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ASSESSMENT OF CLIMATE CHANGE THROUGH TEMPERATURE AND RAINFALL TREND ANALYSIS IN CHAMBA AND KANGRA DISTRICTS OF HIMACHAL PRADESH

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Abstract

Climate change is perhaps the single most significant and challenging phenomenon to impact the human race during the recent times. The present study estimates the trend and magnitude of climate change in Chamba and Kangra districts of Himachal Pradesh using the variables of temperature and rainfall. Data for these variables on monthly basis have been collected from India Meteorological Department, Pune for the period 1901 to 2002. Non-parametric trend tests (Mann-Kendall and Sen's slope estimator) are applied to detect the trends of temperature and rainfall during the study period. Linear regression analysis has been carried out to highlight the magnitude of trends. The results point towards a distinct warming. The warming is particularly visible during the winter and pre-monsoon seasons. Temperature in these districts has increased significantly to the tune of 1.5°C during the month of February in winter season; whereas it has declined to the tune of 0.5°C during the July month of monsoon season. Rainfall trends show a shift in the rainfall pattern with more rain being received in the months of February and March than December and January. Such changes in temperature and rainfall have their own implications for the agricultural regime of the region.

Introduction

Climate change is perhaps the most significant and challenging phenomenon to impact the human race during the recent times. Temperature and rainfall are the primary variables used for characterization of the climatic regime of a region. Variations in these variables are used as indicators of climate change (Kumar et al., 2008). Climate change refers to the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean or the variability of its properties that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity. Studies have demonstrated that global surface warming has taken place to the extent of 0.74 ± 0.18°C over 1906-2005 (IPCC, 2007). Global annual land mean precipitation showed a small, but uncertain, upward trend of approximately 1.1 mm per decade (uncertainty ± 1.5 mm) over 1901-2005. Climate change is neither equal nor uniform over different parts of the globe. Over the Indian region for instance, warming will be restricted to 1.4 ± 0.3°C until the 2020s; 2.5 ± 0.4°C until the 2050s; and 3.8 ± 0.5°C until the 2080s, and the projected increase in rainfall will be limited to 2±1 per cent in the 2020s; 3± 1 per cent in the 2050s; and 7 ± 3 per cent in the 2080s (IPCC, 2001).

A number of studies focussing on temperature and rainfall trends have been carried out in India. Pingale et al. (2016) noticed an increase in the wet day frequency, surface temperature and evapotranspiration (ET) during the non-monsoon season in the Ajmer district of Rajasthan. Kothawale and Rupa (2005) have reported substantial changes in temperature trends, with all India mean annual temperature showing significant warming trends of 0.05°C/10 years during the period of 1901-2003. The period from 1971-2003 has seen an even more accelerated warming of 0.22°C/10 years largely attributed to unprecedented warming during the last decade. Jain and Kumar (2012) have also highlighted a rise in mean minimum temperatures in the southern, central and western parts of India and a fall in the annual mean temperature in some parts of north and north-eastern India. Jain et al. (2013) in their study of the north-east region of India found that all the four variables of temperature (maximum, minimum, mean temperature and temperature range) have shown a rising trend. Arora et al. (2005) have investigated the temperature trends over whole of India on an annual as well as seasonal basis and revealed an increase in temperature levels. The increase during the post-monsoon and winter season has been relatively higher than during the pre-monsoon season. Duhan et al. (2013) also found that seasonally, the warming is more pronounced during the winter than the summer. Basistha et al. (2009) in their study of rainfall trends in the Indian Himalayas reported an increasing trend till 1964 and a decreasing trend thereafter. Changes have been found to be most conspicuous over the Shiwaliks and the southern face of the Lesser Himalayas. Ghosh et al. (2009) have also reported spatially varying mixed responses of global warming towards rainfall occurrences and amounts all over India. Deka et al. (2016) revealed a statistically significant decreasing trend in annual as well as monsoonal rainfall in Brahmaputra valley with large spatial and temporal variations. Kumar et al. (2010) in a study of monthly, seasonal and annual trends of rainfall for 30 sub-divisions of India reported a decrease in the annual and monsoonal rainfall and a simultaneous increase in pre-monsoon, post-monsoon and winter rainfall at the national scale. Duhan and Pandey (2013) in their study of rainfall in Madhya Pradesh highlighted a 2.6 per cent decrease in annual precipitation over a period of 102 years. Narayanan et al. (2013) have brought out a significant increase in pre-monsoon rainfall in north-western parts of the country. To sum up, India as a whole or in parts reveals a tendency towards warming. A shift in the rainfall trends is also noticeable with an increase in rainfall during the pre-monsoon and post-monsoon periods and a relative decrease in the rainfall amount received during the monsoon and winter months.

Mountains are among the most fragile ecosystems on earth and are highly sensitive to climate change and are being affected at a faster rate than other terrestrial ecosystems (Beniston and Rebetez, 1996; Messerli and Ives, 1997; Diaz and Bradley, 1997; Liu and Chen, 2000; Ceppi et al., 2010; Rangwala et al., 2012). Several studies have revealed that mountainous systems warm at a faster pace than their other low elevation counterparts, often with greater increases in daily minimum temperatures than daily maximum temperatures (Beniston and Rebetez, 1996; Diaz and Bradley, 1997; Rangwala et al., 2009; Liu et al., 2009; Qin et al., 2009; Pederson et al., 2010). A continuous warming trend at high altitudes since the last century (Beniston and Rebetez, 1996; Diaz and Bradley, 1997; Liu and Chen, 2000; Liu et al., 2009; Rangwala and Miller, 2012), has resulted in the modification of the hydrological cycle (Nijssen et al., 2001; Singh and Bengtsson, 2004; Hamlet et al., 2005; Kumar et al., 2009; Xu et al., 2009; Kohler et al., 2010), change in mountain snow and glaciers (Ageta, 1992; Haeberli et al., 2007; Sorg et al., 2012; Rai et al., 2016), shift in precipitation regime (Beniston and Rebetez, 1996; Beniston, 2003; Mauget, 2003; Theobald et al., 2016), change in biodiversity characteristics such as ecotone, species diversity, habitat characteristics, ecological succession and tree line altitude (Weltzin and McPherson, 2000; Hampe and Petit, 2005; Thuiller, 2007; Xu et al., 2009; Willis and Bhagwat, 2009; Chen et al., 2011; Booth, 2012) as well as the creation of mountain hazards (IPCC, 2007; Keiler et al., 2010; Manandhar et al., 2015). It is in this context that the present paper seeks to analyse the trends in climatic variables such as temperature and precipitation over Chamba and Kangra districts of Himachal Pradesh a mountainous state of India.

Objectives

The major objectives of the study are:

- To examine the trends in mean, minimum and maximum temperatures on monthly, seasonal and annual basis for Chamba and Kangra districts of Himachal Pradesh during 1901-2002.
- To investigate the rainfall trends in terms of total rainfall and number of rainy days during the study period.

Study Area

The study area comprises the districts of Chamba and Kangra of Himachal Pradesh located between 31° 38' 35" and 33° 13' 59" north latitudes and 75° 29' 9” and 77° 5' 4" east longitudes (Fig. 1). The study area is spread over the southern and northern aspects of the Dhauladhar range in Himalayas, and comprises of the drainage basin of two rivers, namely upper Ravi (Chamba district) and middle Beas (Kangra district). The climatic conditions vary with altitude. The lower valleys are semi-tropical in character, where temperatures are relatively higher during summer and the rainy season is well marked. The winter is cold with sporadic and light snowfall. At the higher altitudes climatic conditions are more severe and vary from the temperate to semi-arctic type. Semi-arctic conditions prevail along the high ranges for several months in winters and the passes are then blocked with snow.

Database and Methodology

Data pertaining to temperature and rainfall of Chamba and Kangra districts on monthly basis have been collected from the India Meteorological Department, Pune for the period 1901 to 2002. Data pertain to the five parameters including mean monthly temperature, mean monthly minimum temperature, mean monthly maximum temperature, total monthly rainfall and total number of rainy days. These have been subjected to trend analysis. The main objective of trend analysis is to detect whether values of data are increasing, decreasing or trendless over time. The detection, estimation and prediction of trends and associated statistical and physical significance are important aspects of climate research. Tests for the detection of significant trends in climatological time series can be classified as parametric and non-parametric methods. Parametric trend tests require data to be independent and normally distributed, while non-parametric (i.e., distribution free) test can also be used to assess monotonic trend (linear or non-linear) significance. In this study, non-parametric

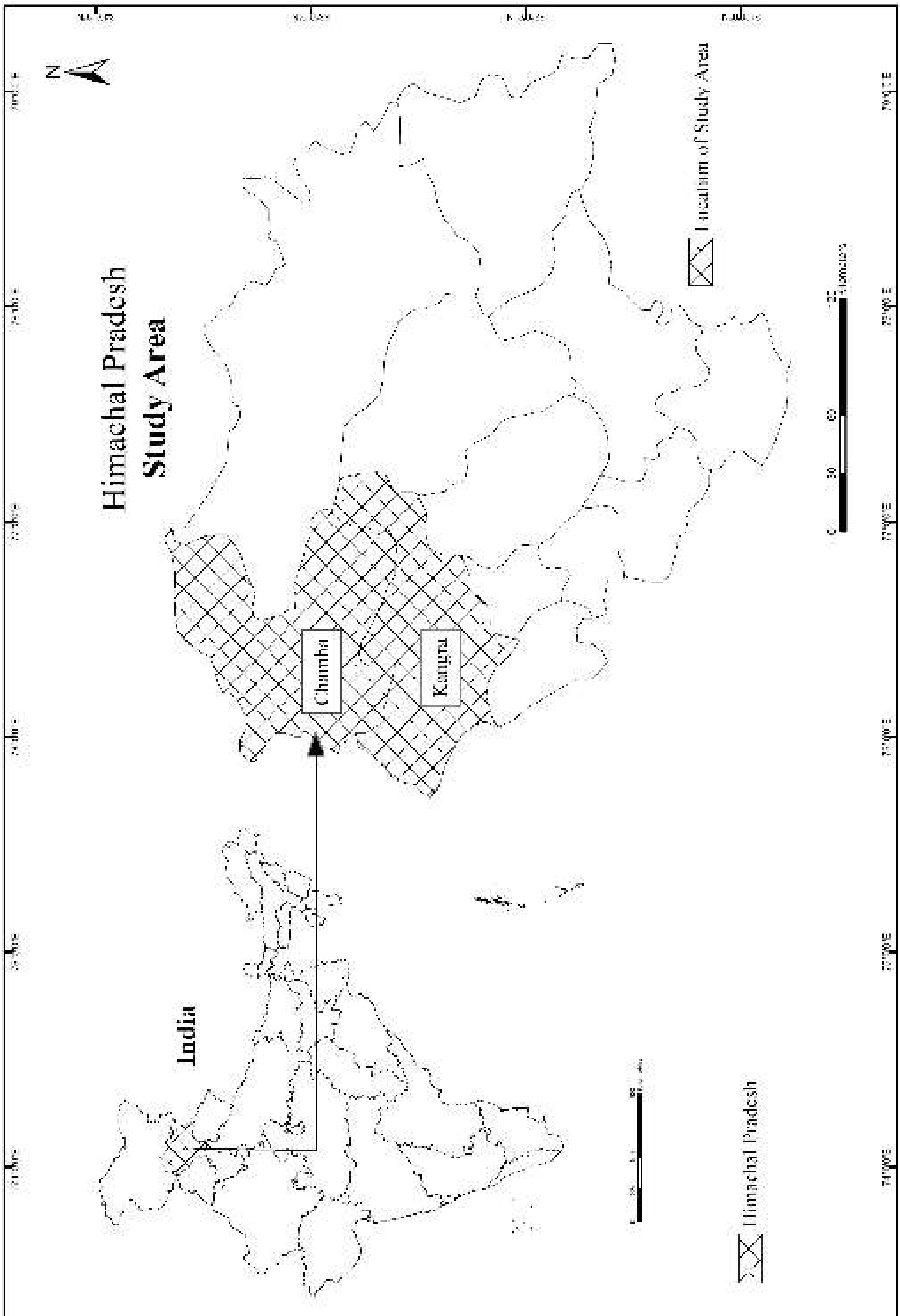

Himachal Pradesh
Study Area
Chamba
Kangra
Location of Study Area
India
Himachal Pradesh
N

Fig. 1

methods (Mann-Kendall and Sen's slope estimator) are used to detect the climatic variables' trends. Linear regression technique has been applied to calculate the magnitude of trends.

For the seasonal analysis monthly data have been averaged to obtain seasonal temperature and rainfall for both districts. Seasons have been taken as winter (December, January and February), pre-monsoon (March, April and May), monsoon (June, July and August) and post-monsoon (September, October and November). These seasons have been adapted from the classification given by India Meteorological Department and have been modified keeping in mind the specific regional character of the climate of study area. Since, monsoon in the Dhauladhar is restricted to the three months of June, July and August; September has been included in post-monsoon season. Similarly, since there is a relatively early onset of winter in this region, December has been included in the winter season.

A brief description of all the non-parametric and parametric trend test methods used for analysing the climatic data in the present study are given below.

Mann-Kendall Trend Test

The Mann-Kendall test is a non-parametric rank based test (Kendall, 1975; Mann, 1945), which is suitable for cases where the trend may be assumed to be a monotonic and normal distribution and thus no seasonal or other cycle is present in the data. The test statistic 'S', which means zero and a variance computed by Eq. (3), is calculated using Eqs. (1) and (2) as given below:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x_j - x_i) \qquad (1)$$

where, n is the number of data points, xi and xj are the data values in time series i and j (j>i), respectively and sgn (xj−xi) is the sgn function as:

$$sgn(x_j - x_i) = \begin{cases} +1, & if \quad x_j - x_i > 0 \\ 0, & if \quad x_j - x_i = 0 \\ -1, & if \quad x_j - x_i < 0 \end{cases} \qquad (2)$$

The variance is computed as:

$$var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \qquad (3)$$

where, n is the number of data points, m is the number of tied groups and t_i denotes the number of ties of extent i. A tied group is a set of sample data having the same value. In cases where the sample size n > 10, the standard normal test statistic Z_s is computed using Eq. (4):

$$Z_S = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & if\ S > 0 \\ 0, & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & if\ S > 0 \end{cases} \qquad (4)$$

Positive values of Z_s indicate increasing trends while negative Z_s values show decreasing trends. Testing of trends is done at the specific α significance level. When $|Z_s| > Z_{1-\alpha=2}$, the null hypothesis is rejected and a significant trend exists in the time series. In this study, significance levels α=0.01 and α=0.05 were used which indicate a confidence level of 99% and 95% respectively on the results produced.

Sen's Slope Estimator

Sen's method assumes a linear trend in the time series and has been widely used for determining the magnitude of trend in hydro-meteorological time series. Sen (1968) developed the non-parametric procedure for estimating the slope of trend in the sample of N pairs of data:

$$Q_i = \frac{x_j - x_k}{j - k} \ for \ i = 1, ..., N, \quad (5)$$

where, x_j and x_k are the data values at times j and k (j>k), respectively.

If there is only one datum in each time period, then

$$N = \frac{\mathbf{n - (n - 1)}}{\mathbf{2}}$$

where n is the number of time periods. If there are multiple observations in one or more time periods, then

$$N = \frac{\mathbf{n - (n - 1)}}{\mathbf{2}}$$

where n is the total number of observations.

The N values of Qi are ranked from smallest to largest and the median of slope or Sen's slope estimator is computed as:

$$Q_{med} = \begin{Bmatrix} Q_{\left[(N+1)/2\right]} & if \ N \ is \ odd \\ \frac{Q_{\left[N/2\right]} + Q_{\left[(N-2)/2\right]}}{2}, & if \ N \ is \ Even \end{Bmatrix} \quad (6)$$

The Q_{med} sign reflects data trend reflection, while its value indicates the steepness of the trend. To determine whether the median slope is statistically different than zero, one should obtain the confidence interval of Q_{med} at specific probability.

Linear Regression Method

Linear regression method is used to estimate slope of trend. The slope indicates the mean temporal change of the studied variable. Positive values of the slope show increasing trends, while negative values of the slope indicate decreasing trends.

Results and Discussion

Temperature Trends

Temperature is most important variable to understand the change in the climate of any region. Because, all other variables associated with climate, like precipitation, atmospheric pressure, winds etc. are controlled by it. In this study, therefore trends in all the aspects of temperature like mean monthly temperature, mean monthly maximum temperature and mean monthly minimum temperature are analysed and presented as under:

(i) Mean Monthly Temperature Trends

Temporal variations in mean monthly temperature trends over the period 1901-2002 reveal statistically significant rising trends at 99% and 95% confidence levels for both Chamba and Kangra districts during the months of February, March, April, November and December (Table 1).This gets reflected in statistically significant rising trends of temperature at the annual scale as well as during the winter and pre-monsoon seasons. However, statistically significant decreasing trends in mean monthly temperature at the 99% confidence level are observed for the months of July and August in the district of Kangra (Table 1; Fig. 2). The monsoon season in both the districts of Chamba and Kangra exhibits decreasing trends in mean monthly temperature that are significant at the 95% and 99% confidence levels, respectively (Table 1; Fig. 2). The Sen's slope estimator reveals an increase of 1.53°C in Chamba district and 1.52°C in Kangra district in the mean monthly temperature of February. The month of July on the other hand has become cooler by 0.38°C in Chamba district and 0.59°C in Kangra district respectively. Thus, while the winters are becoming warmer, the monsoon months are becoming cooler leading to a decrease in the annual range of temperature by close to 2°C.

(ii) Mean Monthly Maximum Temperature Trends

An analysis of mean monthly maximum

Table 1
Chamba and Kangra Districts: Mean Monthly Temperature, 1901-2002

Months/Seasons	Chamba			Kangra		
	Kendall's tau	p-value (Two-tailed)	Sen's Slope	Kendall's tau	p-value (Two-tailed)	Sen's Slope
January	0.130	0.053	0.010	0.116	0.084	0.007
February	0.219**	0.001	0.015	0.207**	0.002	0.015
March	0.155*	0.021	0.012	0.145*	0.031	0.011
April	0.163*	0.015	0.012	0.157*	0.020	0.013
May	0.082	0.225	0.006	0.086	0.203	0.007
June	-0.068	0.312	-0.003	-0.096	0.154	-0.004
July	-0.125	0.062	-0.004	-0.186**	0.006	-0.006
August	-0.112	0.096	-0.003	-0.175**	0.009	-0.005
September	-0.009	0.892	-0.0004	-0.091	0.178	-0.003
October	-0.008	0.908	-0.0004	-0.049	0.464	-0.002
November	0.169*	0.012	0.007	0.186**	0.006	0.008
December	0.185**	0.006	0.009	0.189**	0.005	0.009
Annual	0.203**	0.002	0.005	0.161*	0.017	0.004
Winter	0.273**	0.000	0.010	0.261**	0.0001	0.009
Pre Monsoon	0.197**	0.003	0.010	0.193**	0.004	0.010
Monsoon	-0.135*	0.045	-0.003	-0.197**	0.003	-0.005
Post Monsoon	0.088	0.191	0.002	0.019	0.775	0.001

Source: Calculated by Authors
** Statistically significant trends at the 95% confidence level.*
*** Statistically significant trends at the 99% confidence level.*

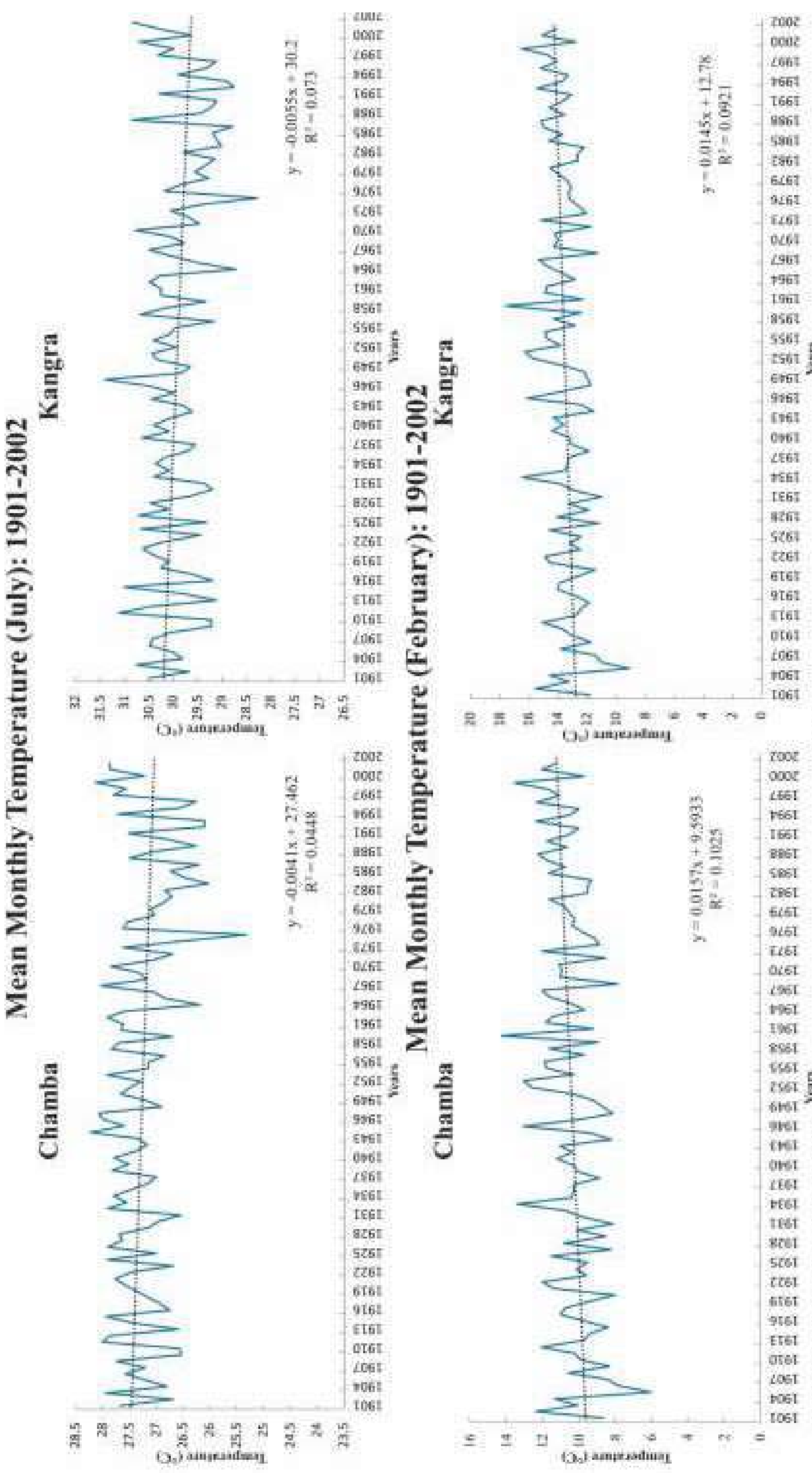

Mean Monthly Temperature (July): 1901-2002
Chamba
Kangra
y = -0.0041x + 27.462
R² = 0.0448
y = -0.0055x + 30.2
R² = 0.073
Mean Monthly Temperature (February): 1901-2002
Chamba
Kangra
y = 0.0157x + 9.5933
R² = 0.1025
y = 0.0145x + 12.78
R² = 0.0921
Temperature (°C)
Years

Fig. 2

temperature trends (Table 2) reveals that the months from November to May comprising the seasons of winter and pre-monsoon show an increasing trend for both the districts of Chamba and Kangra. Leaving aside, the months of January and May in Chamba district and January, March and May in Kangra district, the trends are significant at the 95% and 99% confidence levels (Table 2). The Sen's slope estimator indicates an increase of 1.54°C over the last century in the mean monthly maximum temperature for the month of February in the district of Chamba. The mean monthly maximum temperature for the month of February in the district of Kangra has increased by 1.47°C during the same period. The mean monthly maximum temperature shows a declining trend from June to October comprising the seasons of monsoon and post-monsoon. Such trends for the months of July and August are particularly significant at the 95% and 99% confidence levels for both the districts of Chamba and Kangra (Table 2; Fig. 3). The Sen's slope estimator indicates a drop of 0.52°C during the month of July for Chamba and 0.6°C for Kangra in the mean monthly maximum temperature during the study period. Viewed at the seasonal scale the trends of mean monthly maximum temperature are found to be significant at the 99% confidence level during the winter and pre-monsoon seasons for the district of Chamba and the winter, pre-monsoon and monsoon seasons for the district of Kangra (Table 2). Whereas during the winter and pre-monsoon seasons mean monthly maximum temperatures have increased by 1°C in both the districts, but for the monsoon season these have decreased by 0.5°C in Chamba district and 0.6°C in Kangra district (Fig. 3).

(iii) Mean Monthly Minimum Temperature Trends

The analysis of the mean monthly and seasonal minimum temperature series using the Man-Kendall test trend and Sen's slope estimators shows a rising trend of mean monthly minimum temperature for the months of December and February in both the districts of Chamba and Kangra (Table 3; Fig. 4). These have been found to be statistically significant at a confidence level of 99%. The rising trend in temperature indicated by the Sen's slope estimator is to the tune of 1.6°C for Chamba and 1.46°C for Kangra in the month of February Minimum temperature shows a rising trend throughout the winter and the pre-monsoon seasons (Table 3). The only exception is the month of January which shows a statistically weak increasing trend in temperature. The monsoon season shows declining, though statistically insignificant trend in mean minimum temperature, again indicating a fall in the range of temperature.

To sum up, it has been observed that in the winter and pre-monsoon seasons, mean monthly maximum temperatures have increased by 1°C, while in monsoon season these have decreased by 0.5°C in the study area. Similarly, the monsoon season shows declining trend, though statistically insignificant, in mean minimum temperature indicating a fall in the range of temperature. Thus, the study concludes that, while the winters are becoming warmer the monsoon months are becoming cooler suggesting about 2°C decrease in the annual range of temperature.

Rainfall and Rainy Days Trends

Rainfall is another important variable to study the change in climate. An examination of the magnitude and direction of rainfall trends visible from the time series data, as determined by the Man-Kendall trend test and Sen's slope estimator on monthly, seasonal and annual basis reveals that the amount of rainfall has witnessed an increasing trend at the annual as

Table 2
Chamba and Kangra Districts: Mean Monthly Maximum Temperature, 1901-2002

Months/Seasons	Chamba			Kangra		
	Kendall's tau	p-value (Two-tailed)	Sen's Slope	Kendall's tau	p-value (Two-tailed)	Sen's Slope
January	0.107	0.111	0.007	0.090	0.183	0.006
February	0.195**	0.004	0.015	0.189**	0.005	0.014
March	0.133*	0.047	0.010	0.128	0.057	0.010
April	0.152*	0.023	0.011	0.145**	0.031	0.012
May	0.067	0.323	0.005	0.070	0.297	0.006
June	-0.092	0.172	-0.005	-0.108	0.110	-0.005
July	-0.175**	0.009	-0.005	-0.217**	0.001	-0.007
August	-0.155*	0.021	-0.004	-0.176**	0.009	-0.006
September	-0.009	0.894	-0.0004	-0.085	0.204	-0.003
October	-0.021	0.755	-0.001	-0.068	0.313	-0.003
November	0.162*	0.016	0.008	0.175**	0.009	0.008
December	0.158*	0.019	0.008	0.170*	0.012	0.008
Annual	0.178**	0.008	0.004	0.141*	0.036	0.012
Winter	0.226**	0.001	0.010	0.213**	0.002	0.009
Pre Monsoon	0.178**	0.008	0.010	0.183**	0.007	0.010
Monsoon	-0.161*	0.017	-0.005	-0.202**	0.003	-0.006
Post Monsoon	0.114	0.091	0.004	0.004	0.956	0.000

Source: Calculated by Authors
** Statistically significant trends at the 95% confidence level.*
*** Statistically significant trends at the 99% confidence level.*

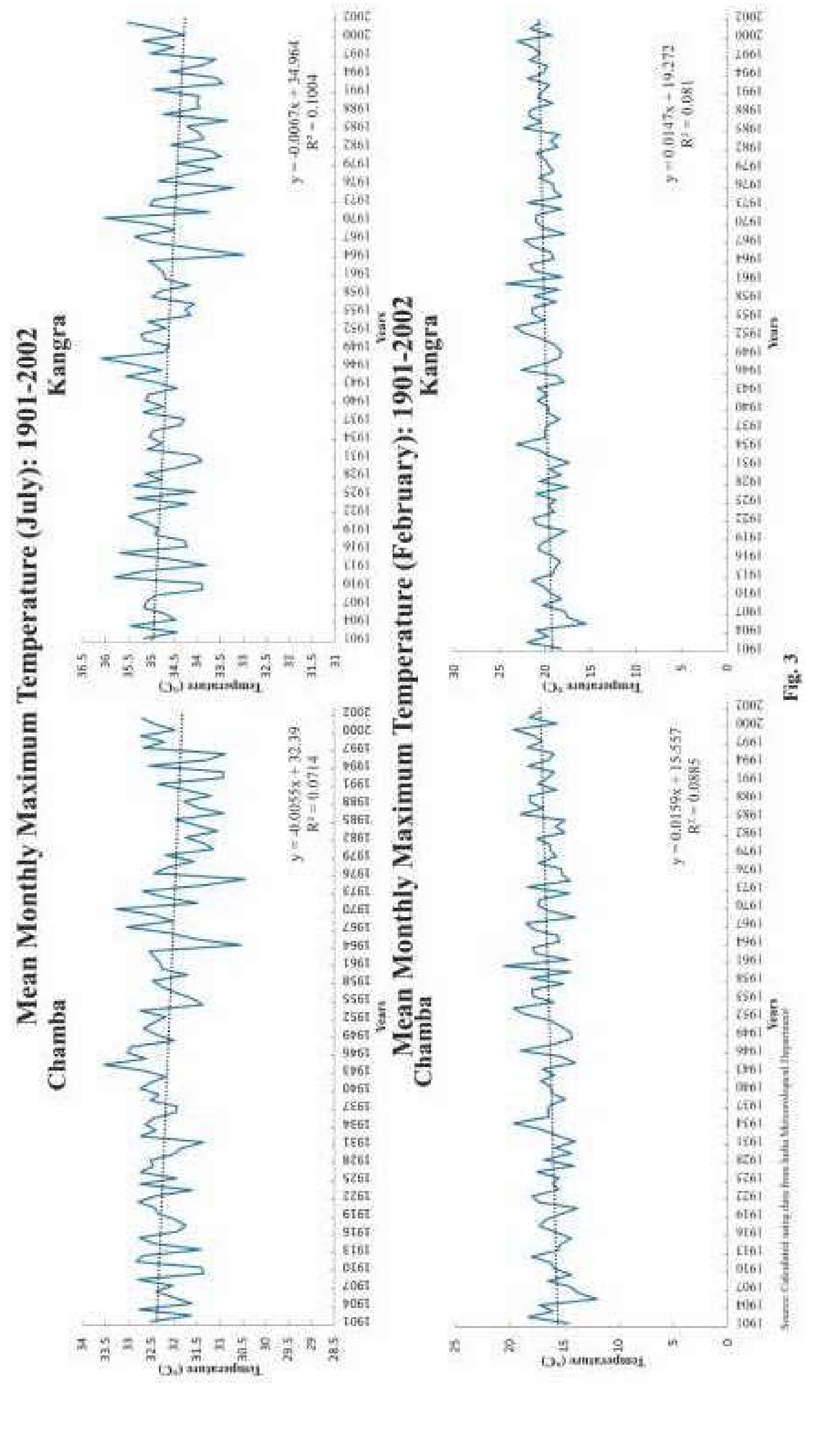

Mean Monthly Maximum Temperature (July): 1901-2002
Chamba
Kangra
y = -0.0055x + 32.39
R² = 0.0714
y = -0.0067x + 34.964
R² = 0.1004
Mean Monthly Maximum Temperature (February): 1901-2002
Chamba
Kangra
y = 0.0159x + 15.557
R² = 0.0385
y = 0.0147x + 19.272
R² = 0.081
Temperature (°C)
Years

Fig. 3

Table 3
Chamba and Kangra Districts: Mean Monthly Minimum Temperature, 1901-2002

Months/Seasons	Chamba			Kangra		
	Kendall's tau	p-value (Two-tailed)	Sen's Slope	Kendall's tau	p-value (Two-tailed)	Sen's Slope
January	0.128	0.057	0.010	0.110	0.101	0.008
February	0.221**	0.001	0.016	0.204**	0.002	0.014
March	0.167*	0.013	0.013	0.150*	0.026	0.011
April	0.172*	0.011	0.011	0.162*	0.016	0.013
May	0.097	0.148	0.007	0.100	0.137	0.008
June	-0.042	0.536	-0.002	-0.083	0.219	-0.005
July	-0.068	0.310	-0.002	-0.152*	0.024	-0.005
August	-0.068	0.314	-0.002	-0.123	0.069	-0.004
September	0.048	0.473	0.002	-0.046	0.495	-0.002
October	0.010	0.885	0.0004	-0.051	0.449	-0.002
November	0.154*	0.022	0.007	0.172**	0.010	0.008
December	0.179**	0.008	0.010	0.173**	0.010	0.010
Annual	0.239**	0.000	0.006	0.195**	0.004	0.004
Winter	0.300**	0.000	0.010	0.270**	0.000	0.010
Pre Monsoon	0.214**	0.001	0.010	0.207**	0.002	0.011
Monsoon	-0.081	0.231	-0.002	-0.154*	0.022	-0.004
Post Monsoon	0.087	0.197	0.003	0.035	0.603	0.001

Source: Calculated by Authors
** Statistically significant trends at the 95% confidence level.*
*** Statistically significant trends at the 99% confidence level.*

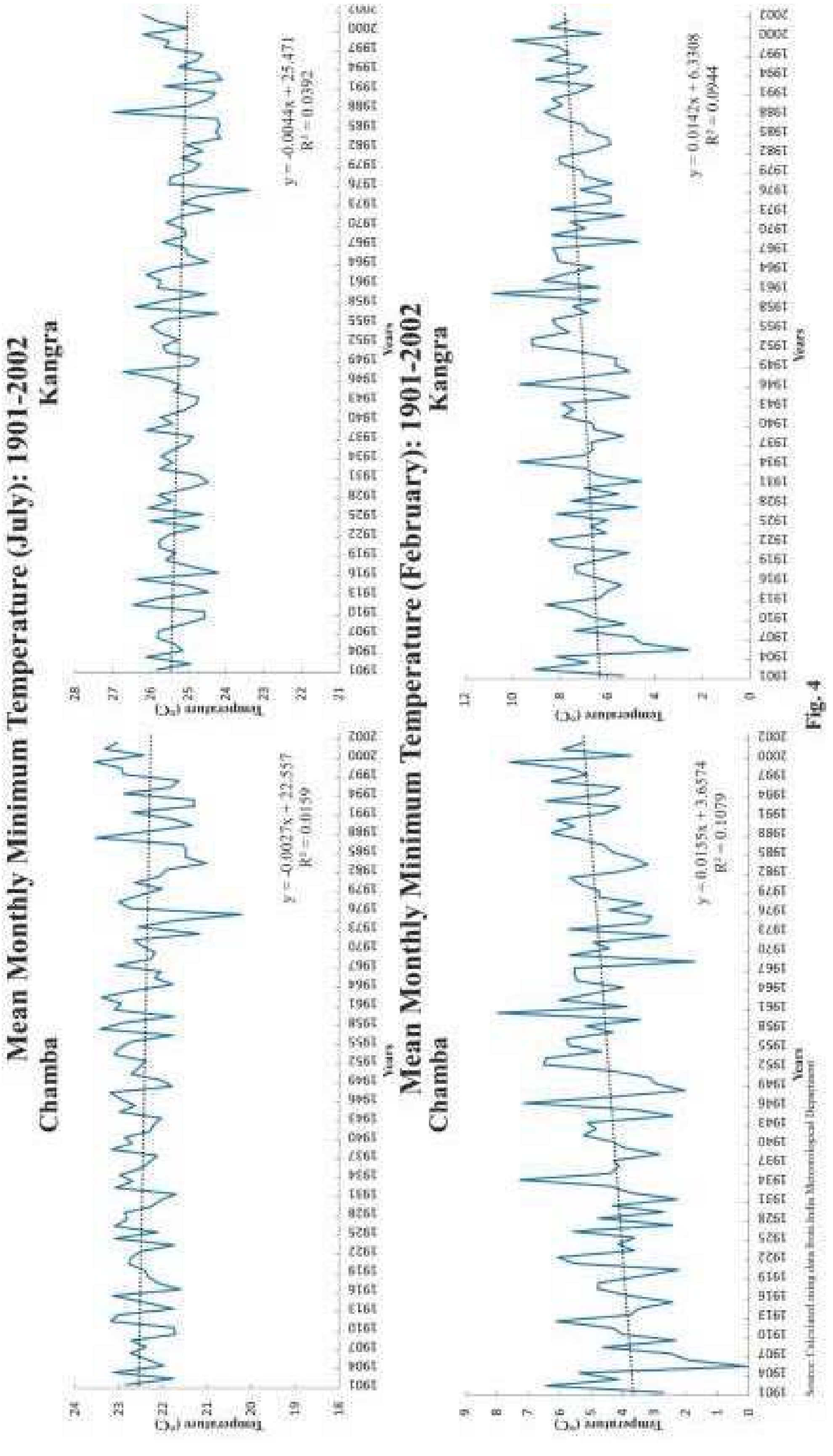
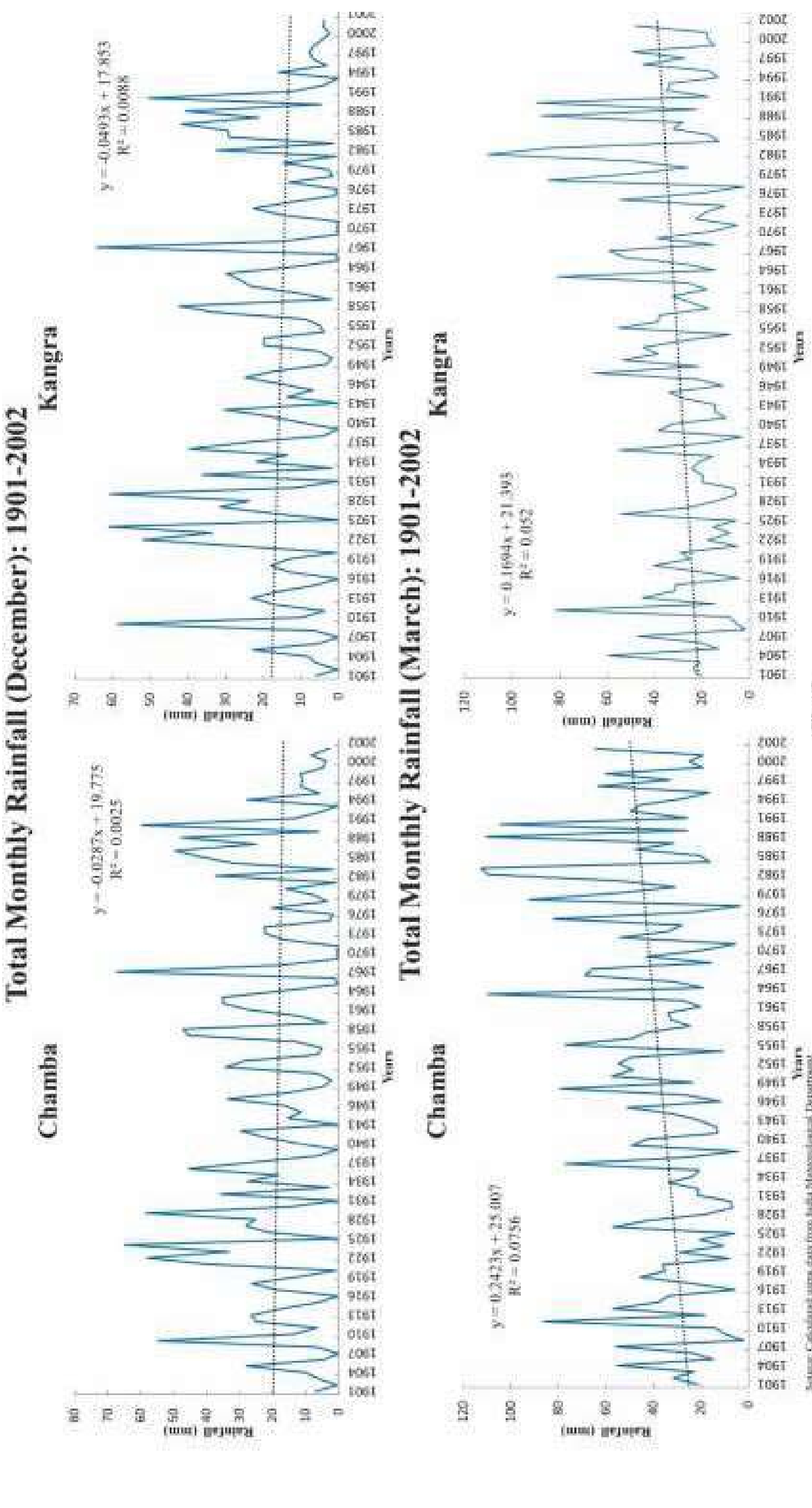

Mean Monthly Minimum Temperature (July): 1901-2002
Chamba
Kangra
y = -0.0027x + 22.557
R² = 0.0159
y = -0.0044x + 25.471
R² = 0.0392
Mean Monthly Minimum Temperature (February): 1901-2002
Chamba
Kangra
y = 0.0135x + 3.6574
R² = 0.1079
y = 0.0142x + 6.3308
R² = 0.0944
Temperature (°C)
Years

Fig. 4

Table 4
Chamba and Kangra Districts: Total Monthly Rainfall, 1901-2002

Months/Seasons	Chamba			Kangra		
	Kendall's tau	p-value (Two-tailed)	Sen's Slope	Kendall's tau	p-value (Two-tailed)	Sen's Slope
January	-0.010	0.878	-0.013	-0.039	0.567	-0.044
February	0.142*	0.034	0.178	0.115	0.088	0.124
March	0.163*	0.015	0.180	0.140*	0.037	0.122
April	0.031	0.644	0.029	-0.003	0.963	-0.002
May	0.134*	0.046	0.098	0.113	0.092	0.069
June	0.021	0.753	0.072	0.019	0.781	0.051
July	0.048	0.477	0.250	0.061	0.364	0.351
August	-0.004	0.954	-0.012	0.016	0.817	0.063
September	0.015	0.831	0.053	0.019	0.781	0.070
October	0.067	0.318	0.030	0.071	0.294	0.021
November	0.045	0.517	0.000	0.042	0.544	0.000
December	-0.032	0.633	-0.012	-0.054	0.421	-0.022
Annual	0.067	0.323	0.662	0.070	0.298	0.770
Winter	0.048	0.477	0.102	0.016	0.817	0.033
Pre Monsoon	0.187**	0.005	0.353	0.157*	0.019	0.234
Monsoon	0.010	0.885	0.089	0.023	0.733	0.182
Post Monsoon	0.028	0.681	0.102	0.027	0.686	0.112

Source: Calculated by Authors
** Statistically significant trends at the 95% confidence level.*
*** Statistically significant trends at the 99% confidence level.*



Source: Calculated using data from India Meteorological Department

Fig. 5

Table 5
Chamba and Kangra Districts: Total Number of Rainy Days, 1901-2002

Months/Seasons	Chamba Rainy Days			Kangra Rainy Days		
	Kendall's tau	p-value (Two-tailed)	Sen's Slope	Kendall's tau	p-value (Two-tailed)	Sen's Slope
January	-0.047	0.488	-0.004	-0.075	0.267	-0.004
February	0.128	0.057	0.011	0.129	0.056	0.009
March	0.167*	0.013	0.014	0.159*	0.018	0.01
April	-0.017	0.808	-0.001	0.003	0.972	0.0001
May	0.062	0.355	0.005	0.079	0.242	0.004
June	0.037	0.583	0.003	0.032	0.639	0.002
July	0.102	0.130	0.013	0.106	0.116	0.012
August	0.009	0.894	0.001	0.038	0.575	0.004
September	-0.015	0.828	-0.002	0.008	0.913	0.0005
October	0.066	0.330	0.002	0.060	0.372	0.0008
November	0.044	0.523	0.000	0.027	0.698	0.000
December	-0.042	0.538	-0.002	-0.055	0.420	-0.001
Annual	0.110	0.103	0.037	0.122	0.069	0.032
Winter	0.035	0.603	0.005	0.019	0.781	0.003
Pre Monsoon	0.091	0.178	0.013	0.105	0.118	0.012
Monsoon	0.067	0.320	0.017	0.087	0.197	0.016
Post Monsoon	0.020	0.772	0.003	0.013	0.849	0.001

Source: Calculated by Authors
** Statistically significant trends at the 95% confidence level.*

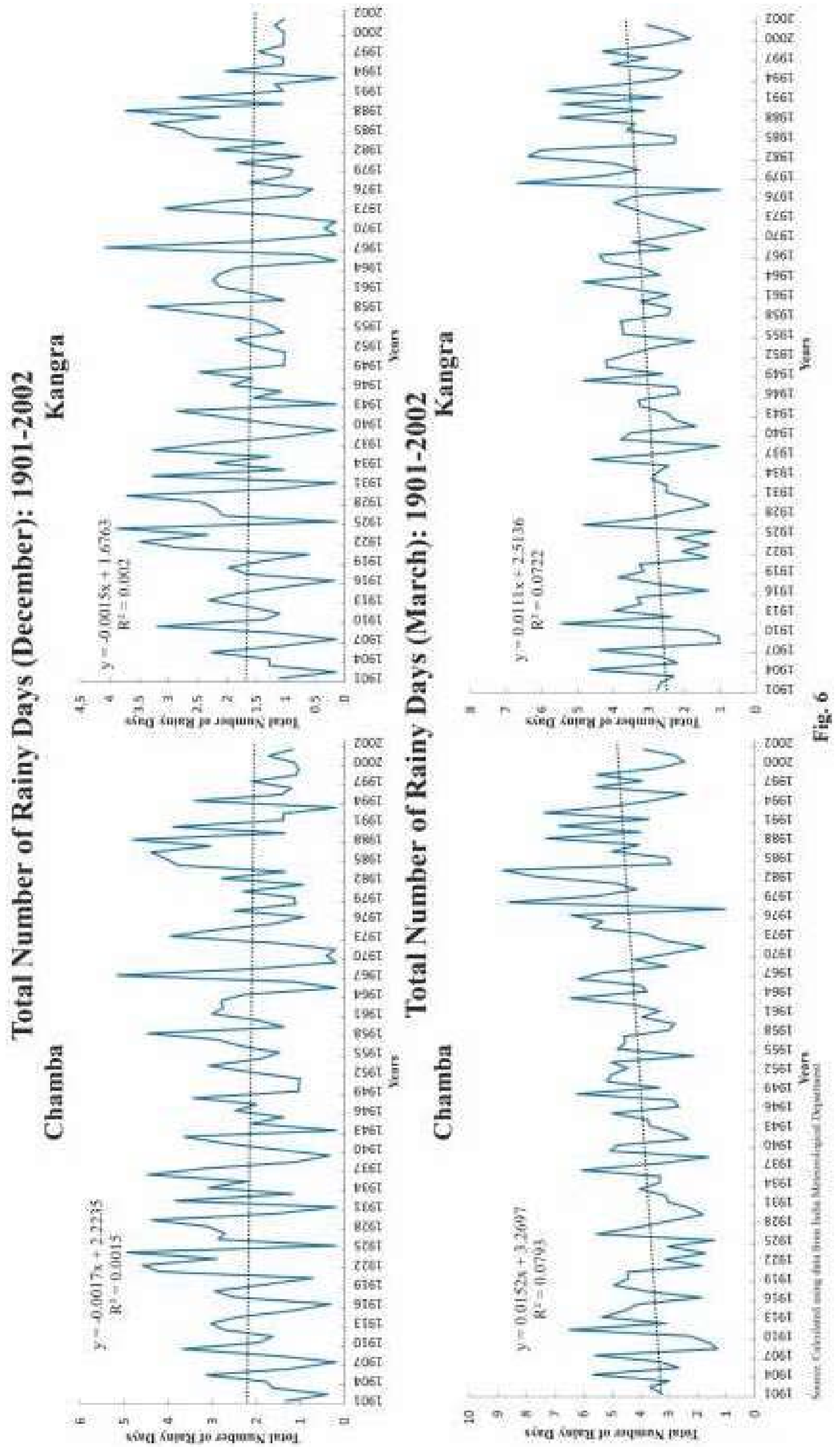

Total Number of Rainy Days (December): 1901-2002
Chamba
Kangra
y = -0.0017x + 2.2235
R² = 0.0015
y = -0.0015x + 1.6763
R² = 0.002
Total Number of Rainy Days
Years
Total Number of Rainy Days (March): 1901-2002
Chamba
Kangra
y = 0.0152x + 3.2697
R² = 0.0793
y = 0.0111x + 2.5136
R² = 0.0722
Source: Calculated using data from India Meteorological Department

Fig. 6

well as seasonal levels (Table 4). The increasing trend is statistically significant at 99% confidence level for the pre-monsoon season for the month of February, March and May in Chamba and statistically significant at the 95% confidence level for the pre-monsoon season in Kangra, for the month of March (Table 4). This indicates an increasing trend in rainfall received during the pre-monsoon period in both Chamba and Kangra districts (Fig. 5). The maximum increase in rainfall as indicated by the Sen's slope estimator has been noticed for the months of February and March with the amount of rainfall increasing by 18 mm during each of these months in Chamba district and by 12 mm in Kangra district, over the entire span of 102 years. There appears an increasing trend in the amount of rainfall received in almost all months and seasons of the years. However, this trend is not statistically significant for the seasons other than pre-monsoon. A decline in the rainfall received during the month of January in both the districts is also visible. According to the Sen's slope estimator rainfall received in Chamba district during this month has decreased by 1.3 mm and that in Kangra district by 4.4 mm. However, the level of significance of the trend is weak. It may be highlighted that Chamba district received 18 mm more rainfall in each of the months of February and March at present than it received in 1901. This has translated into 36 mm more rain for Chamba district and 24 mm more rain for Kangra district during the pre-monsoon season.

The total number of rainy days as well as the seasonal and monthly distribution of these days has a significant impact on the climatic regime of the study area. The increase or decrease in the total number of rainy days influences the intensity of rainfall, while the season/month during which these occur determines the form of precipitation received which could be snow, hail or rain. An analysis of the trends in the number of rainy days using the same tests reveals an increase in the number of rainy days for the month of March. This increasing trend is statistically significant at the 95% confidence level for both the districts (Table 5). A fall in the number of rainy days in the months of January and December for both the districts has also been noticed. The trend however, is not statistically significant (Fig. 6). Similarly, no significant trends are noticeable at the seasonal or annual levels. The Sen's slope estimator indicates an increase in the number of rainy days experienced during a year by 3.8 days in Chamba district and 3.3 days in Kangra district over the study period of 102 years.

Thus, from the above it can be concluded that the Chamba and Kangra districts at present are receiving 36 mm and 24 mm more rainfall, respectively during the pre-monsoon season than they have been receiving in 1901. It is due to an increase in the number of rainy days to the extent of 4 days during a year in Chamba district and 3 days in Kangra district during the study period. On the whole, the study shows significant rising trends in temperature during winter and pre-monsoon seasons, while declining trends of temperature have been noticed in the monsoon season resulting increase in range of temperature. Similarly increase in number of rainy days and amount of rainfall has been noticed in the study area during the study period. Hence, the study suggests a significant change in the climate of the study area.

Conclusions

An analysis of the incidence of climate change and its detection in terms of the trends in temperature and rainfall for the districts of Chamba and Kangra in Western Himalayas points towards a distinct warming of the climatic regime. The warming is particularly visible during the winter and pre-monsoon seasons, where temperatures have increased by up to 1.5°C during the month of February. The temperature during the monsoon months of July on the other hand shows a statistically significant declining trend to the tune of 0.5°C. This translates to a decrease in the annual range of temperature in the study area. Rainfall trends show a shift in the rainfall pattern with more rain being received in the months of February and March than December and January. While the total rainfall received during the monsoon period shows no significant trends, there is a statistically significant increasing trend in the total rainfall received during the pre-monsoon period with an increase of 36 mm for Chamba district and 24 mm for Kangra district. The number of rainy days has decreased for the months of December and January and increased significantly during the month of March with the total number of rainy days during the year having increased by 3.8 for Chamba district and 3.3 for Kangra district. The trends in temperature and rainfall have significant implications for the agricultural regime. The most visible impact is in terms of a reduction in the number of chilling hours available to the winter crops, due to a rise in mean temperature particularly during the months of February and March and a shift in the temporal trends of rainfall with more rainfall being received in the months of February and March as against December and January. This translates into more rainfall than snow and leads to reduction in chilling hours, which may have subsequently affected the quantity and quality of the winter crops in these two districts.

References

Ageta, Y. 1992. Predictions of changes of glacier mass balance in the Nepal Himalaya and Tibetan Plateau: a case study of air temperature increase for three glaciers. *Annals of Glaciology*, 16: 89-94.

Arora, M., Goel, N.K. and Singh, P. 2005. Evaluation of temperature trends over India. *Hydrological Sciences Journal*, 50(1): 81-93.

Basistha, A., Arya, D.S. and Goel, N.K. 2009. Analysis of historical changes in rainfall in the Indian Himalayas. *International Journal of Climatology*, 29(4): 555-572.

Beniston, M. 2003. Climatic change in mountain regions: a review of possible impacts. *Climatic Change*, 59: 5-31.

Beniston, M. and Rebetez, M. 1996. Regional behaviour of minimum temperatures in Switzerland for the period 1979-1993. *Theoretical and Applied Climatology*, 53: 231-243.

Booth, T.H. 2012. Biodiversity and climate change adaptation in Australia: strategy and research developments. *Advances in Climate Change Research*, 3(1): 12-21.

Ceppi, P., Scherrer, S., Fischer, A. and Appenzeller, C. 2010. Revisiting Swiss temperature trends 1959-2008. *International Journal of Climatology*, 32(2): 203-213.

Chen, I.C., Hill, J.K., Ohlemüller, R., Roy, D.B. and Thomas, C.D. 2011. Rapid range shifts of species associated with high levels of climate warming. *Science*, 333: 1024-1026

Deka, R.L., Mahanta, C., Nath, K.K. and Dutta, M.K. 2016. Spatio-temporal variability of rainfall regime in the Brahmaputra valley of North East India. *Theoretical and Applied Climatology*, 124(3&4): 793-806.

Diaz, H.F. and Bradley, R.S. 1997. Temperature variations during the last century at high elevation sites. *Climatic Change*, 36: 253-279.

Duhan, D. and Pandey, A. 2013. Statistical analysis of long term spatial and temporal trends of precipitation during 1901-2002 at Madhya Pradesh, India. *Atmospheric Research*, 122: 136-149.

Duhan, D., Pandey, A., Gahalaut, K.P.S. and Pandey, R.P. 2013. Spatial and temporal variability in maximum, minimum and mean air temperatures at Madhya Pradesh in central India. *Comptes Rendus Geoscience*, 345(1): 3-21.

Ghosh, S., Luniya, V. and Gupta, A. 2009. Trend analysis of Indian summer monsoon rainfall at different spatial scales. *Atmospheric Science Letters*, 10(4): 285-290.

Haeberli, W., Hoelzle, M., Paul, F. and Zemp, M. 2007. Integrated monitoring of mountain glaciers as key indicators of global climate change: The European Alps. *Annals of Glaciology*, 46: 150-160.

Hamlet, A.F., Mote, P.W., Clark, M.P. and Lettenmaier, D.P. 2005. Effects of temperature and precipitation variability on snowpack trends in the western U.S. *Journal of Climate*, 18(21): 4545-4561.

Hampe, A. and Petit, R.J. 2005. Conserving biodiversity under climate change: the rear edge matters. *Ecology Letters*, 8(5): 461-467.

IPCC. 2007. *Climate Change 2007: Synthesis Report*. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Geneva, Switzerland: 104.

IPCC. 2001. *Climate Change 2001: Science of Climate Change*. Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge: 881.

Jain, S.K. and Kumar, V. 2012. Trend analysis of rainfall and temperature data for India. *Current Science*, 102(1): 37-49.

Jain, S.K., Kumar, V. and Saharia, M. 2013. Analysis of rainfall and temperature trends in northeast India. *International Journal of Climatology*, 33(4): 968-978.

Keiler, M., Knight, J. and Harrison, S. 2010. Climate change and geomorphological hazards in the eastern European Alps. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, 368(1919): 2461-2479.

Kendall, M.G. 1975. *Rank Correlation Methods*. Griffin, London, UK: 260.

Kohler, T., Giger, M., Hurni, H., Ott, C., Wiesmann, U., Wymann von Dach, S. and Maselli, D. 2010. Mountains and climate change: a global concern. *Mountain Research and Development*, 30(1): 53-55.

Kothawale, D.R. and Rupa Kumar, K. 2005. On the recent changes in surface temperature trends over India. *Geophysical Research Letters*, 32 (18):1-4.

Kumar, K., Joshi, S. and Joshi, V. 2008. Climate variability, vulnerability and coping mechanism in Alaknanda catchment, Central Himalaya, India. *Ambio: A Journal of the Human Environment*, 37(4): 286-291.

Kumar, V., Jain, S.K. and Singh, Y. 2010. Analysis of long-term rainfall trends in India. *Hydrological Sciences Journal*, 55(4): 484-496.

Kumar, V., Singh, P. and Singh, V. 2009. Snow and glacier melt contribution in the Beas River at Pandoh dam, Himachal Pradesh, India, *Hydrological Sciences Journal*, 52(2): 376-388.

Liu, X. and Chen, B. 2000. Climatic warming in the Tibetan Plateau during recent decades. *International Journal of Climatology*, 20: 1729-1742.

Liu, X., Cheng, Z., Yan, L. and Yin, Z. 2009. Elevation dependency of recent and future minimum surface air temperature trends in the Tibetan Plateau and its surroundings. *Global and Planetary Change*, 68(3): 164-174.

Manandhar, S., Pratoomchai, W., Ono, K., Kazama, S. and Komori, D. 2015. Local people's perceptions of climate change and related hazards in mountainous areas of northern Thailand. *International Journal of Disaster Risk Reduction*, 11: 47-59.

Mann, H.B. 1945. Non-parametric tests against trend. *Econometrica: Journal of the Econometric Society*, 13: 245-259.

Mauget, S.A. 2003. Multi-decadal regime shifts in US streamflow, precipitation, and temperature at the end of the twentieth century. *Journal of Climate,* 16 (23): 3905-3916.

Messerli, B. and Ives, J.D. 1997. *Mountains of the World: A Global Priority*. Parthenon Publishing Group: 495.

Narayanan, P., Basistha, A., Sarkar, S. and Kamna, S. 2013. Trend analysis and ARIMA modelling of pre-monsoon rainfall data for western India. *Comptes Rendus Geoscience*, 345(1): 22-27.

Nijssen, B., O'Donnell G.M., Hamlet, A.F. and Lettenmaier, D.P. 2001. Hydrologic sensitivity of global rivers to climate change. *Climatic Change*, 50: 143-175.

Pederson, G.T., Graumlich, L.J., Fagre, D.B., Kipfer, T. and Muhlfeld, C.C. 2010. A century of climate and ecosystem change in Western Montana: what do temperature trends portend? *Climatic Change*, 98: 133-154.

Pingale, S.M., Khare, D., Jat, M.K. and Adamowski, J., 2016. Trend analysis of climatic variables in an arid and semi-arid region of the Ajmer District, Rajasthan, India. *Journal of Water and Land Development*, 28(1): 3-18.

Qin, J., Yang, K., Liang, S. and Guo, X. 2009. The altitudinal dependence of recent rapid warming over the Tibetan Plateau. *Climatic Change*, 97: 321-327.

Rai, P.K., Mohan, K., Mishra, V.N., Biswari, M., Sharma, A. and Rai, S. 2016. Changing regimes of Gangotri and surrounding glaciers: A case study of Garhwal Himalaya, India. *Remote Sensing Applications: Society and Environment*, 3: 53-72.

Rangwala, I. and Miller, J.R. 2012. Climate change in mountains: a review of elevation-dependent warming and its possible causes. *Climatic Change*, 114 (3-4): 527-547.

Rangwala, I., Barsugli, J., Cozzetto, K., Neff, J. and Prairie, J. 2012. Mid 21st century projections in temperature extremes in the southern Colorado Rocky Mountains from regional climate models. *Climate Dynamics*, 39 (7-8): 1823-1840.

Rangwala, I., Miller, J. and Xu, M. 2009. Warming in the Tibetan Plateau: possible influences of the changes in surface water vapour. *Geophysical Research Letters*, 36:1-6.

Sen, P.K. 1968. Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association*, 63: 1379-1389.

Singh, P. and Bengtsson, L. 2004. Hydrological sensitivity of a large Himalayan basin to climate change. *Hydrological Processes*, 18: 2363-2385.

Sorg, A., Bolch, T., Stoffel, M., Solomina, O. and Beniston, M. 2012. Climate change impacts on glaciers and runoff in Tien Shan (Central Asia). *Nature Climate Change*, 2(10): 725-731.

Theobald, A., McGowan, H. and Speirs, J. 2016. Trends in synoptic circulation and precipitation in the snowy mountains region, Australia, in the Period 1958-2012. *Atmospheric Research*, 169: 434-448.

Thuiller, W. 2007. Biodiversity: Climate change and the ecologist. *Nature*, 448 (7153): 550-552.

Weltzin, J.F. and McPherson, G.R. 2000. Implications of precipitation redistribution for shifts in temperate Savannah ecotones. *Ecology*, 81(7): 1902-1913.

Willis, K.J. and Bhagwat, S.A. 2009. Biodiversity and climate change. *Science*, 326 (5954): 806-807.

Xu, J., Grumbine, R.E., Shrestha, A., Eriksson, M., Yang, X., Wang, Y.U.N. and Wilkes, A. 2009. The melting Himalayas: cascading effects of climate change on water, biodiversity and livelihoods. *Conservation Biology*, 23(3): 520-530.

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