Trends in Temperature for the Himalayan Environment of Leh (Jammu and Kashmir), India

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Abstract Climate parameters variability affects significantly on water resources, and therefore on the livelihood of the common people, especially in water scarce countries. The aim of this study was to explore changes in the maximum, minimum, and mean temperatures using the monthly data of Leh taking last 15 years from 2000 to 2014, which is situated in the western Indian Himalaya. Trends analyses were performed with nonparametric statistics proposed by Mann-Kendall at different time scales in arid environments of Leh. On monthly basis, a significant falling trend in maximum temperature and minimum temperature has been observed at 5% significance level in the month of July at the rate of 1.7 °C per decade and in the month of August at the rate of 1.3 °C per decade, respectively. However, no trend has been observed in other time scales at 5% level of significance. The observed change in temperature will affect all biochemical reactions of photosynthesis thus in turn will have negative impact on plant growth.

Keywords Trend · Mann-Kendall · Maximum and minimum temperature Himalayan region, Leh

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Introduction

Climate change has brought in unexpected changes not only in India but all over the regions across the world. Emergence of global warming due to climate change is the new and most talked subject of today's world as it is the most threatening issue for very existence of life on the earth. One of the consequences of climate change is the alteration of rainfall patterns and increase in temperature. According to Intergovernmental Panel on Climate Change (IPCC 2001) reports, the surface temperature of the earth has risen by 0.6 ± 0.2 °C over the twentieth century. Also in the last 50 years, the rise in temperature has been 0.13 ± 0.07 °C per decade. As the warming depends on emissions of greenhouse gases in the atmosphere, the IPCC has projected a warming of about 0.2 °C per decade. Further, surface air temperature could rise by between 1.1 and 6.4 °C over twenty-first century. In case of India, the climate change expected to adversely affect its natural resources, forestry, agriculture, and change in precipitation, temperature, monsoon timing, and extreme events. Due to global warming, precipitation amount, type and timing are changing or expected to change because of increased evaporation, especially in the tropics.

The pattern and amount of rainfall are among the most important factors that affect agricultural production (Jhajharia et al. 2015). Agriculture is vital to India's economy and the livelihood of its people. Agriculture is contributing 21% to the country's GDP, accounting for 115 of total export, employing 56.4% of the total workforce, and supporting 600 million people directly and indirectly (Beena 2010; McVicar et al. 2010, 2012). Temperature drives the hydrological cycle, influencing hydrological processes in a direct or indirect way. A warmer climate leads to intensification of the hydrological cycle, resulting in higher rates of evaporation and increase of liquid precipitation. These processes, in association with a shifting pattern of precipitation, will affect the spatial and temporal distribution of runoff, soil moisture, groundwater reserves, and increase the frequency of droughts and floods. The future climatic change, though, will have its impact globally and will be felt severely in developing countries with agrarian economies, such as India. Surging population and associated demands for freshwater, food, and energy would be areas of concern in the changing climate. Changes in extreme climatic events are of great consequence owing to the high vulnerability of the region to these changes. Parry et al. (2001) have shown that there is a steep rise in the water shortage curve when plotted against rise in temperature. They reported that this is due to large urban populations in China and India being newly exposed to risk. There has not been conducted previous study on behavior of temperature for the Himalayan environment of Leh, this study was carried out to analyze the temperature trend of Leh using Mann-Kendall test for the year 2000–2014.

Materials and Methods

Study Area

The Indian Himalayan Region (IHR) is spreading to 10 states (administrative regions) namely, Jammu & Kashmir, Himachal Pradesh, Uttaranchal, Sikkim, Arunachal Pradesh, Meghalaya, Nagaland, Manipur, Mizoram, Tripura, and hill regions of two states viz. Assam and West Bengal of Indian Republic. It contributes about 16.2% of India's total geographical area, and most of the area is covered by snow-clad peaks, glaciers of higher Himalaya, dense forest cover of mid-Himalaya. The IHR shows a thin and dispersed human population as compared to the national figures due to its physiographic condition and poor infrastructure development, but the growth rate is much higher than the national average.

In this study Himalayan region of Leh was taken into consideration. Mountains dominate the landscape around the Leh as it is at an altitude of 3,500 m. Leh has a cold desert climate with long, harsh winters, with minimum temperatures well below freezing for most of the winter. The city gets occasional snowfall during winter. The weather in the remaining months is generally fine and warm during the day. Average annual rainfall is only 102 mm. The temperature can range from −42 °C in winter to 33 °C in summer. In 2010, the Leh city experienced flash floods which killed more than 100 people. The study area of Himalayan region is shown in Fig. 1.

The data sets used in this study was obtained from High Mountain Research Station Leh, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir for the period of 15 years from 2000 to 2014 of cold desert.

The trend analysis of temperature at monthly, annual and seasonal (winter, spring, summer and autumn) basis was carried out. Trends in data can be identified by using

Fig. 1 Study area of Leh

either parametric or nonparametric methods. In the recent past, both methods have been widely used for the detection of trends (WMO 1997; Mitosek 1992; Chiew and McMahon 1993; Burn and Elnur 2002). Then parametric tests are more suitable for non-normally distributed, censored data, including missing values, which are frequently encountered in hydrological time series (Hirsch et al. 1984).

Mann-Kendall Test

Mann-Kendall test is a statistical test widely used for the analysis of trend in climatologic and in hydrologic time series. There are two advantages of using this test. First, it is a nonparametric test and does not require the data to be normally distributed. Second, the test has low sensitivity to abrupt breaks due to inhomogeneous time series. According to this test, the null hypothesis H_0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H_1, which assumes that there is a trend. Mann-Kendall test is a nonparametric test for identifying trends in time series data. This test compares the relative magnitudes of data rather than the data values themselves (Gilbert 1987). This test assumes that there exists only one data value for a time period. When multiple data points exist for a single time period, the median value will be used. The initial value of the Mann-Kendall statistic S is assumed to be 0. If a data value from a later time period is higher than a data value from an earlier time period, S is increased by 1. On the other hand, if the data value from the later time period is lower than a data valued sampled earlier, it is decreased by 1. The net result of increments and decrements yields the final value of S. This method is more suitable for non-normally distributed and censored data, and is less influenced by the presence of outliers in the data (Mann 1945; Kendall 1975).

Let $x_1, x_2, x_3, \ldots, x_n$ represent n data points, then the Mann-Kendall test statistic S is given by

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

where n is the number of observations and x_j is the jth observation and sgn (θ) is the sign function which can be defined as follows:

$$\mathrm{sgn}(\theta) = \begin{bmatrix} 1 & \text{if} & \theta > 0 \\ 0 & \text{if} & \theta = 0 \\ -1 & \text{if} & \theta < 0 \end{bmatrix} \tag{2}$$

Under the assumption that the data are independent and identically distributed, the mean and variance of the S statistic are given by (Kendall 1975)

$$E(S) = 0 \tag{3}$$

$$\frac{n(n-1)(2n+5) - \sum_{i=0}^{m} t_i(t_i - 1)(2t_i + 5)}{18} = V_S, \tag{4}$$

where m is the number of groups of tied ranks, each with tied observations.

The Z-statistic can be computed as follows:

$$Z = \frac{S-1}{\sqrt{(\text{var}(S))}} \quad \text{IF} \ \ S > 0 \tag{5}$$

$$Z = 0 \quad \text{If} \ \ S = 0 \tag{6}$$

$$Z = \frac{S+1}{\sqrt{(\text{var}(S))}} \quad \text{if} \ \ S < 0 \tag{7}$$

Estimation of Magnitude of Trends

The magnitude of the identified trends in the meteorological parameters was obtained through the parametric linear regression test, a commonly used parametric method.

The linear relationship between two variables is represented by a straight line, which is given as

$$y = m \times x + c$$

x denote the time variable
m slope of regression line
c intercept

Results and Discussion

The value of Z statistics with p-value in parenthesis obtained by Mann-Kendall test for all the parameters on monthly and annual time scales are tabulated below. The value test Statistics (z) is summarized in Table 1.

It is witnessed from Table 1 that the statistically significant falling trends are witnessed in maximum temperature in the month of July at the rate of 1.70 °C/decade, at 5% level of significance as the values of Z (test statistics) obtained through the MK

Table 1 The value of test statistics (z) obtained through Mann-Kendall test on monthly and annual basis

Month	Maximum temperature	Minimum temperature
January	*0.291* *(0.923)*	*0.132* *(0.846)*
February	*−0.172* *(0.254)*	*−0.357* *(0.282)*
March	*0.306* *(0.495)*	*0.325* *(0.328)*
April	*0.363* *(0.282)*	*0.254* *(0.298)*
May	*0.038* *(0.814)*	*0.166* *(0.457)*
June	*0.097* *(0.697)*	*0.073* *(0.435)*
July	**−2.114** **(0.032)**	*0.122* *(0.656)*
August	*0.116* *(0.137)*	**−1.999** **(0.015)**
September	*0.068* *(0.657)*	*−0.139* *(0.495)*
October	*0.032* *(1.000)*	*−0.132* *(0.770)*
November	*0.320* *(0.804)*	*0.132* *(0.626)*
December	*0.052* *(0.298)*	*−0.138* *(0.499)*
Annual	*0.014* *(0.846)*	*0.138* *(0.770)*

Note: *Bold values* denote statistically significant at 5% level of significance. *Italic values* are cases of no trends (statistically non-significant even at 10% level of significance)

test are more than −1.96 (Table 1). However, the remaining months witnessed no statistically significant trends in maximum temperature at 5% level of significance as the Z values are between +1.96 and −1.96 (or at 10% level of significance as the Z values are between +1.65 and −1.65). The monthly trend in maximum temperature during 2000–2014 is shown in Fig. 2a–d.

It is evident from Table 1 that in case of minimum temperature MK test revealed that statistically significant falling trend at 5% level of significance, as the values of Z (test statistics) obtained, is more than −1.96 and was witnessed in the month of August at the rate of 1.31 °C/decade (Fig. 3a–d). Statistically significant falling trend was witnessed in the month of December at the rate of 1.74 °C/decade at 10% significance level as the Z value is more than 1.65 and less than 1.96. However, the remaining months witnessed no significant trends at 5% level of significance as the Z values are between +1.96 and −1.96 (or at 10% level of significance as the Z values are between +1.65 and −1.65).
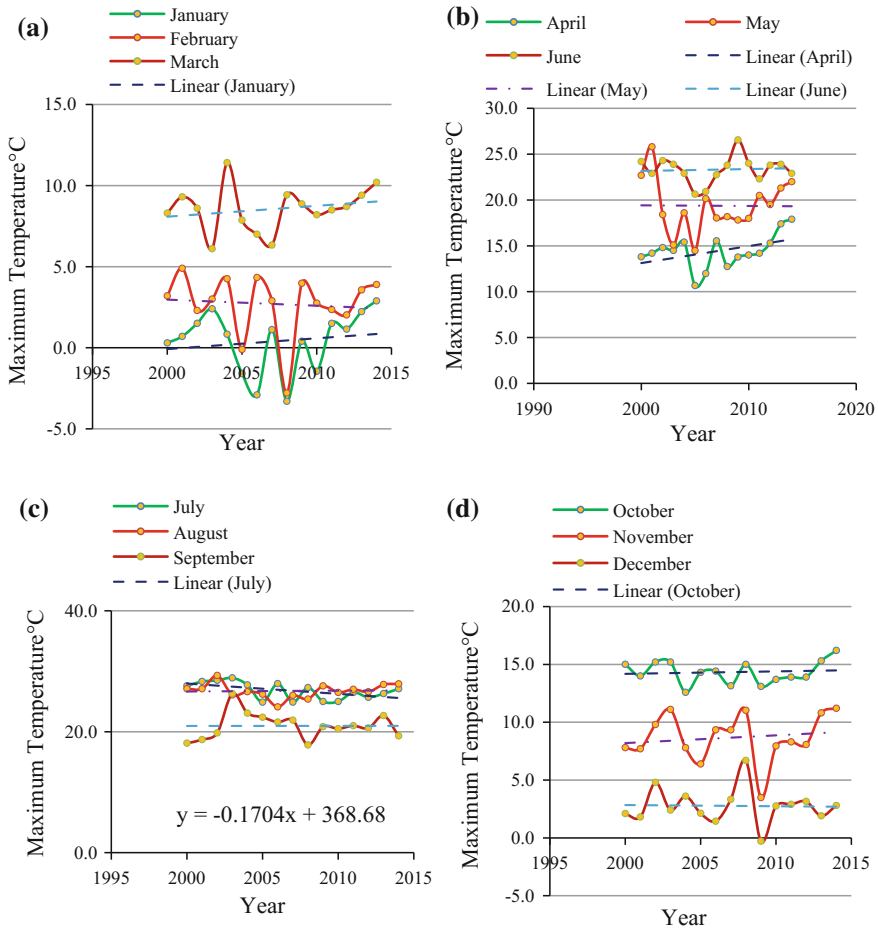
Fig. 2 a–d Time series of maximum temperature on monthly basis with linear trend lines

On annual basis, no significant trend was witnessed in case of maximum and minimum temperature at 5% level of significance as the Z values are between $+1.96$ and -1.96 (or at 10% level of significance as the Z values are between $+1.65$ and -1.65). The annual trend of maximum and minimum temperature is shown in Fig. 4a–b.

Test statistics (Z) values with p-value in parenthesis obtained through the Mann-Kendall test on seasonal basis is tabulated and shown in Table 2.

It is evident from Table 2 that on seasonal basis no significant trend was witnessed in case of maximum and minimum temperature at 5% level of significance
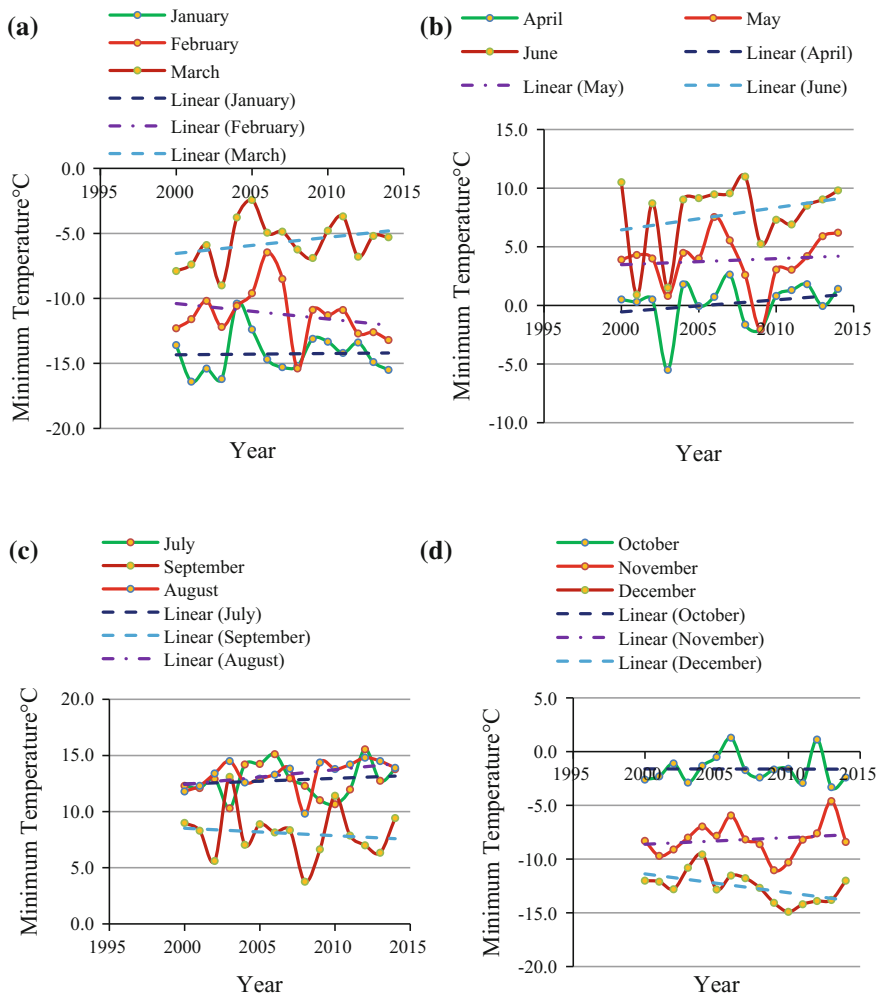
Fig. 3 a–d Time series of minimum temperature on monthly basis with linear trend lines

as the Z values are between +1.96 and −1.96 (or at 10% level of significance as the Z values are between +1.65 and −1.65). The graphical representation of seasonal basis between maximum temperature is shown in Fig. 5a–b.

The seasonal trend in minimum temperature in different years was also carried. The graphical representation of seasonal basis between minimum temperatures is shown in Fig. 6a–b.
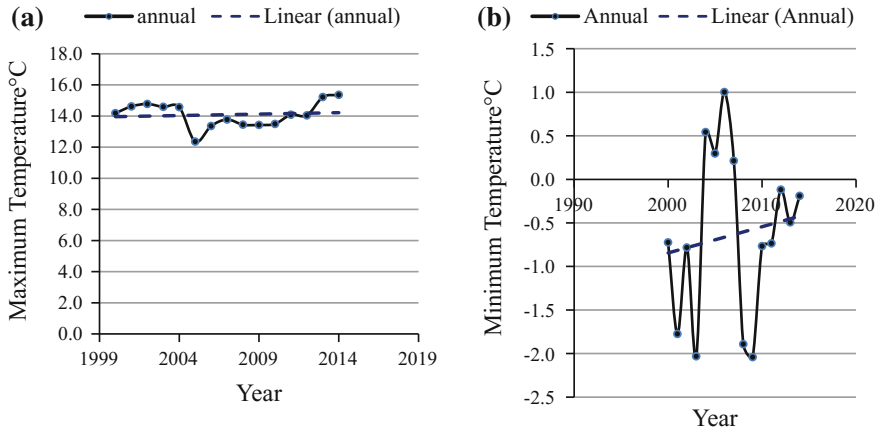
Fig. 4 a–b Time series of different weather parameters on annual basis

Table 2 Value of Z statistics with p-value in parenthesis on seasonal basis

Season	Maximum temperature	Minimum temperature
Spring	0.306 (0.179)	0.261 (0.667)
Summer	−0.135 (0.667)	0.370 (0.114)
Autumn	0.198 (1.000)	0.058 (0.923)
Winter	−0.017 (0.590)	−0.452 (0.659)
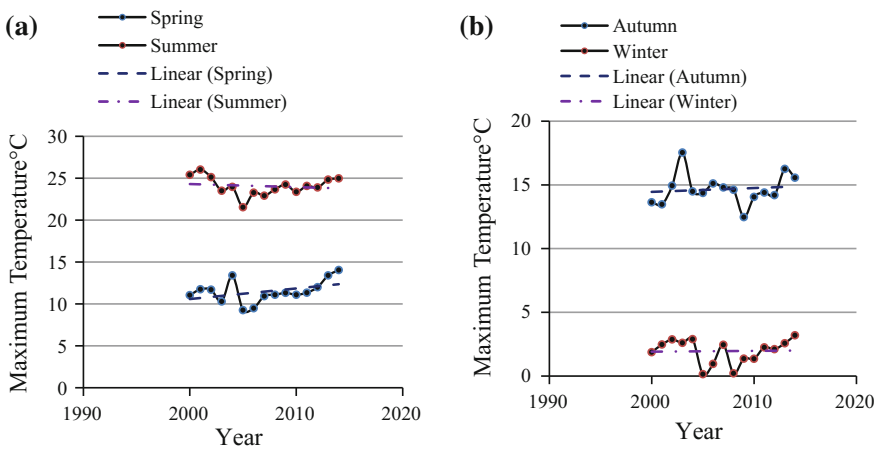
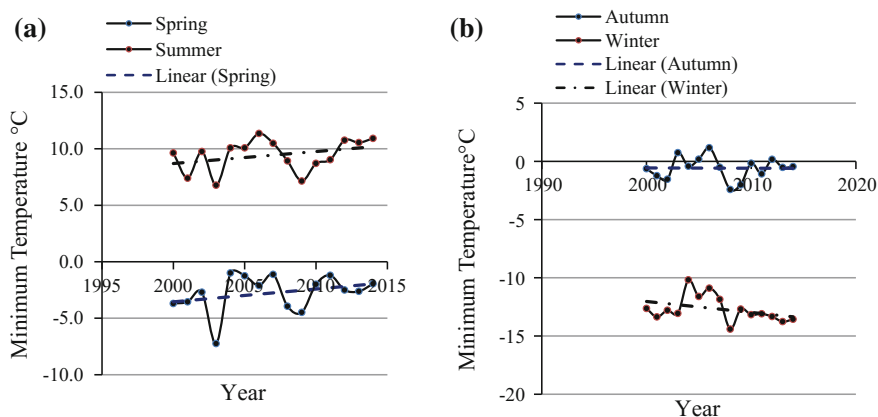Fig. 5 a–b Maximum temperature on seasonal with linear trend lines

Fig. 6 a–b Minimum Temperature on seasonal with linear trend lines

Conclusions

The weather is a continuous, data-intensive, multidimensional, dynamic and complex process and these properties make weather forecasting a formidable challenge. Thus an attempt has been made in is study to estimate the trends of maximum and minimum temperature, on monthly, seasonal, and annual basis over climatic conditions of Himalayas because of the importance of these parameters in water balance studies, irrigation planning, planning, and operation of reservoirs. The trends in different climatic parameters were investigated using the nonparametric Mann-Kendall (MK) test. The conclusions drawn from the study are summarized as follows:

1. In case of maximum temperature a significant falling trend has been observed at 5% significance level in the month of July.
2. In case of minimum temperature a significant falling trend has been observed at 5% significance level in the month of August and at 10% significance level in the month of December.
3. On annual and seasonal basis, it was witnessed that neither maximum nor minimum temperature showed significant falling trend at 10% significance level.

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