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Original Research Article

An Analysis of Trend Variation in Minimum and Maximum Temperature Pattern in Uttarakhand

S.B. Bhardwaj[1*], Manoj Raghav[2] and Rajendra Bhatt[2]

[1]Directorate of Experiment Station, GBPUA&T, Pantnagar, India
[2]Department of Vegetable Science, College of Agriculture, GBPUA&T, Pantnagar, India

**Corresponding author*

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A B S T R A C T

Besides crop response, there are many other climate factors like sun shine, wind flow, rainfall, temperature, humidity etc. accounting for agricultural yield. The agricultural production is greatly affected by almost all these factors. Though, most of these factors, as such, cannot be controlled, but variations due to these factors can be studied to explore the impact on the agricultural yields. Temperature, which may be considered as one of the most important extraneous factors, is having a direct impact on the growth of crops. In the present study, an attempt has been done to investigate a comparative analysis and trend variation of the minimum and maximum temperature pattern in Uttarakhand. For the purpose, Mann–Kendall's test and Sen's Slope Estimator have been used and concluded that the maximum temperature for the observed period showed a slight warming or increasing trend (Sen's slope = 0.00) while the minimum temperature trend showed a cooling trend (Sen's slope = 0.00294) but result of maximum temperature trend analysis is statistically significant at 95% confidence limit, on the contrary the trend analysis result of minimum temperature is not statistically significant.

Introduction

Agricultural production is greatly affected by climate change as the crops are sensitive to the spontaneous change in climate. The crop production faces many constraints such as flooding, drought, sun shine, wind flow and variation in temperatures, all of which are expected to worsen with climate change. Drastic changes in temperatures and rainfall patterns generally introduce unfavourable growing conditions into cropping systems and subsequently reduce crop productivity. Variation in temperature may be considered as one of the major components responsible for climate change and plays a vital role for policymakers in ensuring food security, agriculturalists and crop breeders. For adopting plausible strategies, it has become important to assess the magnitude of climatic variations in such factors. Most of these factors cannot be controlled as such. Variation in different climatic factors is having a great concern now-a-days. Fluctuation in such factors alters from place to place. Various studies have been done to study the impact of these factors on the productivity of crops. Effect of temperature on the growth characters is a major factor. In order to enhance crop yield, we need to analyze these variations in temperature and observe the impact through different statistical estimates. Such statistical procedures improve our confidence in the assessments of different parameters responsible for increasing the crop productivity and adopting region-specific strategies in ensuring food security.

Climate may be defined as the average weather. There are many variables such as humidity, temperature, atmospheric pressure, rainfall etc., which form climate and weather. Kumar *et al.,* (2010) paid considerable attentions to understand the past and present climate changes through recent observations and extensions of numerous datasets with more sophisticated data analyses across the globe.

According to Webber and Hawkins, (1980), the trend is defined as the long- term change in the dependent variable over a long period of time or it is the general movement of a series over an extended period of time. A trend is determined by the relationship between the two variables. Descriptive statistics like minimum and maximum values, mean, standard deviation (SD), coefficient of variation (CV), skewness and kurtosis are used to have an idea about the central values and scatteredness of the trend. The skewness is a measurement of asymmetry in a frequency distribution around the mean and it helps in the selection of statistical tests that can be applied when the data are not normally distributed while kurtosis, describes the peakedness of a symmetrical frequency distribution.

Arora *et al.,* (2005), evaluated temperature trends over India to analyze the impact of climate change and to identify trends in temperature time series of 125 stations distributed over the whole of India. The authors applied non-parametric Mann-Kendall test to detect monotonic trends in annual average and seasonal temperatures considering three variables related to temperature, viz. mean, mean maximum and mean minimum by dividing each year into four principal seasons, viz. winter, pre-monsoon, monsoon and post-monsoon and have presented the percentages of significant trends obtained for each parameter in the different seasons.

Zarenistanak *et al.,* (2014), have presented results of trend analysis and change point detection of annual and seasonal precipitation, and mean, maximum and minimum temperature time series of the period 1950–2007. Their research was carried out for 50 precipitation stations and 39 temperature stations located in southwest Iran. The authors have used three statistical tests including Pettitt’s test, Sequential Mann–Kendall test and Mann–Kendall rank test for the analysis. The results indicated that most stations showed insignificant trends in annual and seasonal series. The analysis of temperature trends revealed a significant increase during summer and spring seasons. Increasing temperature, snow cover retreat and changing patterns of precipitation, are among the many consequences which are attributed to climate change. Trend detection in temperature and precipitation time series is one of the interesting research areas in climatology. The authors have noticed that precipitation and temperature changes are not globally uniform.

Palte *et al.,* (2016) have detected trend by analyzing the variability in rainfall and temperature using non parametric Mann Kendall test approach Sen’s slope estimator. The authors have explored changes in the seasonal and annual rainfall and temperature using time series data of 16 districts of Arunachal Pradesh and identified trends as an indicator to climate variability in the state. The trend analysis indicated that the average annual minimum daily temperature increased over the study period and maximum temperature remained constant. Trend analysis of seasonal minimum temperature showed higher rates of warming in the post-monsoon season followed by monsoon and least in pre-monsoon season.

Padhiary *et al.,* (2018) used the Mann Kendall (1975) test for analyzing trend of rainfall and temperature and possible relationship between the two in annual, monthly and seasonal time steps in Brahmani river basin. The authors observed a definite pattern in maximum and minimum temperature and rainfall in monthly analysis. Though, no direct relationship between increasing rainfall and increasing maximum temperature was found in the study, yet, the authors concluded that the relations between the trends of rainfall and temperature have large scale spatial and temporal dependence.

Panda and Sahu (2019) analyzing trend of seasonal rainfall and temperature pattern in 3 districts of Odisha, India concluded that the annual maximum temperature and annual minimum temperature have shown an increasing trend, whereas the monsoon's maximum and minimum temperatures have shown a decreasing trend. Statistical trend analysis techniques namely Mann–Kendall test and Sen's slope estimator were used to examine and analyze the trend variations for 37 years' observations. The study revealed statistically significant trends for rainfall, increasing trend in maximum temperature and a cooling trend for the minimum temperature.

Materials and Methods

The current study explores long-term changes and short-term fluctuations in minimum and maximum temperatures (in ^{o}C). To analyze the trend variation in minimum and maximum temperature pattern over the epoch, statistical tools Mann–Kendall test and Sen's slope estimator have been used.

The meteorological data of 30 years (1990 to 2019) used for this research has been collected by Department of Agrometeorology, Agriculture College, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, U.S Nagar (Uttarakhand). Pantnagar is situated in the Tarai belt at an altitude of 244 m above MSL. The climate of Pantnagar comprises of sub-humid to sub-tropical with hot dry summers and cool winters. Generally, the monsoon sets in around third week of June and lasts upto September end. May is the hottest month of the year and temperature generally rises up to 45.5±1.5°C. However, minimum temperature can be low as 1.5±1.0°C in the month of January. The mean annual rainfall is about 1430 mm. Maximum relative humidity remains in the range of 90-95 percent which is experienced during monsoon season and also during winter season. Thirty years (1990-2019) data set of minimum and maximum temperature have been used for the study. Month-wise averages of temperature and descriptive statistics like, mean, SD, CV, skewness & kurtosis have been computed. The line graph shows variations in minimum and maximum temperature about the average.

Tukey (1977) describes the compact nature of box and whisker plots 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 graphical plots elaborate the statistical distribution. Elaborating on box-whisker plots, Panda A. and Sahu, N. (2019) stated that 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. 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 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). Hence, it is clearly visible that the dataset are not normally distributed and most of the data fall in upper whisker that is, in the 4th quartile. According to Panda A. and Sahu (2019) and literature, CV is used to classify the degree of variability as less (CV≤20%), moderate (20≤CV≤30%), high (CV≥30%), very high (CV≥40%) and CV≥70% indicate extremely high inter- annual variability of temperature. Based on this, from the observed data considered that all the months had above 30% of CV highlighting the high variability of precipitation over the area. The result indicated that the amount of rainfall in the region is extremely variable. Then, if the kurtosis values are analyzed, then it can be understood that during monsoon (July, August, September) the kurtosis values are less and also the skewness value which explains that the dataset are light tailed during monsoon months and follows a symmetric pattern.

According to Hollander and Wolfe (1973), such trends generally exhibit nonparametric, distribution free characteristics for which, M-K test, Mann (1945) and Kendall (1975) is one of the best methods preferred by various researchers (Jain and Kumar, 2012). M–K method is used to analyze if there is a monotonic upward or downward trend of the variable over time.

The Mann Kendall test is a statistical non-parametric test, widely used for analysis of trend in hydrologic and climatologic parameters. The test was suggested by Mann (1945) and has been extensively used with environmental time series. There are two advantages to use 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 heterogeneity in the data series. Any non-detected data are assigned with a smaller value than the smallest measured data. According to this test, the null hypothesis H_0 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 trend. The mathematical procedure for the Mann Kendall test is presented as follows:

The Mann-Kendall S Statistic is computed as follows:

$$S = \sum \sum sign(x_j - x_i)$$

$$Sign(x_j - x_i) = \begin{cases} +1, \text{ if } x_j - x_i > 0 \\ 0, \text{ if } x_j - x_i = 0 \\ -1, \text{ if } x_j - x_i < 0 \end{cases}$$

The variance is computed as

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

Where n is the number of data points and x_i and x_j are two data subsets of time series i and j (j, i = 1,2,3,…, n-1 and j = i+1, i+2, i+3, …, n, j > i respectively. The sign(x_j-x_i) is a sign function. Data are evaluated in an orderly manner and each data is compared with all subsequent data values. The statistic S is incremented by 1, if a data value is higher than its earlier data value. On the contrary, S is decremented by 1, if the data value is lower than its earlier data value.

The summation of all increments and decrements gives the final value of S. If n <10, the value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall. The two tailed test is used. At certain probability level H_0 is rejected in favor of H_1 if the absolute value of S equals or exceeds a specified value $S_{\alpha/2}$,where $S_{\alpha/2}$ is the smallest S which has the probability less than α/2 to appear in case of no trend. A positive (negative) value of S indicates an upward (downward) trend. For n ≥ 10, the statistic S is approximately normally distributed with the mean and variance as follows:

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S-1}{\sqrt{Var(S)}} & \text{if } S < 0 \end{cases}$$

Positive values of Z_S indicate increasing trends while negative Z_S values show decreasing trends. Testing 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. $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table.

Sen (1968) Slope Estimator Test : The magnitude of a trend in a time series can be determined using a nonparametric method known as Sen's estimator. Gocic and Trajkovic (2013) To estimate the true slope of an existing trend such as amount of change per year, Sen's nonparametric method is used and the test has been performed using R software. A positive value of Sen's slope indicates an upward or increasing trend and a negative value gives a downward or decreasing trend in the time series. Sen (1968) developed the non-parametric procedure for estimating the slope of trend in the sample of N pairs of data:

$$Q_i = \frac{xj-xk}{j-k} \text{ for } i = 1,2\ldots\ldots;N$$

where xj and xk are the data values at times j and k (j>k), respectively. If there is only one datum in each time period, then $N = \frac{n(n-1)}{2}$; where n is the number of time periods. If there are multiple observations in one or more time periods, then $N < \frac{n(n-1)}{2}$ 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

$$Q_{med} = \begin{cases} Q_{\left[(N+1)/2\right]} & \text{if N is odd} \\ \frac{Q_{(N/2)} + Q_{(N+2)/2}}{2} & \text{if N is even} \end{cases}$$

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.

The confidence interval about the time slope (Hollander and Wolfe, 1973; Gilbert, 1987) can be computed as follows: $C_\alpha = Z_{1-\alpha/2}\sqrt{Var(S)}$

The statistical method such as regression analysis and coefficient of determination R^2 are used for the significance of trend of variables. This particular test has been calculated using R software. A very high positive value of *S* is an indicator of an increasing trend and a very low negative value indicates a decreasing trend. The presence of a statistically significant trend is evaluated using Z value.

Table 1 elaborates descriptive statistics of month-wise averages minimum temperature during the period. Figure 1 represents the trend variation in minimum temperature around the average during 1990-2019. Figure 2 elucidates Box Whisker plot of descriptive statistics in minimum temperature during 1990-2019 (°C). In the same manner, Table 2 elaborates descriptive statistics of month-wise averages maximum temperature during the period. Figure 3 represents the trend variation in maximum temperature around the average during 1990-2019. Figure 4 elucidates Box Whisker plot of descriptive statistics in maximum temperature during 1990-2019 (°C). In the same manner,

Results and Discussion

A variability analysis of meteorological parameters like temperature is of great importance for researchers in decision making as temperature plays dominant role in agricultural production. Table 1 elucidates a minimum temperature variation ranging from 4.3°C (January) to 24.7°C (July) while variation in maximum temperature is having a range from 8.8°C (January) to 26.7°C (July), resulting variation in the mean of these two temperatures ranging from 6.54°C (January) to 25.61°C (July). The standard deviation ranges from 0.32 °C (August) to 1.37°C (May). The coefficient of variation for mean monthly minimum temperature shows a variation ranging from 1.27 to 15.59%. As far as coefficient of skewness is concerned, it is the highest in November (0.33°C) and lowest in February (-0.43°C). Similarly, in kurtosis, a maximum value 3.42°C in May and a minimum value -1.11°C in September is obtained over the 30 years studied.

The variation in trend of minimum temperature around the average value during the period under study *i.e.* 1990-2019 has been elucidated by the regression equation Y= 0.06 X- 103.94. Using this linear regression model, the rate of change is defined by the slope of regression line which in this case is 0.145°C during this period study. The coefficient of determination R-squared, is a statistical measure of how close the data are to the fitted regression line. A 0% is an indication that the proposed model explains no variability of response data around its mean.

As it can also be observed from the Table 2, showing month-wise average of minimum temperature ranging from 14.5°C (January) to 32.4 °C (May). Almost the same trend can be seen in range of maximum temperature *i.e.* from 21.4°C (January) to 40.1 °C (June). The annual mean temperature ranges from 19.16°C (January) to 36.96 °C (May). As far as standard deviation is concerned, it ranges from 0.72°C (August) to 2.13°C (June) over the 30 years studied. The coefficient of variation for mean monthly maximum temperature shows a variation ranging from 2.25 to 9.36%. As far as coefficient of skewness is concerned, it is the highest in July (0.94°C) and lowest in December (-1.58°C). Similarly, in kurtosis, a maximum value 2.97°C in November and a minimum value -0.71°C in June is observed during the period under review.

Similarly, the variation in trend of maximum temperature around the average during 1990-2019 has been depicted by the regression equation Y= -0.0002X-30.001. Using this linear regression model, the rate of change is defined by the slope of regression line which in this case is about -0.0002°C during the period of study. The value of R-squared is found to be 0.0000112. A 0% indicates that the model explains none of the variability of the response data around its mean.

The Kendall's tau values for mean annual minimum temperature is 0.41 °C while for maximum temperature is 0.044°C and the values of Sen's slope for mean annual minimum and maximum temperatures are found to be 0.025 and 0.003 respectfully. A great variation in S value can be seen for for mean annual minimum temperature (178) and maximum temperature (19) can be observed.

Almost the same variation can be seen in p-value. The p-values for mean annual minimum temperature is 0.002°C indicating significant difference and for mean maximum temperature is 0.748°C indicating an insignificant difference.

Table.1 Descriptive summary of month-wise average minimum temperature during 1990-2019 (°C)

Month	Min	Max	Mean	SD	CV	Skewness	Kurtosis
Jan	4.3	8.8	6.54	1.02	15.59	-0.12	-0.02
Feb	5.7	11.5	8.93	1.17	13.18	-0.43	1.39
Mar	10.7	14.3	12.36	1.01	8.15	-0.02	-0.91
Apr	15.5	19.4	17.38	1.07	6.17	0.25	-0.93
May	17.6	25.0	22.23	1.37	6.18	-1.19	3.42
Jun	24.1	26.2	25.12	0.61	2.41	0.07	-0.99
Jul	24.7	26.7	25.61	0.51	1.95	-0.01	-0.53
Aug	24.6	26.1	25.27	0.32	1.27	0.19	1.03
Sep	22.4	24.3	23.49	0.58	2.47	-0.23	-1.11
Oct	15.5	19.8	17.57	1.13	6.43	0.01	-0.77
Nov	9.5	13.7	11.38	1.04	9.16	0.33	-0.23
Dec	4.9	9.5	7.54	1.01	13.41	-0.14	0.57

Table 2: Descriptive summary of month-wise average maximum temperature during 1990-2019 (°C)

Month	Min	Max	Mean	SD	CV	Skewness	Kurtosis
Jan	14.5	21.4	19.16	1.79	9.36	-0.74	-0.23
Feb	19.5	26.7	23.03	1.52	6.61	-0.03	0.27
Mar	25.3	31.7	28.55	1.63	5.71	-0.01	-0.41
Apr	32.1	39.1	35.19	1.45	4.12	0.42	1.49
May	32.4	40.0	36.96	1.58	4.29	-0.47	1.16
Jun	32.0	40.1	36.06	2.13	5.91	-0.21	-0.71
Jul	30.6	35.1	32.54	0.96	2.93	0.94	1.51
Aug	30.1	33.4	31.95	0.72	2.25	-0.71	1.34
Sep	29.9	33.4	31.76	0.79	2.51	-0.34	0.21
Oct	28.4	32.5	30.87	0.84	2.72	-0.58	1.47
Nov	24.7	28.2	27.24	0.77	2.86	-1.48	2.97
Dec	17.9	24.2	22.51	1.32	5.86	-1.58	4.02

Table.3 Mann-Kandall, Sen's Statistics, p-value for Month-wise Average Minimum and Maximum Temperature During 1990-2019 (°C)

	Mean annual minimum temperature	Mean annual maximum temperature
Kendall's tau	0.410	0.044
Sen's slope	0.025	0.003
S	178	19
p-value	0.002	0.748
Significance	Significant	Not Significant

Figure.1 Trend variation in minimum temperature around the average during 1990-2019

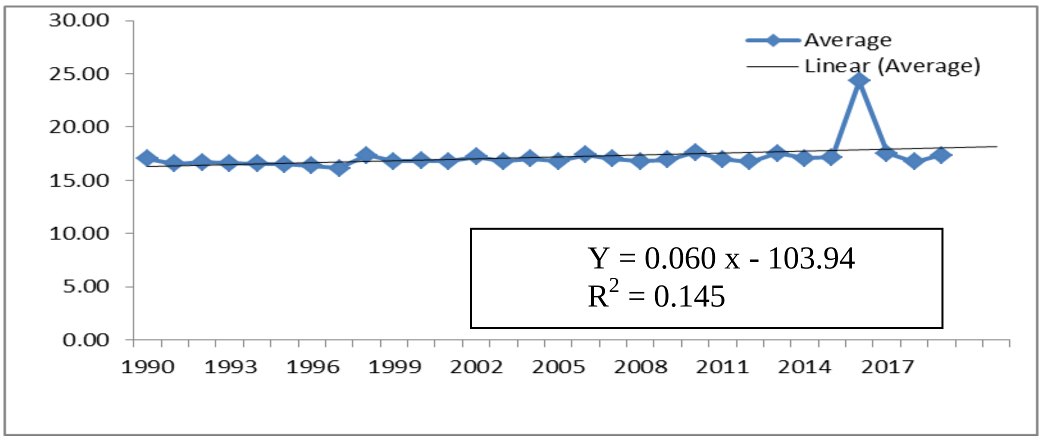


Figure.2 Box Whisker plot depicting descriptive statistics in minimum temperature during 1990-2019 (°C)

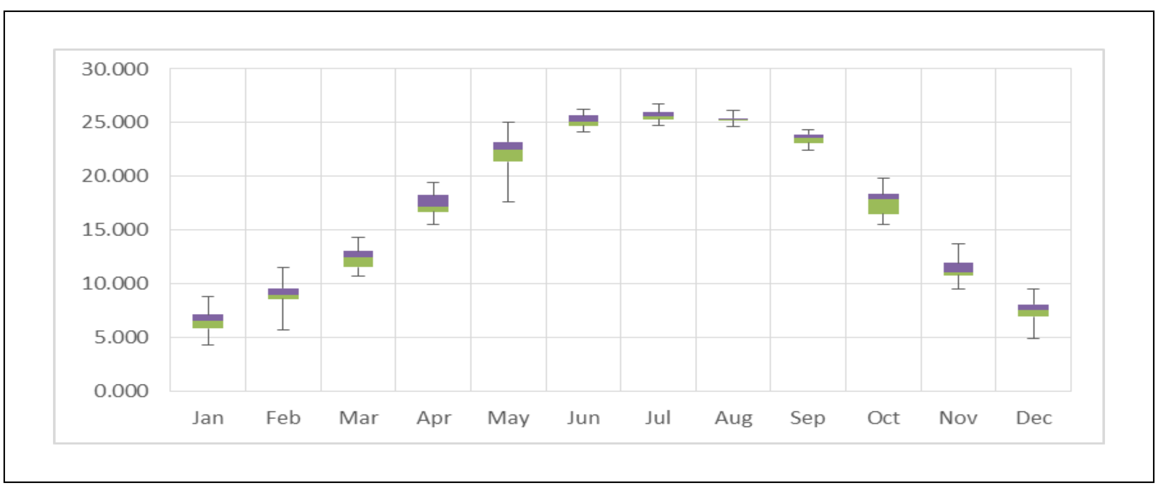


Figure.3 Trend variation in maximum temperature around the average during 1990-2019 (°C)

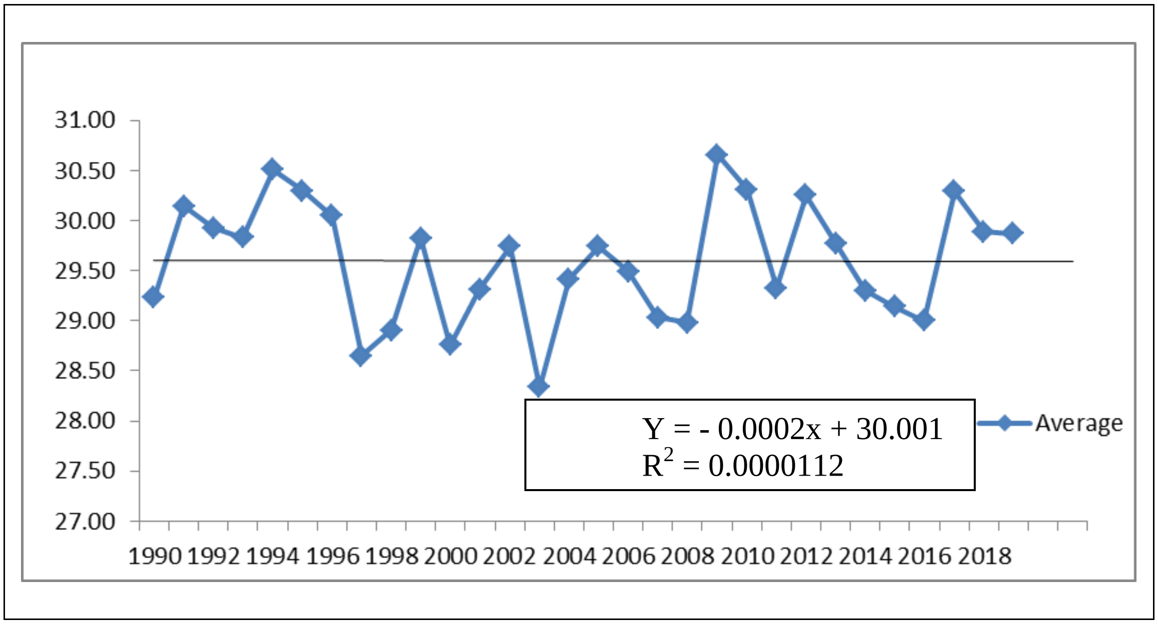
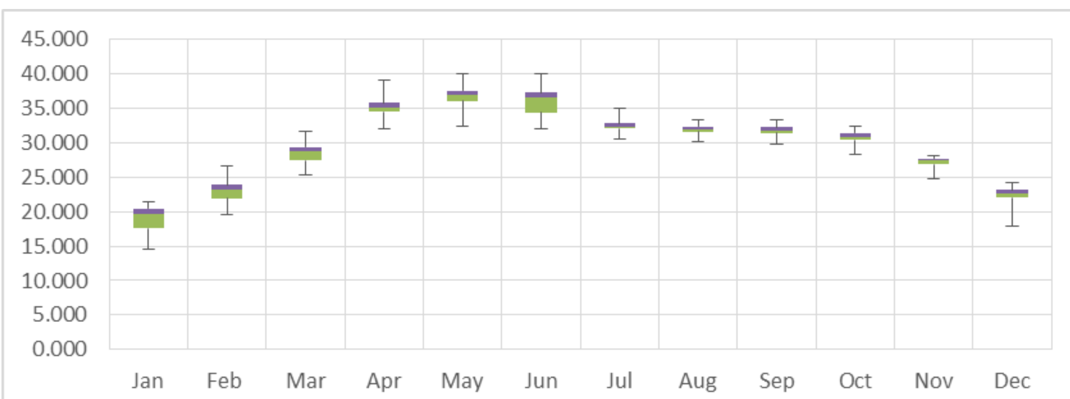


Figure.4 Box Whisker plot depicting descriptive statistics in maximum temperature during 1990-2019 (°C)



In computing the variation in trend of minimum and maximum temperatures around the average value during the period under study *i.e.* 1990-2019, obtaining Rsquared value almost equal to zero is indicating that the proposed model in both of the cases explain no variability around the mean.

M–K test is also applied for trend test, result of which is shown in Table 3. In general, maximum temperature for the observed period showed a slight warming or increasing trend (Sen's slope = 0.00) while the minimum temperature trend showed a cooling trend (Sen's slope = 0.00294) but result of maximum temperature trend analysis is statistically significant at 95%

confidence limit, on the contrary the trend analysis result of minimum temperature is not statistically significant.

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