ASSESSMENT OF TRENDS AND VARIABILITY OF RAINFALL AND TEMPERATURE FOR THE DISTRICT OF MANDI IN HIMACHAL PRADESH, INDIA

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Abstract

Climate variability, particularly, that of the annual air temperature and precipitation, has received a great deal of attention worldwide. The magnitude of the variability of the factors changes according to the locations. The present study focuses on detecting the trends and variability in the annual temperature and rainfall for the district of Mandi in Himachal Pradesh, India. This study used annual and monsoon time series data for the time period 1981-2010 and modified the Mann-Kendall test and Sen's slope estimator in analyzing the problem. The results of the analysis indicate that the annual maximum temperature (TMX) and annual minimum temperature (TMN) for the period of 30 years have shown an increasing trend, whereas the monsoon's maximum and minimum temperatures have shown a decreasing trend, although it is statistically not significant. The amount of annual rainfall does not show any significant trend, but the monsoonal rainfall has shown an increasing trend that is also statistically not significant. The resulting Mann-Kendall test statistic (Z) and Sen's slope estimate (Q) of all the parameters studied indicate that changes are occurring in the magnitude and timing of the precipitation and temperature events at the Mandi station.

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1 INTRODUCTION

Global climate change may influence long-term rainfall patterns, which affect the availability of water, along with the risk of increasing droughts and floods. According to the Intergovernmental Panel on Climate Change (IPCC), the global temperature has increased by 0.74°C ± 0.18°C over the last 100 years (1905-2005), and precipitation is likely to increase by 0.2 to 0.3% per decade over tropical land areas in the 21st century (IPCC, 2007). It is also recognized that rainfall and temperature are among the most important climatic variables that involve both spatial and temporal patterns of water availability. Taking the Himalayan region into consideration, the variability and trends in temperature are among the most significant aspects of climate change studies. The im-

pact of climate change on the Himalayan ranges affects the snow cover and river flow over the northwestern Himalayas. It is also a well-known fact that longterm alterations in temperature have a significant impact on the hydrological cycle. Disturbances in the hydrological cycle may bring about changes in rainfall patterns, extreme precipitation events and drought conditions, which in turn affect the hydrological, agricultural and economic planning of the country. Understanding trends and variability of climatic factors is essential for appreciating the impact of climate change. It is therefore becoming clearer that analyses of rainfall and temperature trends are important when considering the impact of climate change on water resources planning and management.

The purpose of this study is to investigate the variability of the rainfall and temperature of the district of Mandi in the state of Hi-

machal Pradesh in India. This includes an understanding of the area's rainfall and temperature trends or changes. Understanding the uncertainties associated with precipitation and temperature patterns will provide a knowledge base for better management of agriculture, irrigation, hydropower generation, and other water-related activities in the selected area.

2 LITERATURE REVIEW

The trends in climate change provide a general idea of any changes noticeable within the historical data and point out certain concerns for the area regarding extreme events. Studies related to changes in rainfall over India have concluded that there is no clear trend in the average annual rainfall over the country (Jain and Kumar, 2012). The extreme precipitation indices are becoming more extreme, which could be partially attributed to recent warming in the Himalayan region (Sharif et al. 2010). An analysis of the trends in the northern part of India clearly shows that precipitation patterns are undergoing significant changes, probably under the impacts of climate change (Sharif et al. 2013).

Several precipitation trend studies have also been carried out in the south Asia region. (Marco et al. 2003) showed that there is an increasing precipitation trend throughout the year southwest of Xinjiang, which is an area adjacent to the northern part of Pakistan, and in Jammu- Kashmir, which is southwest of Tibet (Hussain et al. 2012). Heavy rainfall in the summer season over coastal areas of India shows an increasing trend and has been attributed to the possible impacts of climate change (Roy et al. 2005). The frequency of heavy rainfall events is decreasing in major parts of central and northern India, while they are increasing in peninsular, east and northeast India (Guhathakurta et al. 2011). A study of the temperature data (1961-1999) of 7 climate stations in the Karakoram and Hindu Kush mountains using statistical regression techniques revealed winter warming and summer cooling trends (Fowler and Archer, 2006). Several recent studies have revealed that the South Asia region is significantly warming and that the warming tendency is largely consistent with global warming trends (Singh et al. 2008). A study of long-term mean annual temperatures from 1901 to 1982 over India identified an increasing trend in mean surface air temperatures (Hingane et al. 1985). An analysis of extreme flow measures in the Sutlej River basin in India revealed decreasing trends in high flow magnitudes, but no statistically significant trend was observed in low flow events (Sharif et al. 2010).

The safety of water in the northern part of India is likely to be impacted owing to changes in the temporal and spatial distribution of water due to possible climate change effects. The utmost and direct effects of global warming would be on changes in the local and regional availability of water (Jiang et al. 2007). Recent droughts in northern India and unprecedented floods in parts of Southern India are seen as an indicator of current climate changes, and changes in the patterns of the monsoon in the northern parts affect the country's agriculture since India is an agriculture-dependent economy, and monsoons are the lifeline of the agriculture sector (Sharif et al. 2013). Several studies have reported that warming has taken place all over India (Singh et al. 2008).

For a trend analysis, non-parametric tests are widely used compared to their parametric counterparts. When comparing their strength, i.e., their ability to distinguish between the null hypothesis and an alternative hypothesis, the Mann-Kendall (M-K) tests (Mann 1945; Kendall 1975) for monotonic trends give better results in comparison to the parametric t - test (Van Belle & Hughes, 1984). Non-parametric methods have been found to be suitable for data commonly skewed, and the sample size is large (Hirsch et al. 1982). Parametric trend tests are more powerful than non-parametric ones, but they require data to be independent and normally distributed (Chen et al. 2007). The main advantage of the Mann-Kendall test is that it is free from the assumption of the normality of the data and can tolerate outliers in the data series (Hamid et al, 2013). The M-K test has been approved as a powerful tool to detect trends in hydro-meteorological time series (Chen et al. 2007). Nonparametric tests have various advantages over parametric ones. Some of these are as follows: (a) prior transformations are not required, even when approximate normality could be achieved; (b) an assumption of normality or the assumption of the homogeneity of a variance is not required; (c) greater power is achieved for skewed distributions; (d) comparisons are made between central values such as the median, rather than the mean; as a result, if the data have one or two outliers, their influence is negated; and, finally, (e) data below the detection limit can be incorporated without any fabrication of the values or bias (Helsel, 1987; Duhan and Pandey 2013).

Many researchers have tried to determine trends in rainfall on both land and regional scales. Most of these studies deal with an analysis of the annual and seasonal series of rainfall for some individual stations or groups of stations. In this study, we have investigated the variability of rainfall and temperature on a local scale at the Mandi station in Himachal Pradesh, India.

3 MATERIAL AND METHODS

3.1 Study Area

Mandi is located at the $31^o 72$'N latitude and $76^o 92$'E longitude (Figure: 1) and covers a geographical area of 3951 km^2. The city is located on the banks of the Beas River, at the confluence of the Suketi Khad stream in Himachal Pradesh. Sikandar Dhar, Ghugar Dhar, and Dhar Kot are some of the prominent hills and mountains found near the city. It lies in the midlands of the Himalayan range. It has a complex terrain with elevations ranging from 450 to 4800 m.

The climate of the district ranges from wet sub-temperate to a dry, cold, alpine climate with snowfalls at higher altitudes, depending upon the elevation. The major seasons are: the winter season, which extends from November to February; the summer season from March to June; the monsoon period extending from July to the end of September. The maximum rainfall occurs from July to September. The average annual rainfall in the Mandi station is about 832 mm. In the non-monsoon season, precipitation in the form of snowfall also occurs in the higher reaches above elevations of 2400 to 4800 m. The average temperature during the summer is between 18.9 °C and 39.6 °C and varies between 6.7 °C and 26.2 °C in the winter.

3.2 Data used

Daily Climate Forecast System Reanalysis (CFSR) data was used due to the limited availability of data; it was procured from the global weather data for SWAT (https://globalweather.tamu.edu/), which was only available for the time period of 1981-2010. Some missing values were filled in using interpolations between the previous and the next day's data. The data was checked for any discrepancies before it was used. The distribution of monthly rainfall for the Mandi station is shown in Figure 2. It reveals that the maximum rainfall in the area occurs during the monsoon period (June to September). During the winter season (December, January and February) only a small amount of rainfall occurs. The distribution of the monthly maximum temperatures is shown in Figure 3 and reveals that May and June are the
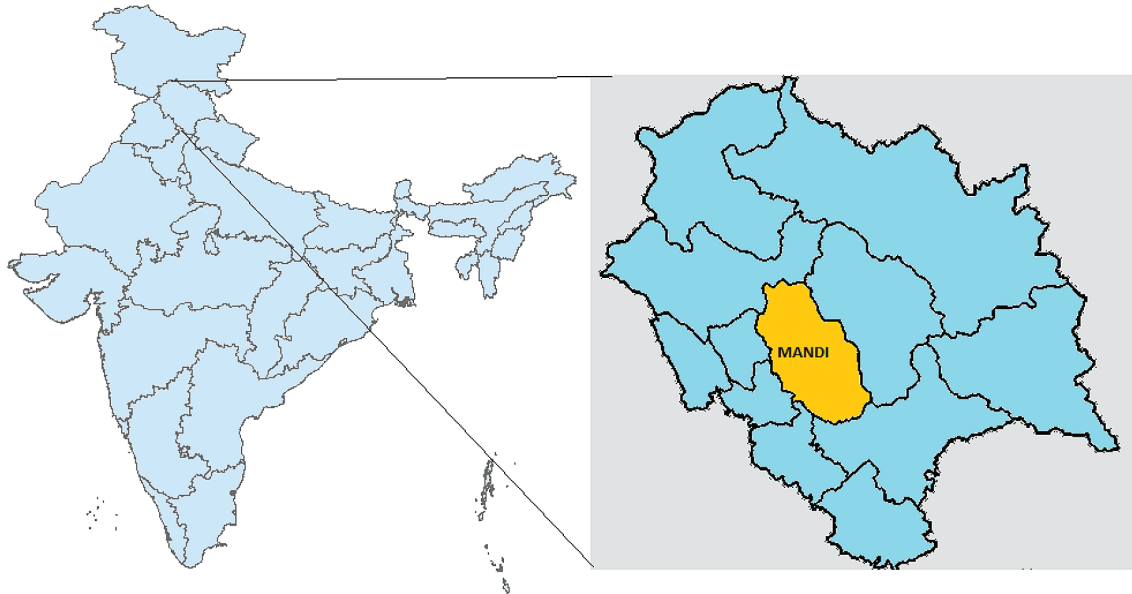
Fig. 4 *Comparison of the required reinforcement area according to the NDP in NA of EN 1992-1-1 and Model Code 2010 (Sonnenschein et al., 2016)*

hottest months in the area. The distribution of the monthly minimum temperature is shown in Figure 4.

4 METHODOLOGY

4.1 Mann-Kendall test

The Mann-Kendall (M-K) test is a statistical test widely used for trend analysis in climatological and hydrological time series. There are two advantages to using this test. First, it is a non-parametric 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. Any data reported as "non-detects" are included by assigning them a common value that is smaller than the smallest measured value in the data set. According to this test, the null hypothesis H0 assumes that there is no trend (the data is independent and randomly ordered). This is tested against the alternative hypothesis H_1, which assumes that there is a trend.

The Mann-Kendall statistic is computed as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_j - x_k) \qquad (3)$$

The trend test is applied to a time series x_k, which is ranked from $k = 1,2,3, ... n - 1$ and x_j, which is ranked from $j = i + 1, i + 2, i + 3, ... n$. Each of the data points x_j is taken as a reference point, which is compared with the rest of the data points x_k, so that,

$$\operatorname{sgn}(x_j - x_k) = \begin{bmatrix} 1 \text{ if } (x_j - x_k) > 0 \\ 0 \text{ if } (x_j - x_k) = 0 \\ -1 \text{ if } (x_j - x_k) < 0 \end{bmatrix} \qquad (4)$$

Here x_j and x_k are the sequential data values, and n is the length of the data set. For samples greater than 10, the test is conducted using a normal distribution (Helsel et al. 1992) with the mean and variance as follows:

The variance σ^2 for the S statistic is defined by:

$E[S] = 0$

$$Var(S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5)] \qquad (5)$$

Here t_p is the number of data points in the pth tied group, and q is the number of tied groups in the data set.

The standardized test statistic Z_{mk} is calculated by:

$$Z_{mk} = \begin{bmatrix} \dfrac{S-1}{\sqrt{\operatorname{var}(S)}} & \text{if } S > 0 \\[2ex] \dfrac{S+1}{\sqrt{\operatorname{var}(S)}} & \text{if } S < 0 \\[2ex] 0 & \text{if } S = 0 \end{bmatrix} \qquad (6)$$

where the value of Z_{mk} is the Mann-Kendall test statistics that follow the standard normal distribution with a mean of zero and a variance of one. Thus, in a two-sided trend test, the null hypothesis H_O is accepted if $-Z_{1-\alpha/2} \le Zmk \le Z_{1-\alpha/2}$, where α is the level of significance that indicates the trend's strength.

4.2. Sen's Slope Estimator Test

The magnitude of a trend in a time series can be determined using a non-parametric method known as Sen's estimator (Sen, 1968). To estimate the true slope of an existing trend such as the amount of change per year, Sen's nonparametric method is used. Sen's method can be used in cases where the trend can be assumed to be linear such as:

$$f(t) = Qt + B \qquad (7)$$

Here Q is the slope, and B is a constant.

To get the slope estimate Q in Eq. 7, the slopes of all the data value pairs are calculated as:

$$Q_i = \frac{x_j - x_k}{j - k} \qquad (8)$$

Here x_j, and x_k are the data values in years j and k, $j > k$.

If there are n values of x_j in the time series, one gets as many as $N = n(n – 1)/2$ slope estimates Q_i.

Sen's estimator of the slope is the median of these N values of Q_i. The N values of Q_i are ranked from the smallest to the largest, and Sen's estimator is

$$Q = Q_{[(N+1)/2]} \qquad\qquad \text{if } N \text{ is odd}$$
$$Q = \frac{1}{2}(Q_{[N/2]} + Q_{[(N+1)/2]}) \quad \text{if N is even} \qquad (9)$$

A $100(1 – \alpha)$% two-sided confidence interval about the slope estimate is obtained by the nonparametric technique based on the normal distribution. The method is valid for n as small as 10 unless there are many ties. A positive value of Q_i indicates an upward or increasing trend, and a negative value gives a downward or decreasing trend in the time series.

5 RESULTS AND DISCUSSION

5.1 Analysis of Monthly Rainfall

A variability analysis of hydro-meteorological parameters is of great importance for researchers in their decision-making. The compact nature of box and whisker plots (Tukey, 1977) assists side-by-side assessments of multiple datasets, which can otherwise be difficult to interpret using more complete representations, such as the histogram (Banacos, 2011). These plots graphically describe the statistical distribution in a way that is easy to understand for a wide range of users. The form of the box and whisker plot here include: a central horizontal line representing the median and the interquartile range's top and bottom horizontal lines (shown by the box). The bottom and top horizontal lines in the boxes indicate the 25th and 75th percentiles, respectively. The outer ranges are drawn as vertical lines (as shown by the whiskers).

The location of the median line can suggest skewness in the distribution if it is noticeably shifted away from the center. The length of the interquartile range (IQR) as shown by the box is a measure of the relative dispersion of the middle 50% of a dataset, just as the length of each whisker is a measure of the relative dispersion of the dataset's outer range (10th to 25th percentiles and 75th to 90th percentiles) (Banacos, 2011). Figure 2 presents the box plots of the monthly rainfalls observed at Mandi from 1981-2010. The total monthly rainfall was obtained by totaling the daily values of each month for each year. The plots show the relatively maximum amount of rainfall in July and August; since the length of the boxes and whiskers is longer, the variability is greater compared to the other months.
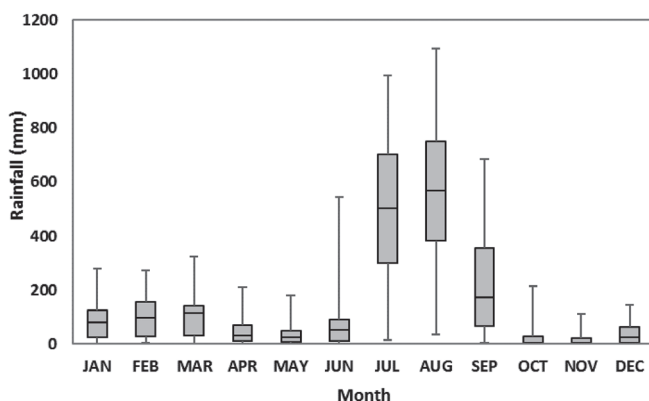

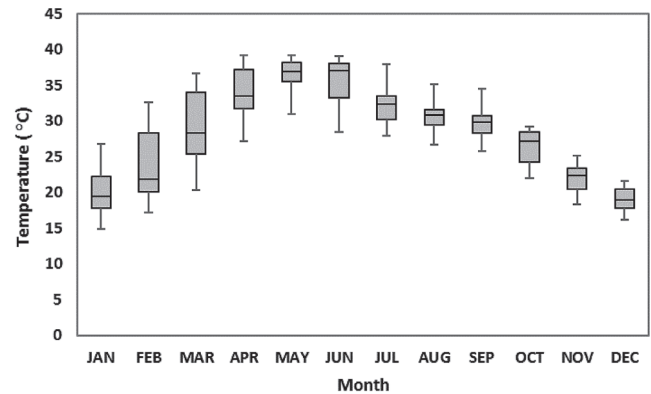**Fig. 2.** *Box and Whisker plot of monthly rainfall (mm)*

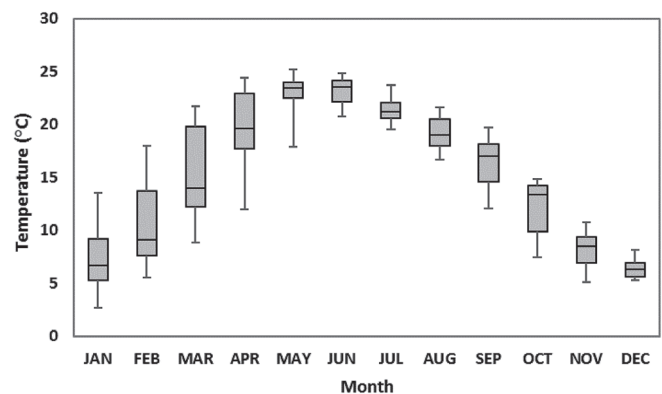**Fig. 3.** *Box and Whisker plot of the monthly maximum temperature (TMX) (ºC)*

Fig. 4. *Box and Whisker plot of the monthly minimum temperature (TMN) (ºC)*

5.2 Analysis of Monthly Temperatures

Figures 3 and 4 show box plots for the monthly maximum (TMX) and minimum temperatures (TMN). The plots reveal the distribution of the monthly maximum and minimum temperatures for the study area. The total monthly TMX and TMN were obtained by taking the average values of each month for each year. The box length simply gives an indication of the sample's variability, and it can be seen that the variability is more or less the same for all the months as compared to the rainfall.

5.3 Measures of Variability

When analyzing the variability of rainfall, we must not overlook its variations in timescales of seasons to decades. The degree to which rainfall amounts vary across an area or over time is an important characteristic of the climate of an area. Common measures of variability, such as the standard deviation, may be interpreted based upon an assumption of an underlying standard normal distribution for the purpose of climate and weather analyses (Banacos, 2011). To analyze the variability of precipitation, a number of measures of variability have been calculated and analyzed.

The variability of precipitation can be expressed both in absolute as well as in relative terms (Hamid et al. 2013). Some of the absolute measures of variability, i.e., the standard deviation (SD), absolute mean deviation (AMD), and mean absolute inter-annual variability (MAIV) are used for analyses of variability.

$$SD = [(N-1)^{-1} \sum_{i=1}^{N} (P - \overline{P})^2]^{\frac{1}{2}} \qquad (10)$$

$$AMD = (N-1)^{-1} \sum_{i=1}^{N} |P_i - \overline{P}| \qquad (11)$$

$$MAIV = (N-1)^{-1} \sum_{i=1}^{N} |P_i - P_{i-1}| \qquad (12)$$

Here P is the daily precipitation or monthly precipitation, and $\overline{P}$ is the corresponding average term.

$$CV = \frac{100\,SD}{\overline{P}} \qquad (13)$$

$$RV = \frac{100\,AMD}{\overline{P}} \qquad (14)$$

$$PIV = \frac{100\,MAIV}{\overline{P}} \qquad (15)$$

Table 1 shows the absolute measures of variability (SD, AMD and MAIV) for the monthly rainfall data. The highest values of these parameters have been observed for the months of July and August, which are associated with high values of rainfall. The coefficient of variability (CV), relative variability (RV), and percentage interannual variability (PIV) have also been computed, as they are useful measures of variability widely used in hydro-climatological studies (Hamid et al. 2013).

Tab. 1: *SD, AMD, MAIV, CV, RV, and PIV for the monthly rainfall at Mandi during the period 1981-2010*

Month	June	July	August	September
SD	114.84	268.73	240.82	201.44
AMD	73.91	225.01	199.99	162.04
MAIV	97.73	386.24	282.54	228.57
CV (%)	134.64	53.83	42.89	86.33
RV (%)	86.65	45.07	35.62	69.45
PIV (%)	114.58	77.36	50.32	97.97

The results of SD, AMD, and MAIV for the seasonal maximum and minimum temperatures respectively are shown in Tables 2 and 3. For the seasonal maximum temperature, the parameters SD, AMD and MAIV have the highest values for May - March. For the monthly minimum temperature, the maximum values of SD and AMD have been observed in the autumn season (September – November).

Tab. 2: *SD, AMD, MAIV, CV, RV, and PIV for the seasonal maximum temperature (TMX) at Mandi during the period 1981-2010*

Month	DJF	MAM	JJA	SON
SD	2.64	2.91	2.06	2.03
AMD	2.34	2.37	1.60	1.74
MAIV	2.05	2.80	2.80	1.98

Tab. 3: *SD, AMD, MAIV, CV, RV, and PIV for the seasonal minimum temperatures (TMN) at Mandi during the period 1981-2010*

Month	DJF	MAM	JJA	SON
SD	2.09	2.66	1.03	1.90
AMD	1.76	2.24	0.90	1.73
MAIV	1.30	1.78	1.43	1.42

5.4 Trend Analysis

A summary of the trend analysis at Mandi station is shown in Table 4 and Figure 5. An analysis of six variables using the Mann-Kendall test and Sen's slope estimator was conducted. Among these variables, the annual rainfall does not show any trend for which the Kendall test statistic (Z) value comes out to be zero, and the monsoon rainfall shows a positive trend for which the Kendall test statistical (Z) value comes out to be 0.71, although it was not statistically significant.

Tab. 4: *Trend analysis for Mandi Station from 1981-2010*

	Mann-Kendall Trend	Sen's Slope estimate	
Variables	**Test (Z)**	Q	**Significance**
Annual rainfall	0.02	-1.96	Not significant
Monsoon rainfall	0.71	12.18	Not significant
Annual TMX	1.95	0.037	*
Monsoon TMX	-1.03	-0.033	Not significant
Annual TMN	1.96	0.029	*
Monsoon TMN	-1.18	-0.021	Not significant

*0.05 level of significance; **0.01 level of significance; ***0.001 level of significance

For the whole of India, no significant trend was detected for the annual, seasonal, or monthly rainfall (Kumar et al. 2010). The annual and monsoonal precipitation have an equal number of increasing and decreasing trends, although the increasing trends were stronger (Sharif et al. 2013). Both the annual maximum temperature (TMX) and the annual minimum temperature (TMN) show a positive increasing trend with a test statistic (Z) value equal to 1.95 and 1.96 respectively for the 95% significance level. Bhutiyani *et al.* (2007) also found an increasing trend in the maximum, minimum, mean, and diurnal temperature range over the northwestern Himalayan region during the 20th century. The maximum and minimum monsoon temperatures show decreasing trends with the Kendall test statistic (Z) values of -1.03 and -1.18 respectively, although they are statistically not significant. Arora *et al.* (2005) also found that there is a rising trend in most cases, except for temperatures for the mean pre-monsoon, mean monsoon, pre-monsoon mean minimum, and monsoon mean minimum. Kothyari et al. (1997) found a decreasing trend in rainfall magnitude and an increasing trend in the annual maximum temperature in the Ganga Basin in India. The results clearly show the changing patterns of all the parameters.
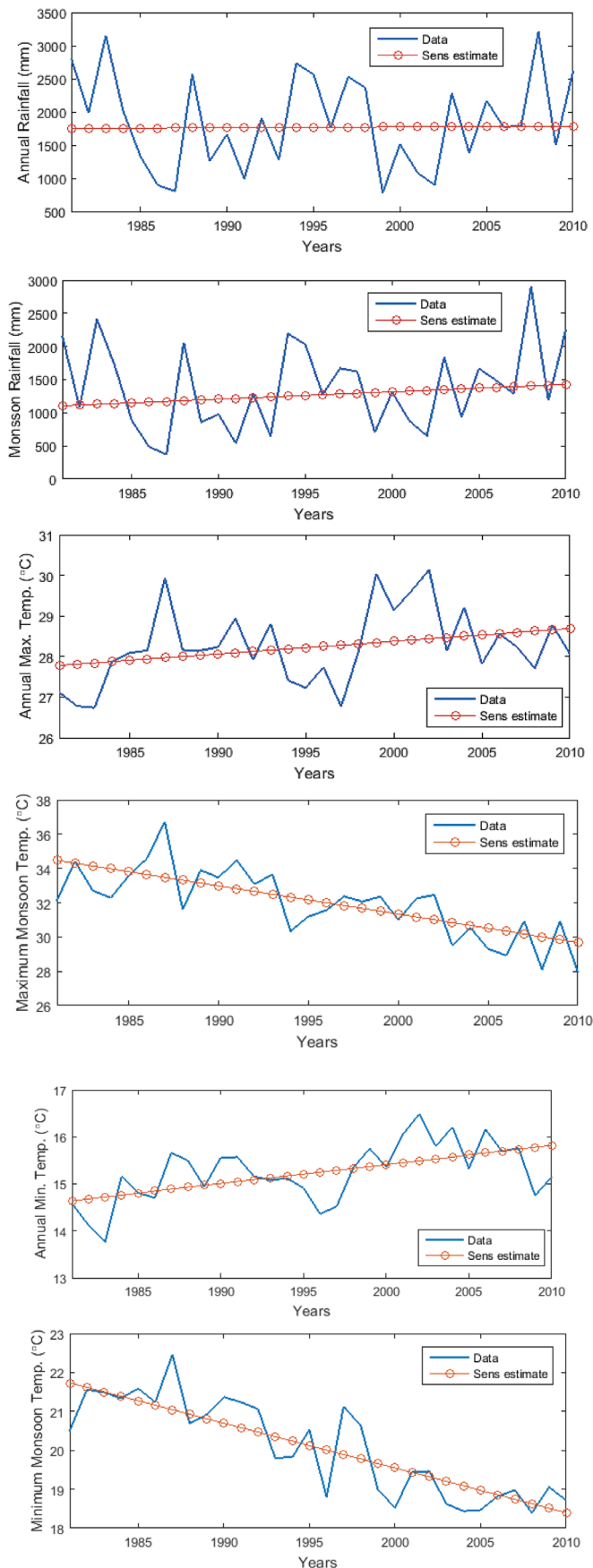
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Fig. 5 *Plots of annual and monsoon rainfall (mm) and annual average monsoon, minimum and maximum temperature (ºC) at Mandi Station*

6 CONCLUSION

The present study analyzed the hydro-meteorological data for the Mandi station in Himachal Pradesh, India. The analysis of the time series was carried out using a modified Mann-Kendall nonparametric test and Sen's slope estimator, which are widely-used tests for conducting trend analyses of hydro-meteorological data. The variability characteristics of the monthly rainfall, annual maximum temperature (TMX), and annual minimum temperature (TMN) are presented using box and whisker plots. The plots show the relatively maximum amount of rainfall in July and August, while in the case of TMX and TMN, the variability is more or less the same for all the months when compared to the rainfall. A total of six variables were analyzed for trends. The results of the analyses indicate that the annual TMX and TMN for the 1981-2010 periods have shown an increasing trend at a 95% confidence level, whereas the monsoon TMX and TMN have shown a decreasing trend, although it is not statistically significant. The annual rainfall does not show any trends whereas the monsoonal rainfall has shown increasing trends, although they are not statistically significant. The results clearly indicate that changes are occurring in the temperature and precipitation patterns in the study area. The results of the study also reveal that there are signs of warming in the data analyzed for this research. A more detailed analysis is essential using Indian Meteorological Department (IMD) observed rainfall data for longer periods to confirm or reject the presence of linkages between the changes in the patterns of rainfall and the temperature and climate indices. However, the limitations of this research work are that a period of 30 years (1981-2010) may be regarded as too short of a duration for the determination of any trends.

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