two sites are abbreviated as “MAH” and “SAN” respectively on the first three words of the sites name. From these two sites total 42 increment cores from 25 trees at the breast height of these trees were collected.

2.2. Chir pine tree ring chronology

Tree ring sequence of each core were cross-dated by visual matching of growth pattern by the preparation of skeleton plots and matching ring width pattern of these with the master plot (Stokes and Smiley, 1968). Dated tree-ring widths were measured using the LINTAB measuring system and TSAP-Win software (Rinn, 2003). The quality of the cross-dating was checked using the COFECHA program (Holmes, 1983). Dated Ring-widths series were then standardized with the program ARSTAN (Cook and Kairiukstis, 1990). For better replication, the samples of these two sites are combined together and designated a common name “MAH” as these sites (MAH and SAN) are located close to each other and trees growing there in almost same elevations and environmental conditions. Moreover, we have recorded a good correlation between tree ring series of each sample of both sites with the Master Plot of the area in the output of COFECHA. For standardization (Cook and Kairiukstis, 1990; Fritts, 1976) i.e. to remove any age-growth trends of the ring width series we used a negative exponential curve, a linear regression or a horizontal line passing through the mean. The series were detrended second time using cubic smoothing splines, with 50% frequency response cutoff of 30 years to reduce the impact of biotic factors on radial growth (e.g., competition, defoliation, etc.). Residual chronology, with the average correlation between all series (Rbar) and the, expressed population signal derived from autoregressive modeling (EPS; Fig. 2a and b) has been taken into consideration in further analyses. For EPS we used a 30-year moving window with 15-year overlaps to evaluate the reliability of the chronology.

2.3. Climate and drought index data

Like most of the other Himalayan regions, the meteorological records from the Garhwal region of the western Himalaya are also spatially and temporally restricted. The longest observatory weather records (temperature and precipitation) close to the study site are available from Shimla (31°10′ N, 77°17′ E; ~2210 m amsl.) Himachal Pradesh (Fig. 1). Though this station located at comparatively higher elevation to the study site but has almost similar environmental conditions. The climatic record of this station reveals that hottest and the coldest months respectively are June and January with mean temperature ~19.66 °C and ~5.27 °C. The mean annual temperature (MAT) is around 13.3 °C. In the area, mean annual precipitation (MAP) is around 1569.73 mm of which ~76% (i.e. ~1203 mm) comes during monsoon season spread over June–September (Fig. 3), whereas winter precipitation contributes only ~9.25% (145.34 mm). However, we record that the quality of the climate data of Shimla station is hampered due to the presence of a good number of missing values, i.e., 4.5% in temperature and 5.2% in precipitation respectively in the available short time data (1901–1988 CE). To avoid this problem, the meaningful climate data were obtained from the gridded temperature and precipitation datasets of nearest grid point (31°75′ N, 78°25′ E) through Climatic Research Unit (CRU TS.3.22, 0.5° latitude x 0.5° longitude, 1901–2015 CE) (Harris et al., 2014). The CRU TS 3.22 data has been found appropriate and used in several previous dendroclimatic studies of the Himalayan regions (Yadav et al., 2014, 2015; Shekhar, 2014). Comparison to met data gridded data of the Climate Research Unit (CRU TS 3.22; 31°75′ N, 78° 25′ E; 1901–2015 CE) is longer; therefore, to understand the relation between CRU TS 3.22 and Shimla data, and suitability for tree growth - climate relationship, the monthly and annual correlation analysis has been performed. The correlation between the CRU TS 3.22 and Shimla data (common period 1901–1988 CE) in respective months were found to be positive and strong ($r = 0.917$–0.527 in temperature and $r = 0.909$–0.233 in precipitation) during 1901–1988 CE; (Table 1). But the correlation for monsoon months (July–August–September) is weak. This reflects that the orography plays a vital role in precipitation variation in the Himalayan region. Although, another longest weather record (temperature and precipitation) is available for Mukteshwar (29° 28′ N, 79° 38′ E; 2171 m amsl)