
Variability of Temperature and Rainfall in the Upper Beas Basin, Western Himalaya

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Abstract

Temperature and rainfall affect both the spatial and temporal patterns of water availability, especially in the Himalayan environment. Hence, it is imperative to analyse the trends in temperature and rainfall. The present study aimed to quantify the inter-annual and intra-seasonal variability in these climate variables at Manali and Bhuntar of the upper Beas river basin. Daily temperature data, including minimum temperature (T_{\min}), maximum temperature (T_{\max}), mean temperature (T_{mean}), lowest minimum temperature (L_{\min}), highest maximum temperature (H_{\max}), amount of rainfall and number of rainy days of Manali and Bhuntar for the period 1980–2010, were obtained from the India Meteorological Department. The Mann–Kendall and Theil–Sen’s slope nonparametric tests were used for the determination of trends and their magnitude. The findings indicate that the upper Beas basin experienced a warming trend at the rate of 0.031 °C/year during the period of analysis. Range of temperature showed a significant decline in the basin. Rainfall showed a significant decreasing trend at Manali. The number of rainy days also showed a reduction at Manali during the period of study. Significant variation has been observed in rainfall intensity in the region over the study period. It is not possible to rule out the link between the warming trend and increase in anthropogenic activities in lower part of basin.

Keywords

Temperature · Rainfall · Mann–Kendall test · Theil–Sen’s slope estimator

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Introduction

One of the most important concerns confronting the Earth is undoubtedly the threat of climate change. Climate change or variability can be quantifiable through its key elements such as insulation, air temperature, precipitation, humidity, and wind. Evidences of variations in these key elements are reported around the world, though the degree of variations varies over time and space. Air temperature has been used widely for climate variability assessment around the globe (IPCC 1996, 2001; Tank et al. 2006; IPCC 2007, 2013) because it is expected that the changes in it will also influence the other climate variables such as precipitation, relative humidity, evaporation, and wind speed. It is an important input to climate models and climate change impact modelling at global and regional levels (Boyer et al. 2010; Luo et al. 2013; Bhatt et al. 2013). According to the Fifth Assessment Report of Intergovernmental Panel on Climate Change (IPCC 2013), the global combined land and ocean temperature data indicate an increase of about 0.89 °C during 1901–2012. Several studies in India have also used air temperature as a key indicator to understand the variability and change in climate (Arora et al. 2005; Gadgil and Dhorde 2005; Dash and Hunt 2007; Dash et al. 2007; Singh et al. 2008; Pal and Al-Tabbaa 2011; Jhajharia and Singh 2011; Singh et al. 2013; Dash et al. 2013; Duhan et al. 2013). Jain and Kumar (2012) reviewed the studies pertaining to trends in air temperature over India and found that the annual mean, maximum and minimum temperature shows significant warming trends of 0.51 °C/100 years, 0.72 °C/100 years and 0.27 °C/100 years, respectively, during 1901–2007.

Dash et al. (2007), Bhutiyani et al. (2007), and Dimri and Dash (2012) found the evidences of warming in the Western Indian Himalaya also. Dash et al. (2007) found that annual mean maximum temperature has increased by 0.9 °C in the Western Indian Himalaya during 1901–2003, and much of this observed trend is related to increases after 1972. This study also observed

a sharp decrease in the annual mean minimum temperature by 1.9 °C in the region. Bhutiyani et al. (2007) estimated an annual warming rate of about 1.6 °C/100 years, with the annual mean minimum temperature rising at relatively lower pace than the annual mean maximum temperature during 1901–2002. According to this study, warming is particularly noteworthy in mean minimum (1.7 °C/100 years) and maximum temperature (1.7 °C/100 years) of the winter season. A warming trend over the Western Indian Himalaya was also observed by Dimri and Dash (2012) with the greatest increase in mean maximum temperature (1.1–2.5 °C) of winter (Dec–Feb) during 1975–2006.

Attempts have also been made around the world to evaluate the inter-annual and intra-seasonal variability in the rainfall (Diaz et al. 1989; IPCC 1996, 2001; Tank et al. 2006; IPCC 2007, 2013; Westra et al. 2013). The studies highlighted important changes in rainfall at the global scale, though changes vary from region to region. At the global scale, downward trends in precipitation have dominated in the tropics since the 1970s, while in South Asia, an increase in summer monsoon mean rainfall is predicted in the near future (IPCC 2013). Changes in rainfall are also a key apprehension for India due to the fact that river run-off in India is mainly depends on the monsoon rain and more than 50% of the population is engaged in agriculture and allied livelihood activities that depend on rain. Therefore, the variability in rainfall, number of rainy days and percentage share of monthly rain to annual rainfall (Naidu et al. 1999; Dash and Hunt 2007; Guhathakurta and Rajeevan 2008; Ghosh et al. 2009; Pal and Al-Tabbaa 2009; Bhutiyani et al. 2010; Kumar et al. 2010; Kumar and Jain 2011; Pal and Al-Tabbaa 2011; Rana et al. 2012; Ratna 2012; Jain and Kumar 2012; Jhajharia et al. 2012; Dash et al. 2013; Babar 2013) are extensively studied in Indian context. Diverse outcomes show both increasing and decreasing trends in the rainfall, and even the magnitude of change indicates regional variations. A significant trend in the

amount of rain was not observed at all-India level (Kumar et al. 2010). Guhathakurta and Rajeevan (2008) and Bhutiyani et al. (2010) analysed the pattern of precipitation distribution in the Western Himalaya and found evidence of increasing trend during the pre-monsoon precipitation and decreasing trend in the monsoon precipitation.

The objective of the study was to analyse the annual, seasonal and monthly trend in air temperature (minimum temperature (T_{min}), maximum temperature (T_{max}), mean temperature (T_{mean}), lowest minimum temperature (L_{min}), highest maximum temperature (H_{max}), rainfall and number of rainy days in the upper Beas basin during 1980–2010. In addition, rainfall intensity was also observed to understand its variations.

Study Area

The analysis was carried out for the upper Beas basin up to Pandoh dam (Fig. 1). Beas River is a tributary of Indus River which originates at the Beas Kund near the Rohtang Pass at an altitude of 4085 m above the mean sea level. The length of upper Beas basin up to Pandoh dam is 116 km, and the catchment area is about 5300 sq. km, out of which only 780 km² is under permanent snow (BBMB 1988). Amongst its tributaries, Parbati and Sainj Khad Rivers are glacier fed. Some of the major tributaries which join the Beas River above Pandoh dam are as follows: Sabari Nala near Kullu, Pārbati River near Bhuntar, Tirthan and Sainj Rivers near Larji and

Bakhli Khad near Pandoh dam. The elevation varies from 802 m near Pandoh dam up to 6600 m along the north-east edge of the Pārbati sub-catchment which is representative of a typical high-rise Himalaya basin.

Materials and Methods

Daily air temperature (T_{min} and T_{max}) in °C and rainfall (in mm) data of Manali and Bhuntar for the period 1980–2010 were obtained from the India Meteorological Department (IMD). Values of lowest minimum temperature (L_{min}) and highest maximum temperature (H_{max}) in all the months for Manali and Bhuntar were carved out from the daily temperature data. Standard normals of air temperature (T_{min} , T_{max} and T_{mean}) and rainfall of Manali and Bhuntar were taken from the IMD Climatological Tables, 1961–1990 (IMD 2010). For better understanding of the trends in temperature, anomalies of annual mean temperature (T_{min} , T_{max} and T_{mean}) were computed using standard normals of reference period annual temperature (T_{min} , T_{max} and T_{mean}). Formula is given below:

$$T_{ano} = T_{c.yr} - T_{nor}$$

Where T_{ano} —anomaly in annual temperature, $T_{c.yr}$ —annual temperature of the current year and T_{nor} normal temperature of the reference period

The percentage departures in the annual rainfall were computed as follows.

$$\frac{\text{Annual rainfall of the current year} - \text{normal annual rainfall of the reference period}}{\text{Normal annual rainfall of the reference period}} \times 100$$

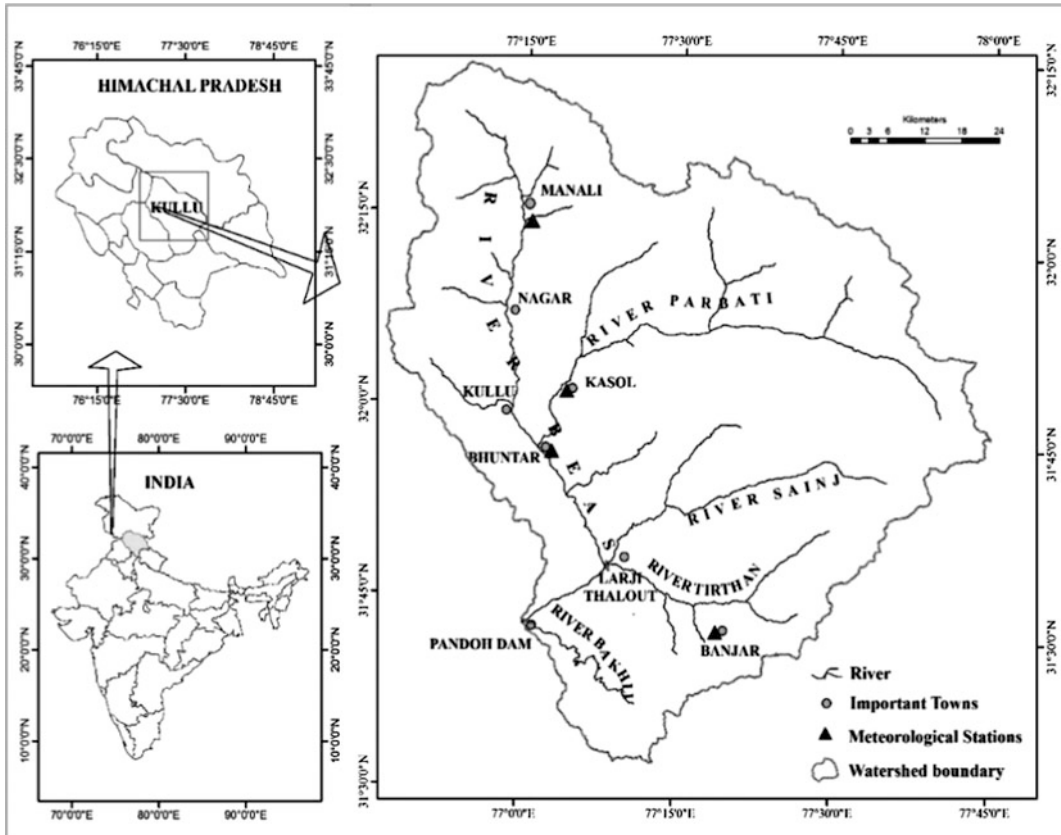


Fig. 1 Location of the upper Beas basin (up to Pandoh dam), Western Himalaya

Interpretation of the percentage departure in annual rainfall was done on the basis of rainfall departure categories defined by IMD.¹ For all the months, the number of days with light (2.5–7.5 mm/day) and moderate rain (7.6–35.5 mm/day) was categorized based on IMD criteria for intensity of rainfall.² IMD has given eight categories of intensity of rainfall in India. Out of eight, two above-mentioned categories were chosen for trend analysis because the majority of the rainy days fall under these two categories during the study period. The seasonal dynamics in temperature and rainfall pattern were analysed using a scheme for seasons adapted from a previous study (Jain et al. 2009). The seasons include winter (December to March),

pre-monsoon (April to June), monsoon (July to September) and post-monsoon (October and November). Trends in temperature and rainfall data could be identified by using parametric or nonparametric methods, and both the methods are widely used. The present study used the Mann–Kendall and Sen slope’s estimator nonparametric tests for computing the trend and its magnitude, respectively, because these methods do not require normality of time series and are less sensitive to outliers and missing values.

Mann–Kendall (MK) nonparametric statistical test was used for analysing the direction of the trend in the climate data. Test, formulated by Mann (1945), as nonparametric test for trend detection and the test statistic distribution has been given by Kendall (1975) for testing non-linear trend and turning point. Mann–Kendall test is used to identify the monotonic trend in

¹<http://imd.gov.in/section/nhac/wxfaq.pdf>.

²Ibid.

climatic time series data. The basic assumption is that it does not require the data to be normally distributed. The null hypothesis (H0) in the test assumes that there is no trend (the data are independent and randomly ordered) and this is tested against the alternative hypothesis (H1), which assumes that there is a trend. All data value is compared with all subsequent data values. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. If the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S. The Mann–Kendall S statistic is computed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(T_j - T_i)$$

$$\text{Sign}(T_j - T_i) = \begin{cases} 1 & \text{if } T_j - T_i > 0 \\ 0 & \text{if } T_j - T_i = 0 \\ -1 & \text{if } T_j - T_i < 0 \end{cases}$$

Where T_j and T_i are the annual values in years j and i , $j > i$, respectively. A positive value and negative value of S indicate upward and downward trends, respectively. For $n \geq 23$, the statistic S is approximately normally distributed with the mean and variance as follows:

$$E(S) = 0$$

The variance (sd (S)) for the S statistics is given as:

$$\text{sd}(S) = \sqrt{\frac{n(n-1)(2n+5) - \sum ti(i-1)(2i+5)}{18}} \tag{1}$$

Where t_i denotes the number of ties to extent i . The summation term in the numerator is used only when the data series contains tied values.

The standardized S statistic denoted by Z for an increasing (or decreasing) trend is given as follows:

$$Z_s = \begin{cases} \frac{s-1}{\sigma} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \frac{s+1}{\sigma} & \text{for } S < 0 \end{cases}$$

The test statistic Z_s is used as a measure of significance of trend. In fact, this test statistic is used to test the null hypothesis, H0. If $|Z_s|$ is greater than $Z\alpha/2$, where α represents the chosen significance level (e.g. 5% with $Z 0.05 = 1.96$), then the null hypothesis is invalid implying that the trend is significant. Mann–Kendall test significance in the present study was tested at 0.05 ($Z = \pm 1.96$) and 0.01 ($Z = \pm 2.58$) level of significance.

Theil–Sen’s Slope Estimator is used to estimate the direction as well as magnitude of trend. This test is given by Theil (1950) and Sen (1968). This test can be used in cases where the trend can be assumed to be linear. Theil–Sen’s trend line is computed with the following equation

$$f(t) = Qt + B$$

Where $f(t)$ is a continuous increasing (or decreasing) function of time, Q is the slope, and B is a constant.

To get the slope estimate Q in equation, first calculate the slopes (m_{ij}) of all data pairs as follows:

$$m_{ij} = \frac{x_j - x_k}{j - k} \text{ for } i = 1, 2 \dots N$$

Where x_j and x_k are data values at time j and k ($j > k$), respectively. If there are n values x_j in the time series, we get as many as $N = n(n-1)/2$ slope estimates Q_i . Order the N pairwise slope estimates, m_{ij} from the smallest to the largest. Determine the Theil–Sen’s estimate of slope, Q , as the median value of this set of N ordered slopes. Computation of the median slope depends on whether N is even or odd. The median slope is computed using the following algorithm

$$Q = \begin{cases} m_{(N+1)/2} & \text{if } N = \text{odd} \\ (m_{N/2} + m_{(N+2)/2})/2 & \text{if } N = \text{even} \end{cases}$$

A positive value of Q indicates an upward (increasing) trend, and a negative value indicates a downward (decreasing) trend in the time series.

Results and Discussion

Anomalies and Trends in Air Temperature

Anomalies in Temperature

The anomalies of air temperature (T_{\min} , T_{\max} and T_{mean}) and their trends were determined for Manali and Bhuntar at annual scales for better understanding of the observed trends for the period 1980–2010. Manali and Bhuntar experienced an annual mean T_{\min} of 6.6 °C and 10.1 °C, respectively, during 1980–2010. It is observed from Fig. 2b that prior to 2001, both positive and negative anomalies were prominent in the annual mean T_{\min} at Manali and Bhuntar but subsequently, positive anomalies are continuous till 2010. Highest and lowest anomalies at Manali in the annual mean T_{\min} were observed as 2.2 °C (2006) and 1.2 °C (2000). Annual mean T_{\min} at Manali demonstrated a rise of 0.4 °C during 1980–2010, with respect to normal annual T_{\min} of reference period. This indicates that the night temperature increased at Manali during the study period. Figure 2b further shows that anomaly in annual mean T_{\min} at Bhuntar ranged between -0.74 °C (1987) and 0.9 °C (2006). Compared to Manali, Bhuntar experienced a steady annual mean T_{\min} during the study period. Overall, a rise of 0.03°C in the annual mean T_{\min} was observed at Bhuntar in relation to normal annual T_{\min} of the reference period.

Manali experienced annual mean T_{\max} of 19.7 °C during 1980–2010. It varied from 16.8 °C (1991) to 20.9 °C (1999) during the period of study (Fig. 3a). A fall of about -0.59 °C was observed in annual mean T_{\max} at Manali during 1980–2010 in relation to normal annual T_{\max} (Fig. 3b). The annual T_{\max} observed at Bhuntar during the same period was 25.4 °C which was nearly 4.5 °C higher than the annual mean T_{\max}

of Manali. It indicates that Bhuntar experienced higher daytime temperature than Manali. It is because of the location of both the stations (Fig. 1). The annual mean T_{\max} at Bhuntar varies from 24 °C in 1982 to 26.8 °C in 2009 during the period of analysis (Fig. 3a). Figure 3b shows higher fluctuations in annual mean T_{\max} at Bhuntar during 1980–2010 and ranged between -1.44 °C (1997) and 1.36 °C (2009). Anomalies in annual mean T_{\max} became positive after 2006 that indicates a warming trend at Bhuntar. Bhuntar also experienced a slight fall of -0.07 °C in the annual mean T_{\max} compared to normal annual T_{\max} of reference period.

Manali and Bhuntar experienced an annual T_{mean} of 13.1 °C and 17.8 °C, respectively, during 1980–2010 (Fig. 4a). Figure 4b shows that Manali experienced a continuous negative anomaly in annual T_{mean} during 1989–1993, and these became positive since 2001. It means that Manali moved towards the warmer conditions during the last decade, though overall a fall of -0.2 °C in the annual T_{mean} (compared to normal annual T_{mean}) was observed during the period 1980–2010. The latter may be attributed to the high decline in the annual mean T_{\max} of about -0.59 °C (Fig. 3b) and the minor rise in the annual mean T_{\min} of around 0.4 °C during 1980–2010 (Fig. 2b). Figure 4b shows more negative anomalies at Bhuntar before 1998 but after that anomalies became positive till 2004. After a sudden negative anomaly in 2005, positive anomalies became prominent till 2010. Anomalies in annual T_{mean} at Bhuntar ranged between -1 °C in 1983 and 0.087 °C in 2007 during the study period. A fall of about -0.02 °C was observed in the annual T_{mean} (compared to normal annual T_{mean}) at Bhuntar during 1980–2000. This is probably because of a minor rise of 0.03 °C in annual mean T_{\min} (Fig. 2b) and high fall of -0.07 °C in the annual mean T_{\max} (Fig. 3b) during 1980–2010.

Annual Trends in Temperature

Annual mean T_{\min} at Manali showed a significant increasing trend at the rate of 0.05 °C/year during 1980–2010 (Table 1). This is consistent with

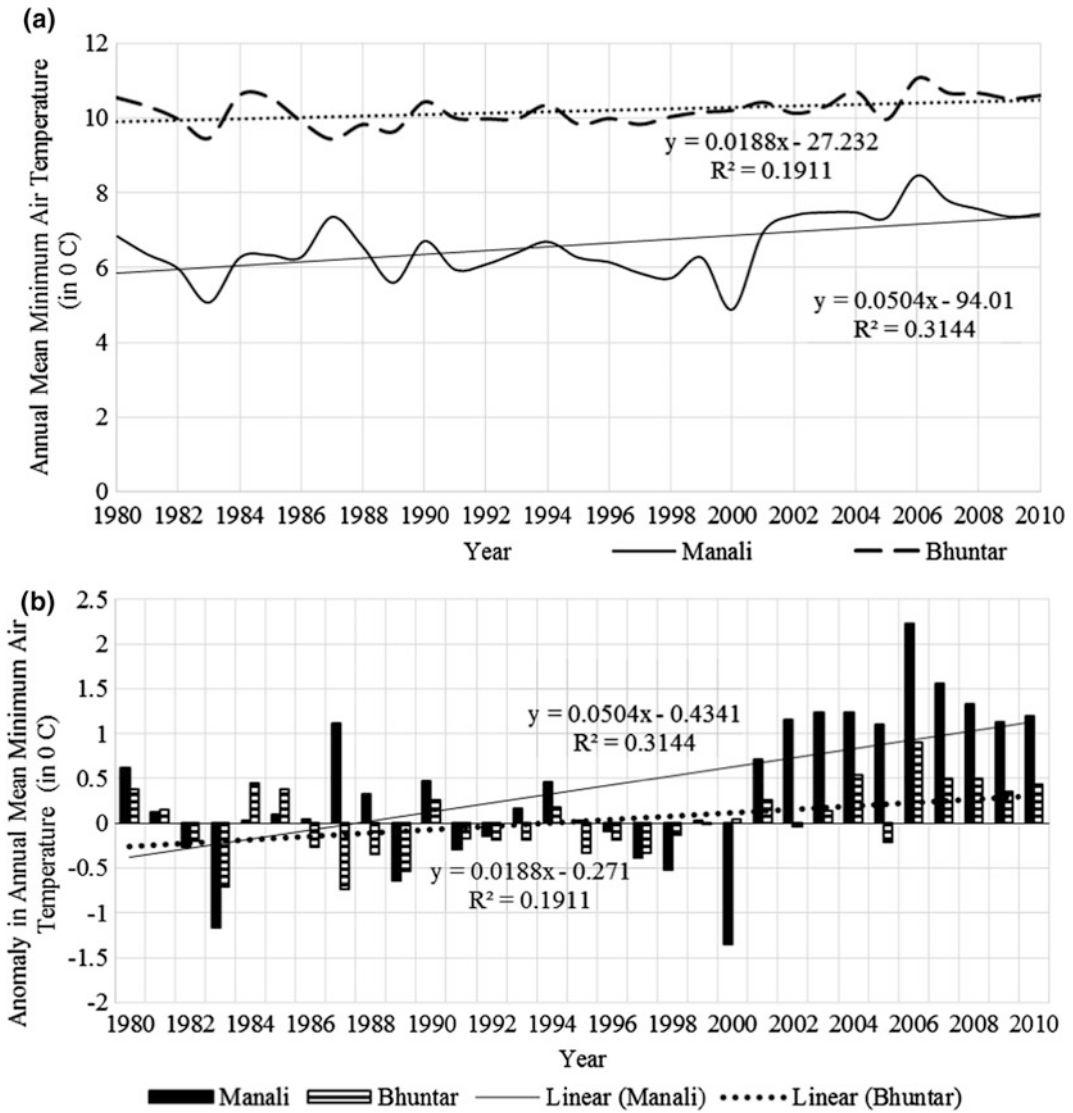


Fig. 2 Trend (a) and anomalies (b) in annual mean minimum air temperature

the study of Pal and Al-Tabbaa (2010) who found a significant increasing trend in annual mean T_{min} in the Western Himalaya. A similar trend in annual mean T_{min} was also observed at Bhuntar with the rate of about $0.02\text{ }^{\circ}\text{C}/\text{year}$ (Table 1) that is slightly lower than the observed trend rate in the annual mean T_{min} at Manali during same period (Table 1).

Results of trend analysis show no trend in the annual mean T_{max} at Manali during the period of

analysis (Table 2), though a statistically significant increasing trend was found in the annual mean T_{max} at Bhuntar at the rate of $0.06\text{ }^{\circ}\text{C}/\text{year}$. Dimri and Dash (2012) and Pal and Al-Tabbaa (2009) also observed a rise in annual mean T_{max} in the Western Himalaya. The present study shows that night-time temperature at Manali has gone up though daytime temperature remained stable. On the other hand, daytime temperature at Bhuntar has increased faster than night-time

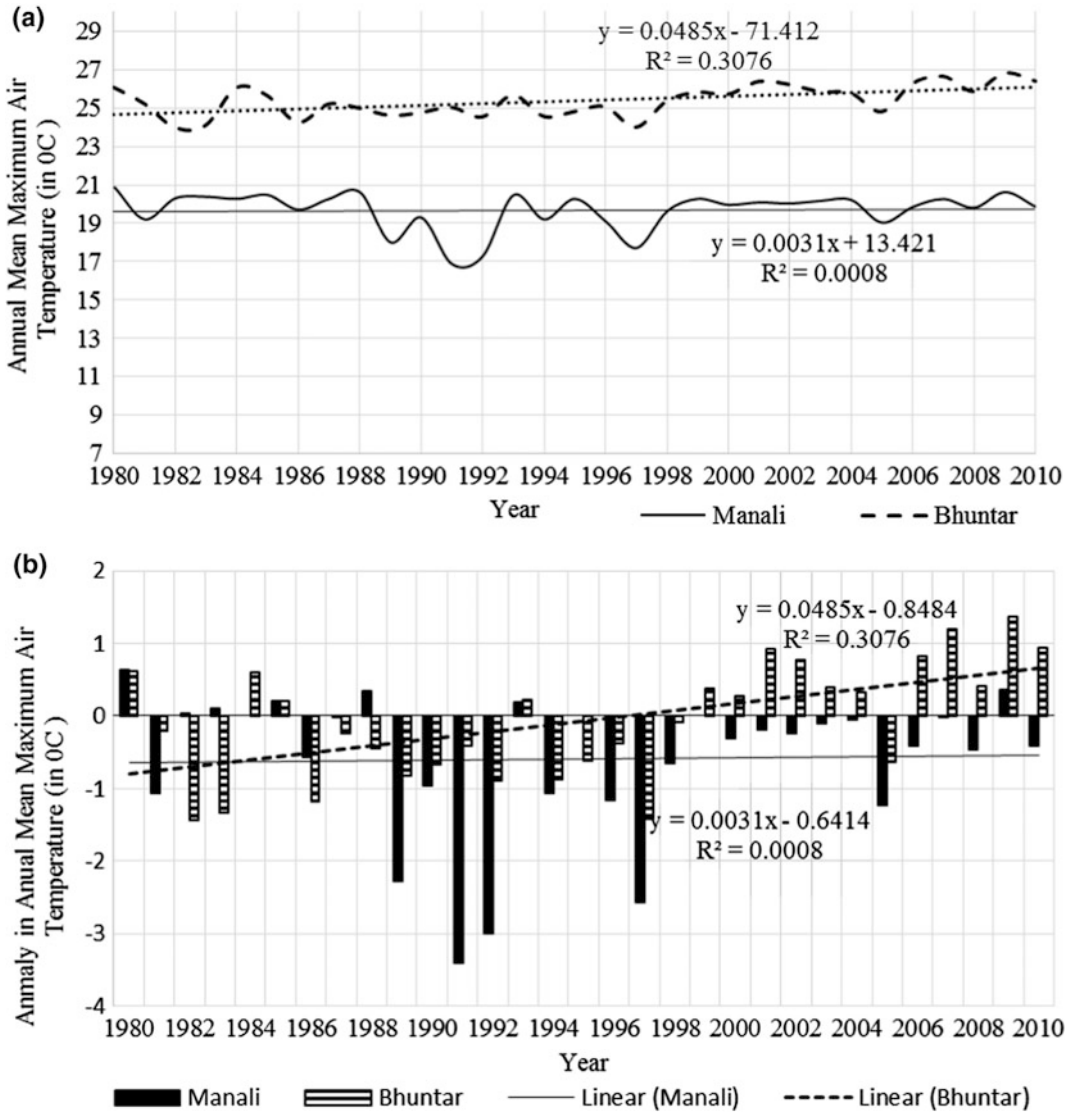


Fig. 3 Trend (a) and anomalies (b) in annual mean maximum air temperature

temperature during 1980–2010. This is an indication of the albedo changes in the region, which might have caused by the changes in land cover conditions. There are continuous changes from a vegetative to non-vegetative cover in this region.

Annual T_{mean} of Manali showed a rising trend at the rate of $0.03^{\circ}\text{C}/\text{year}$ during 1980–2010 (Table 3). Annual mean T_{min} of the station showed an increasing trend while T_{max} remained stable. Therefore, the observed increase in annual T_{mean} at Manali is primarily due to the increase in

annual mean T_{min} . Bhuntar also showed a statistically significant increasing trend in annual T_{mean} at rate of $0.05^{\circ}\text{C}/\text{year}$ during the period of analysis. The observed increase in annual T_{mean} at Bhuntar is mainly due to the increase in annual mean T_{max} because rising rate in annual mean T_{max} was higher than the annual mean T_{min} . Observed trend in annual T_{mean} is consistent with study of Bhutiyani et al. (2007) who also found a warming trend over the north-west Indian Himalaya during the last century.

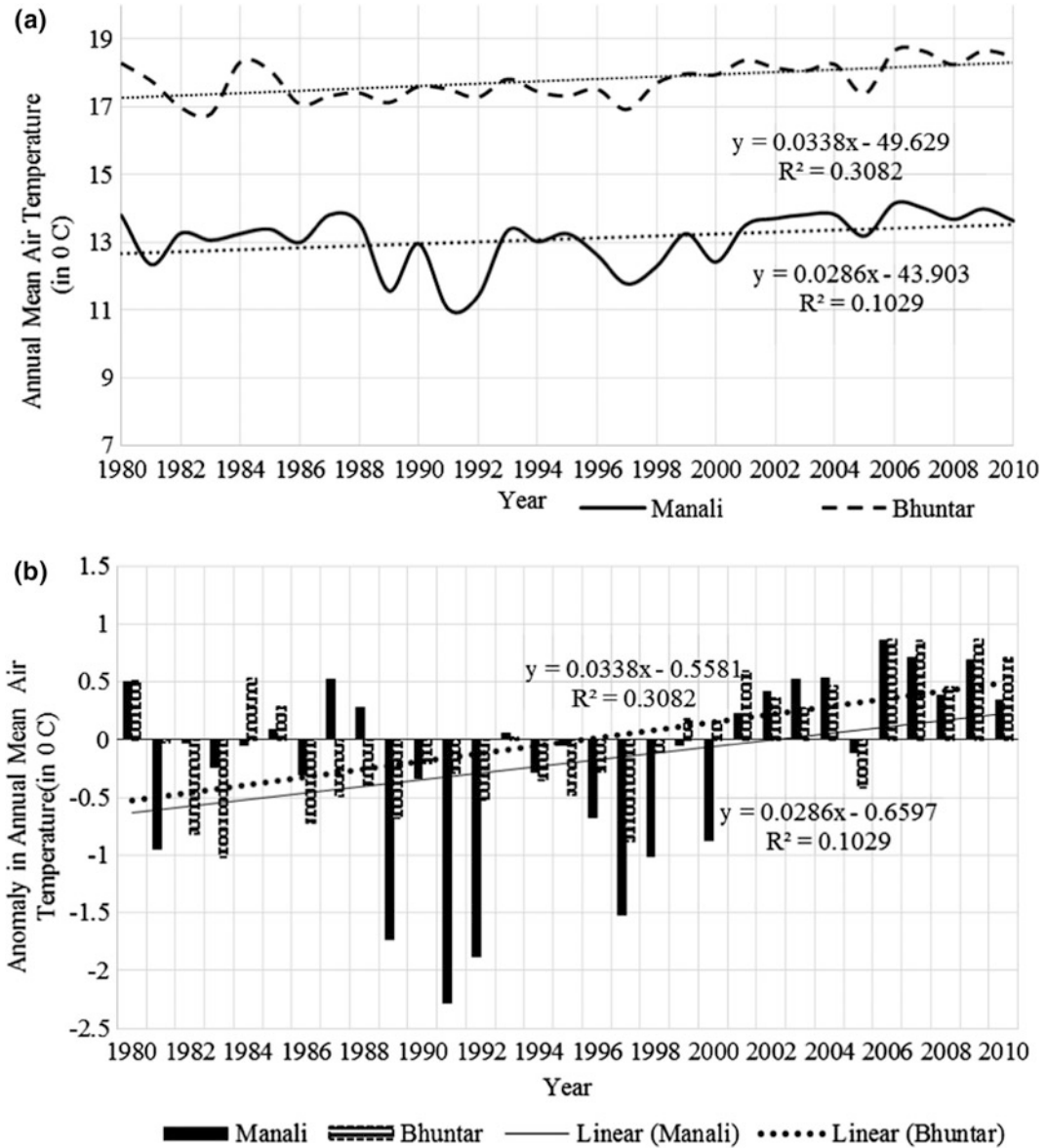


Fig. 4 Trend a and anomalies b in annual mean air temperature

Seasonal Trends of Temperature

To ascertain whether the warming trend is uniform across seasonal temperature, trends were computed for Manali and Bhuntar for the period 1980–2010. Table 1 shows that mean T_{min} at Manali during winter, pre-monsoon, monsoon and post-monsoon seasons was 0.3, 9.2, 14.3 and 3.6 °C, respectively, during 1980–2010. Trend analysis results of Manali revealed a significant

increasing trend in mean T_{min} in all the seasons except monsoon. Highest change in mean T_{min} was observed in the post-monsoon season (0.09 °C/year) followed by the winter season (0.06 °C/year) and pre-monsoon (0.05 °C/year). Bhuntar experienced a mean T_{min} of 3.39, 12.97, 18.52 and 7.17 °C during winter, pre-monsoon, monsoon and post-monsoon seasons, respectively, during 1980–2010 (Table 1). Significant

Table 1 Trend of mean minimum air temperature

Timescale	Manali			Bhuntar		
	Mean (°C)	MK test (Z)	Sen's slope (°C/yr)	Mean (°C)	MK test (Z)	Sen's slope (°C/yr)
Jan	-1.4	2.04*	0.04*	1.7	-0.07	0.00
Feb	0.1	1.59	0.03	3.7	1.22	0.02
Mar	2.7	3.24**	0.09**	6.6	1.80	0.03
Apr	6.2	1.61	0.05	9.6	2.53*	0.04*
May	9.0	1.80	0.05	12.8	1.75	0.05
Jun	12.5	1.59	0.03	16.6	0.51	0.01
Jul	15.5	-0.15	0.00	19.6	1.33	0.02
Aug	15.7	0.94	0.02	19.6	0.41	0.01
Sep	11.7	1.82	0.06	16.4	0.58	0.02
Oct	5.5	4.48**	0.10**	9.8	1.19	0.02
Nov	1.8	4.15**	0.09**	4.6	0.22	0.00
Dec	-0.04	3.39**	0.07**	1.7	-0.92	-0.02
Winter	0.3	2.96**	0.06**	3.39	0.27	0.00
Pre-monsoon	9.2	2.11*	0.05*	12.97	1.97*	0.04*
Monsoon	14.3	1.74	0.03	18.52	1.63	0.02
Post-monsoon	3.6	4.37**	0.09**	7.17	0.71	0.01
Annual	6.6	2.77**	0.05**	10.2	2.41*	0.02*

Significant at 0.01** level and 0.05* level

increasing trend in mean T_{\min} at the station was found only during the pre-monsoon season at the rate of $0.04^{\circ}\text{C}/\text{year}$ (Table 1) that is slightly lower than the magnitude of change in mean T_{\min} of pre-monsoon, observed at Manali. Pal and Al-Tabbaa (2011) also found a rising trend in the mean T_{\min} during winter, pre-monsoon and post-monsoon seasons in the Western Himalaya.

Mean T_{\max} at Manali during winter, pre-monsoon, monsoon and post-monsoon seasons was 12.9, 23.7, 25 and 19.3 °C, respectively, during the period 1980–2010 (Table 2). The seasonal trend analysis at Manali shows a statistically significant decreasing trend in mean T_{\max} during monsoon at the rate of $-0.03^{\circ}\text{C}/\text{year}$. Broadly, results show that daytime temperature at Manali has gone down during monsoon season while the night temperature remained stable in the same season during the period of analysis. This is inconsistent with the studies of Dash et al. (2007) and Pal and Al-Tabbaa (2010) who found an increase in mean T_{\max} of winter season in the

Western Himalaya. This is probably due to difference in period of study between the present and above two studies. At Bhuntar, the observed mean T_{\max} in the winter, pre-monsoon, monsoon and post-monsoon seasons was 18, 30, 30.7 and 25.3 °C during 1980–2010 (Table 2). Seasonal trend analysis of Bhuntar shows a significant increasing trend in the mean T_{\max} during winter at the rate of $0.12^{\circ}\text{C}/\text{year}$ (Table 2).

At Manali, winter season shows a significant increasing trend in T_{mean} at the rate of $0.04^{\circ}\text{C}/\text{year}$ during the period of study (Table 3). Since the mean T_{\max} of the season remained the same, the above can be attributed to increase in the mean T_{\min} . Broadly, mean T_{\min} at Manali shows high intra-seasonal variability compared to mean T_{\max} during the period of analysis. Significant rising trend in T_{mean} was found at Bhuntar during winter ($0.05^{\circ}\text{C}/\text{year}$), followed by the pre-monsoon ($0.04^{\circ}\text{C}/\text{year}$) and post-monsoon ($0.03^{\circ}\text{C}/\text{year}$) seasons of the period 1980–2010 (Table 3). Results suggest that

Table 2 Trend of mean maximum air temperature

Timescale	Manali			Bhuntar		
	Mean (°C)	MK test (Z)	Sen's slope (°C/yr)	Mean (°C)	MK test (Z)	Sen's slope (°C/yr)
Jan	10.5	0.05	0.00	15.7	2.21*	0.08*
Feb	11.8	-0.24	0.00	17.4	2.58**	0.11**
Mar	15.8	1.68	0.05	21.3	3.37**	0.20**
Apr	20.4	-0.55	0.00	26.6	2.72**	0.12**
May	24.3	-0.05	0.00	30.6	0.88	0.04
Jun	26.3	-1.81	-0.05	32.6	-0.44	-0.02
Jul	25.7	-0.70	-0.01	31.3	0.48	0.01
Aug	25.0	-1.38	-0.02	30.7	-0.60	-0.02
Sep	24.4	-2.43*	-0.05*	30.0	-1.97*	-0.04*
Oct	21.4	-1.07	-0.01	27.7	0.78	0.02
Nov	17.3	-1.45	-0.03	22.9	0.70	0.02
Dec	13.4	-0.64	-0.01	17.7	1.22	0.04
Winter	12.9	1.23	0.02	18.0	4.22**	0.12**
Pre-monsoon	23.7	-0.53	-0.01	30.0	1.87	0.07
Monsoon	25.0	-2.52*	-0.03*	30.7	-0.82	-0.02
Post-monsoon	19.3	-1.79	-0.01	25.3	0.99	0.02
Annual	19.7	-0.77	-0.01	25.4	3.30**	0.06**

Significant at 0.01** level and 0.05* level

the significant changes in T_{mean} occurring during the winter at Bhuntar had the major influence of the variations in winter season mean T_{max} because mean T_{min} of winter showed no trend during the study period.

Monthly Trends of Temperature

Mean T_{min} of Manali ranged between -1.4 °C in January and 15.7 °C in August during 1980–2010 (Table 1). Table 1 indicates that T_{min} of January, March, October, November and December was rising at Manali during the period of analysis. Highest and lowest change in mean T_{min} was found in October (0.1 °C/year) and January (0.04 °C/year), respectively. T_{min} at Bhuntar varies from 1.7 °C (December and January) to 19.6 °C (July and August) during the period of analysis which was much higher than Manali because of altitudinal variation (Table 1). The monthly trend analysis shows a significant increasing trend in mean T_{min} of April (0.04 °

C/year) during 1980–2010 (Table 1). It indicates that Bhuntar experienced less variations in the monthly mean T_{min} compared to Manali (Table 1) during the same period of observation.

T_{max} at Manali varies from 10.5 °C in January to 26.3 °C in June during 1980–2010 (Table 2). Trend analysis at Manali showed a statistically significant decreasing trend T_{max} in September at the rate of -0.05 °C/year (Table 2). Overall, trend analysis of monthly mean T_{min} and T_{max} at Manali indicates more warming trend during the night temperature of winter months while the daytime temperature in the monsoon month shows a decline. Moreover, magnitude of change of monthly mean T_{min} was higher than the monthly mean T_{max} . Monthly mean T_{max} in Bhuntar varies from 15.7 °C in January to 32.6 °C in June during 1980–2010 (Table 2). Table 2 shows a significant increasing trend at Bhuntar in mean T_{max} of March (0.20 °C/year) followed by April (0.12 °C/year), February (0.11 °C/year)

Table 3 Trend of mean air temperature

Timescale	Manali			Bhuntar		
	Mean (°C)	MK test (Z)	Sen's slope (°C/yr)	Mean (°C)	MK test (Z)	Sen's slope (°C/yr)
Jan	4.6	0.89	0.00	8.7	2.35*	0.05*
Feb	5.8	0.80	0.02	10.4	1.77	0.05
Mar	9.2	2.55*	0.08*	13.7	2.65**	0.10**
Apr	13.1	0.14	0.00	18.0	2.48*	0.07*
May	16.6	1.04	0.02	21.6	1.02	0.03
Jun	19.3	-0.84	-0.01	24.6	0.20	0.01
Jul	20.5	0.09	0.00	25.4	0.85	0.02
Aug	20.2	0.63	0.00	25.2	-0.03	0.00
Sep	18.0	-0.46	0.00	23.2	-0.41	-0.01
Oct	13.5	1.50	0.02	19.0	2.11*	0.03*
Nov	9.5	0.67	0.00	13.8	1.89	0.03
Dec	6.7	0.51	0.00	9.8	0.95	0.01
Winter	6.6	2.41*	0.04*	10.7	3.50**	0.05**
Pre-monsoon	16.3	1.95	0.03	21.4	2.11*	0.04*
Monsoon	19.6	0.21	0.00	24.6	0.17	0.00
Post-monsoon	11.5	1.63	0.02	16.4	2.48*	0.03*
Annual	13.1	2.12*	0.03*	17.8	3.38**	0.05**

Significant at 0.01** level and 0.05* level

and January (0.08 °C/year). On the other hand, September shows a significant decreasing trend in T_{\max} (0.04 °C/year). It shows that variations in mean T_{\max} of winter months were higher than other months at Bhuntar during the period of analysis.

T_{mean} of Manali ranged between 4.6 °C in January and 20.5 °C in July during the period 1980–2010 (Table 3). T_{mean} of March showed a statistically significant increasing trend at the rate of 0.08 °C/year. The rise in T_{mean} of March may be attributed to the rise in the mean T_{\min} as mean T_{\max} of the month shows no trend during the study period. At Bhuntar, T_{mean} varies from 8.7 °C in January to 25.4 °C in June during the period 1980–2010 (Table 3). T_{mean} at Bhuntar shows a significant rising trend in January, March, April and October during the period of analysis. Highest change in T_{mean} was found in the March (0.10 °C/year) followed by April (0.07 °C/year), January (0.05 °C/year) and October (0.03 °C/year). Trend analysis results further show that

change in T_{mean} of January and March may be attributed to the rising trend in mean T_{\max} of the respective months as mean T_{\min} of the months remained stable during the period of analysis. Furthermore, both mean T_{\min} and T_{\max} of October show a rising trend, but the highest change was found in mean T_{\max} . Therefore, the observed increase in T_{mean} of October is primarily due to the increase in mean T_{\max} of the month.

Trend analysis results of L_{\min} and H_{\max} of Manali and Bhuntar are shown in Table 4. It shows a significant rising trend in L_{\min} at Manali in February, April, May and November. Highest magnitude of change was found in April followed by May, November and February. A significant rise in mean T_{\min} of November at Manali (Table 2) had the influence on significant rising trend in L_{\min} of the month during the study period. Furthermore, Table 4 shows a significant fall in H_{\max} in September and December at Manali with the highest decline in the former month during 1980–2010. September also had a

Table 4 Trend in lowest minimum (L_{min}) and highest maximum temperature (H_{max})

Months	Manali		Bhuntar	
	L_{min} (°C/year)	H_{max} (°C/year)	L_{min} (°C/year)	H_{max} (°C/year)
Jan	0.325	-0.12	-0.075	0.269
Feb	0.419*	0.13	0.061	0.490**
Mar	0.351	0.358	0.390*	0.543**
Apr	0.731**	-0.144	0.26	0.453*
May	0.437*	0.01	0.35	0.238
Jun	0.247	-0.363	0.268	0.171
Jul	0.172	-0.374	0.544**	-0.037
Aug	0.224	-0.361	0.269	-0.13
Sep	0.066	-0.546**	0.331	-0.133
Oct	0.396	-0.177	0.259	0.379*
Nov	0.435*	-0.136	-0.065	0.282
Dec	0.397	-0.537**	-0.091	0.178

Significant at 0.01** level and 0.05* level

significant decline in mean T_{max} during the study period (Table 2). This may be because of a significant fall in H_{max} in the month over the period. At Bhuntar, L_{min} showed a significant increasing trend in March and July during the period of analysis. In contrast, H_{max} shows a significant rise in most of the winter months. Highest changes were found in March followed by February, April and October. Mean T_{max} of February, March and April showed a statistically significant rising trend at Bhuntar during 1980–2010. Therefore, the observed increase in H_{max} might be influencing the increase in mean T_{max} of the mentioned months.

Manali and Bhuntar experienced a warming trend during 1980–2010. This may be attributed to increase in anthropogenic activities such as, land use/land cover changes, tourism, and construction. Manali is a destination for tourists from all over the world. According to Census of India (2011), Manali and Bhuntar experienced a growth rate of 252 and 62%, respectively, during 1981–2011. It has registered the highest growth rate amongst urban centres in the state during 1991–2001. During the decade 1991–2001, Manali has registered an unprecedented growth rate of 157.50% that was higher amongst the urban centres in Himachal Pradesh that means Manali has attracted a substantial number of

people during this decade in addition to natural growth. During the same decade, Bhuntar has also experienced high population growth of 43.3%. Consequently, over the time, residential area, commercial spaces, transport network, etc., have increased at both stations that led to changes in land cover over the years. Rising vehicular population and industries leads to rise in aerosol which influenced the air temperature at both the stations. Acharya and Sreekesh (2013) found consistent low optical depth (<0.6 at both 0.47 and 0.66 μm) in the area in January, April and October during 2001–2009 which are also the months in which both stations show maximum variations in T_{min} , T_{max} and T_{mean} .

Trends in Rainfall and Rainy Days

Manali experienced a mean annual rainfall of 1091 mm during 1980–2010 (Table 5). Highest and lowest annual rainfall at Manali was 2000 mm (1995) and 429 mm (1992), respectively (Fig. 5). The percentage departure in the annual rainfall from the normal shows that Manali experienced excess rain only in 5 years while 17 years had deficient rain during the study period (Fig. 5). Overall, a fall of about 53 mm was observed at Manali in annual rainfall in

Table 5 Trend in monthly rainfall

Timescale	Manali			Bhuntar		
	Mean (mm)	MK test (Z)	Sen's slope (mm/yr)	Mean (mm)	MK test (Z)	Sen's slope (mm/yr)
Jan	73	-0.20	-0.22	77	-0.27	-0.30
Feb	96	-2.36*	-3.73*	109	0.04	0.08
Mar	151	-2.47*	-4.95*	134	-1.75	-2.15
Apr	108	-1.78	-2.10	80	-1.59	-1.48
May	80	-1.36	-1.31	70	-1.04	-0.82
Jun	79	-0.18	-0.23	53	0.52	0.30
Jul	180	-2.05*	-4.36*	129	0.04	0.12
Aug	174	-0.01	0	111	1.02	1.04
Sep	93	0.43	0.38	72	1.57	1.67
Oct	35	-0.54	-0.05	31	-0.97	-0.26
Nov	29	-0.57	-0.05	21	0.00	0.00
Dec	55	-1.80	-1.71	39	-1.17	-0.46
Winter	380	-2.57*	-8.55*	359	-0.79	-3.00
Pre-monsoon	276	-1.20	-2.56	202	-1.37	-1.53
Monsoon	456	-0.80	-3.16	312	1.75	3.56
Post-monsoon	66	-0.86	-0.82	60	-1.25	-1.23
Annual	1091	-0.78	-7.8	926	-0.87	-3.26

Significant at 0.01** level and 0.05* level

relation to normal during the period. During the same period, Bhuntar received relatively less mean annual rainfall of 926 mm (Table 5). The percentage departure in the annual rainfall from the normal (Fig. 6) shows that Bhuntar received excess rain in 1982, 1988, 1998 and deficient rain in 1980, 1984, 2002 and 2009.

It shows that years of deficient rain at Bhuntar exceed the years of excess rain during 1980–2009. However, a rise of 9 mm was found in the mean annual rainfall of Bhuntar (relative to the normal annual rainfall) during the period of analysis. It was found that the amount of excess rain occurred at Bhuntar was more than the amount of deficient rain during the study period. Therefore, slight rise in mean annual rainfall at Bhuntar is primarily due to the increase in amount of excess rainfall.

Annual Trend of Rainfall and Rainy Days

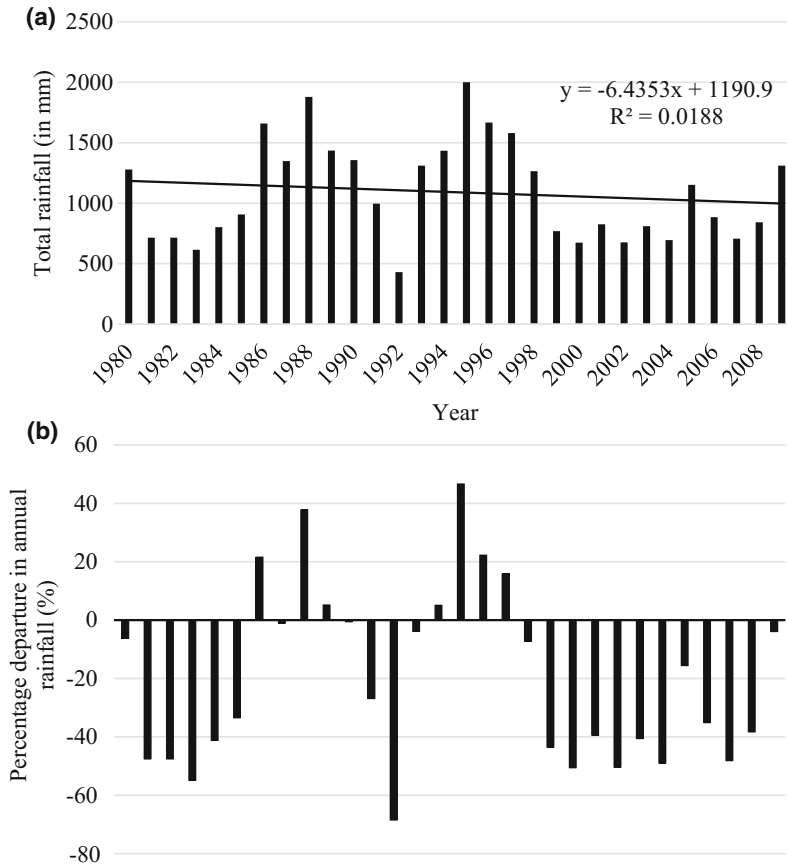
The annual trend analysis indicates no significant trend in the annual rainfall of Manali and

Bhuntar during 1980–2010 (Table 5). Manali had a marginally significant decreasing trend in the annual number of rainy days at the rate of -0.6 days/year during the study period (Table 6). It indicates that Manali received almost same amount of rainfall in less days, which means rainfall intensity had slightly increased over the period. Bhuntar experienced no trend in the annual number of rainy days over the period (Table 6).

Seasonal Trend of Rainfall and Rainy Days

Table 5 indicates that Manali received highest rainfall in the monsoon season (41%) followed by winter (35%), pre-monsoon (25%) and post-monsoon (6%) seasons. The trend analysis of seasonal rainfall shows a significant decreasing trend during the winter season at the rate of -8.55 mm/year (Table 5). This trend is in contrast to the study done by Kumar et al. (2010) who found a decreasing trend in the monsoon

Fig. 5 Annual rainfall, its trend **a** and percentage departure **b** at Manali

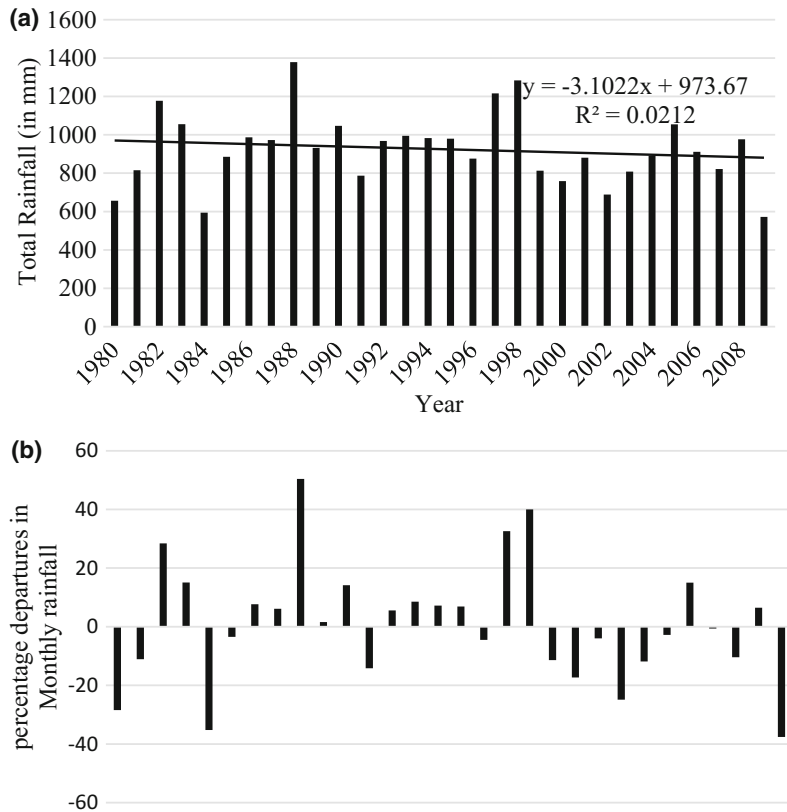


rainfall and increasing trend during the pre-monsoon, post-monsoon and winter rainfall at the national scale. A decreasing trend in winter rainfall at Manali may result in the decrease of river run-off in the season that would negatively affect the availability of water. Bhuntar received the relatively highest rain during winter (39%) followed by monsoon (34%), pre-monsoon (22%) and post-monsoon (7%) seasons (Table 5). The trend analysis of rainfall at Bhuntar shows no trend in the seasons during 1980–2009 (Table 5).

Manali experienced the highest number of rainy days during monsoon season followed by winter, pre-monsoon and post-monsoon seasons (Table 6). The seasonal trend analysis shows a significant decreasing trend during winter and monsoon in the number of rainy days at the rate

of -0.42 day/year and -0.39 day/year, respectively, during the study period (Table 6). This might be the cause for reduction in the amount of rainfall during the season at Manali (Table 5). If this trend continues, it may adversely impact the water availability conditions in the region. The observed mean number of rainy days at Bhuntar in the winter, pre-monsoon, monsoon and post-monsoon was 23, 20, 24 and 3, respectively, during 1980–2009 (Table 6). Results of Bhuntar showed a significant increasing trend in the number of rainy days at the rate of 0.03/year during monsoon (Table 6). However, the amount of rainfall was stable at the station (Table 5), indicating the possibility of reduction in the rainfall intensity at the station during the study period.

Fig. 6 Annual rainfall, its trend **a** and percentage departure **b** at Bhuntar



Monthly Trends of Rainfall and Rainy Days

Mean monthly rainfall at Manali ranged between 180 mm (July) and 29 mm (November) during 1980–2010 (Table 5). Trend analysis shows a significant decreasing trend in rainfall of February, March and July (Table 5). The highest rate of decrease in rainfall at the station was in March (−4.95 mm/year) followed by July (−4.36 mm/year) and February (−3.73 mm/year). Kumar et al. (2010) found an increasing trend in rainfall of June, July and September and decreasing trend in August at the national scale. Rani (2014) found a significant negative correlation at Manali between the percentage departures of monthly rainfall and anomalies in monthly mean air temperature in March that means an increase in positive anomalies in mean air temperature of March could have resulted in a reduction in rainfall in March. Bhuntar experienced mean monthly

rainfall ranged between 134 mm (March) and 21 mm (November) during 1980–2009 (Table 5). Monthly rainfall at Bhuntar shows no significant trend during the period of study.

Average number of rainy days in Manali varied from 2 (November) to 16 (August) (Table 6) during 1980–2010. Trend analysis of the average number of rainy days at Manali shows a significant decreasing trend in February, March and December (Table 6). Rate of decrease in number of rainy days was higher in February followed by March and December. The monthly rainfall of Manali also shows a significant decreasing trend during February and March (Table 5). It indicates that probably decreasing trend in the number of rainy days was responsible for decreasing trend in the amount of rainfall of these months. Average number of rainy days at Bhuntar varied from 2 (October and November) to 9 (July and August) during 1980–2009 (Table 6). Trend analysis at the station shows a

Table 6 Trend in rainy days

Timescale	Manali			Bhuntar		
	Mean (days)	MK test (Z)	Sen's slope (days/yr)	Mean (days)	MK test (Z)	Sen's slope (days/yr)
Jan	6	0.05	0.00	5	0.65	0.00
Feb	8	-2.85**	-0.19**	7	0.71	0.00
Mar	9	-1.96*	-0.14	9	-0.90	-0.08
Apr	6	-0.56	0.00	7	-0.86	-0.05
May	7	-0.26	0.00	7	0.18	0.00
Jun	9	1.85	0.14	6	2.45*	0.17*
Jul	15	-1.81	-0.22	9	1.33	0.11
Aug	16	-0.55	0.00	9	1.62	0.13
Sep	9	-1.06	-0.09	5	2.01*	0.16*
Oct	3	0.36	0.00	2	-0.10	0.00
Nov	2	0.44	0.00	2	0.26	0.00
Dec	3	-2.22*	-0.12	3	-0.71	0.00
Winter	27	-2.67**	-0.42**	23	-0.34	0.00
Pre-monsoon	22	0.61	0.06	20	0.79	0.17
Monsoon	40	-1.99*	-0.39*	24	2.17*	0.36*
Post-monsoon	5	0.22	0.00	3	-0.13	0.00
Annual	94	-2.05*	-0.6	70	0.70	0.33

Significant at 0.01** level and 0.05* level

Table 7 Trend in rainy days under different categories of rainfall intensity

Months	Manali		Bhuntar	
	Light rain (2.5–7.5 mm/day)	Moderate rain (7.6–35.5 mm/day)	Light rain (2.5–7.5 mm/day)	Moderate rain (7.6–35.5 mm/day)
	Sen's slope (days/yr)			
Jan	-0.029	0.064	-0.059	-0.235
Feb	0.123	-0.434*	-0.136	0.082
Mar	-0.268	-0.028	-0.371*	-0.26
Apr	-0.068	-0.273	-0.312	-0.289
May	0.191	-0.059	-0.299	-0.370*
Jun	0.457*	0.128	0.057	-0.034
Jul	-0.323	-0.153	-0.09	-0.284
Aug	0.186	0.109	-0.047	-0.062
Sep	-0.183	0.001	0.266	0.011
Oct	0.081	-0.149	-0.116	-0.195
Nov	-0.122	-0.037	0.309	-0.177
Dec	-0.233	-0.385*	-0.035	-0.111

Significant at 0.01** level and 0.05* level

significant increasing trend in number of rainy days of June and September at the rate of 0.17 days/year and 0.16 days/year, respectively, during the period of analysis. However, the amount of rainfall in these months was stable (Table 5). It indicates a reduction in the rainfall intensity at the station during the study period.

Trend in Rainfall Intensity

Number of days with light and moderate rain at both stations were categorized in the study to understand their trend and magnitude of change during 1980–2010 (Table 7). Manali experienced a significant increase in days with light rain in June and fall in days with moderate rain in the winter months (February and December) during the study period. Reduction in the days of moderate rainfall intensity in February probably led to decrease in the rainfall of that month at Manali. Bhuntar experienced a significant decreasing in days with light (March) and moderate rain (May) during the period of analysis. Despite this, rainfall was almost stable at Bhuntar during 1980–2010.

Conclusions

The present study was an attempt to understand the annual, seasonal and monthly trends, including the magnitude of the trend in T_{\min} , T_{\max} , T_{mean} , L_{\min} , H_{\max} , amount of rainfall, rainy days and rainfall intensity of the upper Beas basin in the Western Indian Himalaya during 1980–2010. The findings show a significant increasing trend in annual mean T_{\min} at Manali. On the other hand, Bhuntar experienced an increasing trend in annual mean T_{\min} and T_{\max} during the period of analysis. The rate of increase in annual mean T_{\max} at the station was higher than that of annual mean T_{\min} . Both the stations also showed a rising trend in annual T_{mean} which is in tune with the finding of Bhutiyani et al. (2007). Manali experienced a significantly higher rate of warming compared to Bhuntar. The seasonal trend analysis of Manali showed a rising

trend in the mean T_{\min} of all the seasons except monsoon while mean T_{\max} showed a decreasing trend in monsoon. Bhuntar experienced a significant increasing trend in mean T_{\min} and T_{\max} during pre-monsoon and winter season, respectively. Overall, both the stations experienced a significant rising trend in T_{mean} of winter season with maximum change at Bhuntar. During post-monsoon season, also Bhuntar had experienced a rising trend in T_{mean} . The rate of change of seasonal T_{\min} at Manali is higher than that of seasonal T_{\max} and Bhuntar experienced opposite to this pattern during the period 1980–2010. Based on the trend analysis of temperature of two stations, it would be difficult to conclude that the upper Beas basin study had a warming tendency during the assessment period, as there is a need for more stations data that could represent altitudinal variations of the whole basin. The slight warming trend at these stations may be attributed to increasing anthropogenic activities, especially towards the lower reaches of the basin. Intensification of tourism and other economic activities resulted in land use/land cover changes ensuing an increase in built-up area and reduction in vegetative cover. This transformed the albedo of those regions, augmenting the temperature. Rise of tourist activities also increased the vehicular movement in this area, and consequent rise in aerosols might have also contributed to rise in air temperature because of increased trapping efficiency.

In case of annual rainfall, Manali showed no significant trend, though significant reduction was observed in monthly (February, March and July) rainfall during 1980–2010. Bhuntar experienced no trend in annual and monthly rain. In case of seasonal rain, Manali shows a significant decreasing trend during winter. Bhuntar showed no trend in seasonal rain. For number of rainy days, Manali showed a significant decreasing trend in February, March and December. Trend analysis of monthly rainfall and rainy days at Manali showed that the decreasing trend in the number of rainy days was responsible for decreasing trend in the amount of rainfall of February and March. Bhuntar experienced a significant increasing trend in number of rainy

days of June and September during the period of analysis. However, the amount of rainfall in these months was stable at Bhuntar. It indicates a reduction in the rainfall intensity at the station during the study period. Therefore, it can be concluded that there are evidences of change in the amount of rainfall and rainy days of the study area with seasonal and monthly variations during the period of analysis. It may influence the hydropower generation and other activities that are directly or indirectly depend on the water availability. The results point to the wider variability in temperature and rainfall implying an increased unpredictability in weather in this area in near future. It may be a precursory indicator of an imminent climate change. So, there is need for wider monitoring of rainfall, considering topography and altitudinal variations, in the upper Beas river basin for proper planning and management.

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