**Decadal trend analysis of maximum temperature at Nagpur district of Maharashtra, India**

**Abstract**

An attempt was made for decadal trend analysis of maximum temperature for monthly, seasonal and annual time series over a period of 1985 to 2024 using the Mann-Kendall Test and Sen’s Slope Estimator method at Nagpur district of Maharashtra. The annual trend in maximum temperatures from 1985 to 2024 showed non-significant increase of 0.004°C. Significant increase of maximum temperature was observed during Northeast monsoon season at 90% confidence level, with a rise of 0.025°C. Winter and summer temperatures exhibit minor, non-significant decreases. Among the months, November showed significant increase of 0.024°C. Between 1985 and 1994, the annual maximum temperatures showed no significant trend. The SW Monsoon experienced non-significant decrease of 0.025°C, while the NE Monsoon season showed a non-significant increase of 0.033°C. Winter recorded increase of 0.088°C, while summer showed no trend. January noticed non-significant increase of 0.238°C. From 1995 to 2004, a statistically significant annual increase of 0.100°C was observed. The NE Monsoon and summer seasons experienced significant increasing trends, with increases of 0.220°C and 0.214°C, respectively. The SW Monsoon season, however, showed a non-significant decreasing trend of 0.150°C. April experienced a significant rise in maximum temperatures of 0.267°C, while August showed a significant decrease of 0.167°C. During 2005–2014, the annual trend showed non-significant decrease of 0.013°C. The NE Monsoon season and winter exhibited decreasing trends, with winter showing a significant decline of 0.100°C at the 90% confidence level. Monthly non-significant decreasing trends was observed during January (-0.125°C) and February (-0.133°C). For the recent decades 2015–2024, annual maximum temperatures observed, non-significant decline of 0.020°C. The SW Monsoon season exhibited, non-significant increase of 0.020°C, while the NE Monsoon and winter seasons experienced non-significant decreases. Summer showed, non-significant decreasing trend, with decline of 0.230°C. Among monthly trends, April (-0.320°C) and May (-0.230°C) exhibited the most notable non-significant decreases.

**Key Words:** Climate change, Maximum temperature, Trends analysis, Climate Resilient Agriculture, Vidarbha.

**Introduction**

Climate is a fundamental component of the Earth's system, encompassing variables such as temperature, rainfall, atmospheric pressure, and humidity, which collectively influence weather and climate (Panda and Sahu, 2019). Climate is often defined as the long-term average of weather, representing the statistical description of relevant quantities over periods ranging from months to thousands or even millions of years (IPCC, 2007).

A trend is defined as the general movement over an extended period, representing the long-term change in a dependent variable across time (Webber and Hawkins, 1980). Over the past five decades, global temperatures have risen by approximately 0.13 ± 0.07°C per decade. Due to the link between warming and greenhouse gas (GHG) emissions, the IPCC projects a temperature increase of about 0.2°C per decade. Projections for the 21st century suggest that surface air temperatures could rise between 1.1°C and 6.4°C. A study by Karl et al. (1993) found that from 1951 to 1990, global minimum temperatures increased by 0.84°C, while maximum temperatures rose by only 0.28°C.

Numerous studies have observed an increase in surface air temperature by approximately 0.2 to 0.6°C over the last century (Abaurrea and Cerian, 2001). The rate of temperature increase varies across geographic regions (Colin et al., 1999), with observations suggesting that global average surface temperatures have increased by 0.6°C since the 19th century (Chahal, 2010). Climate change is driving shifts in rainfall and temperature patterns, significantly impacting regional hydrological cycles and crop calendars (Abrol et al., 2004). Globally, a long-term trend in maximum temperatures, observed between 1961 and 1985, shows an increase of +0.88°C per century (Easterling et al., 1997). In urban areas, maximum temperature increases reached +0.82°C per century, with the greatest warming observed from March to May (Alexander et al., 2006). In the Philippines, increased night temperatures have been linked to reduced rice yields (Peng et al., 2004). The scientific community has widely observed a notable rise in global air temperature (measured at 2 meters above ground level) over the past century (Angell, 1988; Alexander et al., 2006; Mahlstein et al., 2013; Rahmstorf et al., 2017). However, this warming does not occur uniformly across all regions or time periods. Observational data and modeling studies showed that temperature changes vary both spatial and temporal (Folland et al., 2002).

Recent studies have increasingly focused on global warming and its impact on both global and extreme regional air temperatures, which are essential for maintaining ecological balance in human society (Easterling et al., 2000; Meehl et al., 2000). A critical consequence of climate change is the alteration of rainfall patterns and rising temperatures. According to the IPCC, the Earth surface temperature increased by roughly 0.6 ± 0.2 °C over the 20th century (IPCC, 2007). The IPCC's Sixth Assessment Report notes that from 2011 to 2020, global surface temperatures rose by 1.09°C (0.95 to 1.20°C) relative to the 1850–1900 baseline. The report also suggests a more than 50% likelihood that global warming could reach or exceed 1.5°C under a low-GHG emissions scenario. Research has shown that minimum temperatures are rising at a faster rate than maximum temperatures in regions such as Europe (Weber et al., 1997), China (Qian & Lin, 2004), and Turkey (Turkes & Sumer, 2004). For instance, from 1951 to 1990, the average daily mean air temperature (during global daytime) increased by 0.28°C, while the daily minimum temperature (at night) rose significantly by 0.84°C, reflecting a threefold increase (Karl & Easterling, 1999). Subsequent studies (Kothyari and Singh, 1996; Kothawale and Kumar, 2005; Rao et al., 2005) corroborated these findings by documenting rising trends in both maximum and minimum temperatures across various regions of India. Particularly in northern India, a majority of locations experienced an increase in extreme night temperatures.

India's climate variability shows significant inter-annual variation in mean maximum temperatures across its four climatic zones: mountain, arid/semi-arid, humid subtropical, and tropical wet/dry (Bhattacharya et al., 2023). In India, climate change is anticipated to affect natural resources, forestry, and agriculture, while also altering precipitation patterns, temperatures, monsoon timing, and extreme weather events (Fulekar and Kale, 2010). Simulations of crop response at varying levels of nitrogen management reveal that responses can differ based on nitrogen management practices and climate change scenarios (Aggarwal, 2003). An increasing trend in maximum temperatures (1.5 to 2°C per century) has been observed over central India, consistent with IPCC projections (Naveena et al., 2021). However, the Yavatmal station in the Vidarbha region showed a significant decline in mean maximum temperature in the Mann-Kendall Test (Deshmukh et al., 2013). Subash et al. (2011) studied temperature trends in Central Northeast (CNE) India, revealing a significant increase in maximum temperatures. They reported a rising trend of 0.008°C per year during the monsoon season and 0.014°C per year in the post-monsoon season. Srivastava et al. (2017) analyzed the entire country, indicating that the annual maximum temperature and mean temperature have risen by 1.0°C and 0.6°C per century, respectively, from 1901 to 2010. In contrast, the minimum temperature has experienced a more modest increase of 0.18°C per century. Srivastava et al. (1992) noted a distinct diurnal temperature asymmetry in India compared to global patterns, indicating a significant decreasing trend of 0.2°C per century in northern India and an increasing trend of 0.4°C in southern India from 1901 to 1986. This regional variation was further supported by Kumar et al. (1994), who reported that the increase in temperatures during the post-monsoon and winter seasons contributed to a rise in the mean temperature from 1901 to 1987.

Panda and Sahu (2019) analyzed seasonal rainfall and temperature trends in three districts of Odisha, India, and found that annual maximum and minimum temperatures showed an increasing trend, while monsoon maximum and minimum temperatures showed a decreasing trend. Palte et al. (2016) studied rainfall and temperature trends across 16 districts in Arunachal Pradesh using the non-parametric Mann–Kendall test and Sen’s slope estimator. Their research identified an increase in average annual minimum daily temperature, while maximum temperature remained stable. Seasonally, the highest warming occurred during the post-monsoon period, followed by the monsoon, with the least warming observed in the pre-monsoon season, showed climate variability in the region. Additionally, Dhorde et al. (2009) investigated the effects of urbanization on temperature trends in four major Indian cities: Chennai, Delhi, Kolkata, and Mumbai. This study underscored the potential influence of urban development on local temperature changes, emphasizing the complexity of factors driving temperature trends in urban versus rural contexts.

Higher temperatures can reduce crop duration, increase respiration rates, alter pest populations, hasten nutrient mineralization, lower fertilizer-use efficiency, and increase evapotranspiration. Additionally, increased temperatures and changes in water and fodder availability may impact meat and milk production (Aggarwal, 2008). Trend analysis of temperature and other climatic variables across different spatial scales aids in constructing future climate scenarios (Arora et al., 2005; Karanurun and Kara, 2011; Meshram et al., 2018).

Analyzing long-term changes in climatic variables is crucial for detecting climate change. With the expansion and improvement of datasets and more advanced data analysis techniques globally, understanding past and recent climate change has become an increasingly important area of research (Kumar et al., 2010).

**Materials and Methods**

**Study Area and Data Availability**

The required daily maximum temperature data for the period from 1985 to 2024 for the study was obtained from the ICAR- Central Institute for Cotton Research, Nagpur. This daily maximum temperature data was further converted into monthly, seasonal, and annual averages for further analysis. The Weather Cock15 software program was used for the conversion of daily maximum temperature data to various time scales.

**Trend Analysis of Maximum Temperature**

Trend analysis can be described as the analysis of changes over a time series. Temperature, being an independent weather parameter, was analyzed for its monthly, seasonal, and annual trends using the Mann-Kendall Test and Sen’s Slope Estimator method. The Mann-Kendall Test assesses the presence of a monotonic increase or decrease in trend based on the normalized test statistic (Z) value. Sen’s Slope Estimator, a non-parametric method, provides the rate of increase or decrease in trend. Both methods are detailed as follows:

**Mann Kendall method**

Mann Kendall test statistic (S) is calculated by using the following formula; (**Mann, 1945);**

(1)

Where, Xj and Xk are the annual values in year’s j and k, j > k respectively and Xk represents data point at the time k.

(2)

The value of sign (xj - xk) is computed as number follows

This statistic S represents the difference between the number of positive differences and the number of negative differences for all the pairwise differences considered in the time series data. For large samples (N>10), the Mann-Kendall test statistic S is approximated using a normal distribution. The normal approximation is expressed through the Z statistic, which allows for the evaluation of trends in large datasets.

The mean and variance of the test statistic S are calculated as follows:

**Mean of S:**

The mean of S is assumed to be 0 for large sample sizes.

**Variance of S:**

(3)

Where, n = number of years,

g = Number of the tied groups (A tied group is a set of sample data having the same value) and

tp = Number of the items in the tied group

Calculate a normalized test statistic Z by the following equation

(4)

(5)

(6)

Where, S = p - q, p = number of (+1) values and q = number of (-1) values.

The presence of a statistically significant trend was assessed using the 'Z' value. A positive Z value indicates an upward (increasing) trend, while a negative Z value indicates a downward (decreasing) trend. The significance of these trends is determined based on the ZZZ value at three confidence levels: 99%, 95%, and 90%. Positive or negative trends are considered significant if the Z value exceeds the critical threshold at the corresponding confidence level.

1. At the 99 per cent significance level, the null hypothesis of no trend is rejected if │Z│ > 2.575;
2. At the 95 per cent significance level null hypothesis of no trend is rejected at if │Z│ > 1.96; and
3. At the 90 per cent significance level, the null hypothesis of no trend is rejected if │Z│ > 1.645.

**Sen's slope method**

Sen's slope method used for prediction of the magnitude of the temperature time series data. The linear model is used in this method for trend analysis by using a simple non-parametric procedure developed by Sen (1968).

(7)

All the data pairs slope was determined for deriving estimation of the slope Qt.

In the time series data, if there are n values of Xj, then as much as N = n (n-1) / 2 slope estimates, Qt are to be calculated. Sen’s estimator of the slope is median of the N values of the Qt. The ranking of N values of Qt was done from smallest to largest values.

Sen’s estimate was calculated by;

(8)

Median of all slope values gives Q, which is the magnitude of the trend. A positive value indicates increasing and negative values indicate decreasing trends of the rainfall and rainy days. Magnitude of trends was calculated for the statistically significant trends found by Mann- Kendall test.

**Results and Discussion**

**Maximum Temperature Trends in Nagpur (1985–2024)**

The annual trend for maximum temperatures in Nagpur shows a slight increase by 0.004°C over a period of 1985 to 2024, represented by a test Z value of 0.66. However, this trend is non-significant.

The trend analysis across different seasons shows varied directions and significance levels. During the Southwest (SW) Monsoon season, there is a slight non-significant downward trend (Z = -0.09) with no effective change in temperature. Conversely, the Northeast (NE) Monsoon season reveals a notable and significant increase in maximum temperature (Z = 1.75), marked as significant at the 90% confidence level, with an increase of 0.025°C. Winter temperatures show a non-significant decline (Z = -0.29), indicating a slight decrease of 0.004°C. Summer follows a similar pattern with a non-significant decrease (Z = -0.63) and a reduction of 0.012°C in maximum temperatures.

January, February, March, April, and May all showed non-significant trends, with March showing the most considerable decrease (Z = -0.66) and a temperature decline of 0.017°C. May stands out with the largest non-significant decrease (Z = -1.29), showing a decline of 0.027°C. June records no trend, indicating stable maximum temperatures during this month over the observed period.

For July, the trend is slightly downward and non-significant (Z = -0.21), with a minor decrease of 0.003°C. August and October reveal non-significant upward trends, with October having a Z value of 0.90, indicating a slight rise of 0.020°C. Notably, November observed a significant increase (Z = 1.95) at the 90% confidence level, with a rise of 0.024°C in maximum temperatures. December also shows a non-significant increase (Z = 1.29) with a rise of 0.027°C. The values for the time series trends in maximum temperature at Nagpur from 1985 to 2024, including the Mann-Kendall test Z statistics and Sen's slope (Q), are provided in Table-1.

**Maximum Temperature Trends in Nagpur (1985-1994)**

The analysis reveals no significant annual trend in maximum temperatures between 1985 and 1994. The Mann-Kendall test Z value is 0.00, indicating stability, with no recorded increase or decrease.

During the Southwest (SW) Monsoon season, there is a non-significant downward trend (Z = -0.09) with a decrease of 0.025°C. In contrast, the Northeast (NE) Monsoon season shows a slight non-significant increase (Z = 0.36), with an increase of 0.033°C. Winter temperatures also display a non-significant upward trend (Z = 0.72), with a relatively higher increase of 0.088°C. The summer season, however, shows no trend.

January observed non-significant increase (Z = 0.80), with the highest recorded increase among months, at 0.238°C. February also exhibits a slight, non-significant upward trend (Z = 0.36) with a rise of 0.062°C. March shows no trend over the observed period. April showed a non-significant downward trend (Z = -1.34), observed a decrease of 0.100°C, one of the more substantial monthly declines. May showed a slight, non-significant increase (Z = 0.45) with a rise of 0.088°C. June saw a slight, non-significant decline (Z = -0.18) with a temperature decrease of 0.083°C. July displayed non-significant upward trend (Z = 0.27) with an increase of 0.050°C, while August and September both exhibit non-significant downward trends, with decreases of 0.100°C and 0.213°C, respectively. October shows a slight, non-significant increase (Z = 0.27), with a rise of 0.067°C. November exhibited a non-significant downward trend (Z = -0.36) with a small decrease of 0.043°C, and December has no significant trend, with a slight temperature decline of 0.044°C. The values for the time series trends in maximum temperature at Nagpur from 1985 to 1994, including the Mann-Kendall test Z statistics and Sen's slope (Q), are provided in Table-2.

**Maximum Temperature Trends in Nagpur (1995-2004)**

The annual trend for maximum temperatures in Nagpur between 1995 and 2004 shows a statistically significant increase, with a Z value of 1.97, significant at the 95% confidence level. This reflects an increase of 0.100°C in annual maximum temperatures.

The Southwest (SW) Monsoon season showed a non-significant downward trend (Z = -1.25), with a decrease of 0.150°C in maximum temperature. However, the Northeast (NE) Monsoon season exhibits a significant upward trend (Z = 1.70) at the 90% confidence level, with an increase of 0.220°C.

For the winter season, there is a non-significant upward trend (Z = 1.34) with an increase of 0.200°C. The summer season shows a significant upward trend (Z = 1.88) at the 90% confidence level, with a rise of 0.214°C.

The monthly data reveals several trends, with certain months exhibiting statistically significant increases. January shows a non-significant upward trend (Z = 1.52) with the largest increase among all months, at 0.350°C. February and March also display non-significant upward trends (Z = 0.27 and Z = 0.63, respectively), with increases of 0.040°C and 0.220°C. April, however, records a significant increase in maximum temperatures (Z = 1.97) at the 95% confidence level, with a rise of 0.267°C.

May shows a non-significant increase (Z = 0.45) with a rise of 0.080°C. June, experienced a non-significant downward trend (Z = -1.25) with a decrease of 0.425°C, marking it as the month with the largest decline. July and August also exhibit decreasing trends, with July showing a non-significant decrease (Z = -0.54) and a temperature drop of 0.150°C, while August has a significant downward trend (Z = -1.70) at the 90% confidence level, with a reduction of 0.167°C.

September and October both display non-significant upward trends, with temperature increases of 0.080°C and 0.125°C, respectively. In November, there is a significant increase in maximum temperatures (Z = 2.24), significant at the 95% confidence level, with a rise of 0.200°C. December also shows a non-significant upward trend (Z = 1.25), with an increase of 0.217°C. The values for the time series trends in maximum temperature at Nagpur from 1995 to 2004, including the Mann-Kendall test Z statistics and Sen's slope (Q), are provided in Table-3.

**Maximum Temperature Trends in Nagpur (2005-2014)**

From 2005 to 2014, the annual maximum temperature trend in Nagpur shows a slight non-significant decrease (Z = -0.18), with a reduction of 0.013°C.

The Southwest (SW) Monsoon season shows no trend. The Northeast (NE) Monsoon season showed a non-significant downward trend (Z = -0.27), with a decrease of 0.033°C.

In winter, it was significant downward trend (Z = -1.88) at the 90% confidence level, with a decrease of 0.100°C. The summer season shows a non-significant upward trend (Z = 0.36), with a slight increase of 0.040°C.

January and February both show non-significant downward trends, with January decreasing by 0.125°C (Z = -1.07) and February by 0.133°C (Z = -1.34), indicating slight cooling at the start of the year. March showed a non-significant upward trend (Z = 0.09) with a small increase of 0.017°C, while April shows no trend. May and July both exhibit non-significant increases, with May showing a rise of 0.125°C (Z = 0.63) and July a similar increase (Z = 1.43). June and August show no significant trends, although June has a minor decrease of 0.086°C. September also exhibit a slight non-significant downward trend (Z = -0.09) with a small decrease of 0.011°C, while October shows a slightly larger non-significant decline (Z = -0.36) with a reduction of 0.050°C. In November, it was observed non-significant upward trend (Z = 0.63) with an increase of 0.050°C, while December shows a non-significant downward trend (Z = -0.45), with a decrease of 0.100°C. The values for the time series trends in maximum temperature at Nagpur from 2005 to 2014, including the Mann-Kendall test Z statistics and Sen's slope (Q), are provided in Table-4.

**Maximum Temperature Trends in Nagpur (2015-2024)**

The annual analysis for the period 2015 to 2024 indicates a non-significant downward trend in maximum temperature, with a Mann-Kendall test Z value of -0.27 with slight decrease of 0.02°C.

The Southwest (SW) Monsoon season exhibits a non-significant upward trend (Z = 0.36), with an increase of 0.02°C, while the Northeast (NE) Monsoon season has a non-significant downward trend (Z = -0.63), with a decrease of 0.10°C. Winter temperatures also display a non-significant decrease (Z = -0.63) with a reduction of 0.04°C. In summer, a slightly larger non-significant decreasing trend is observed (Z = -0.89), with a more noticeable decrease of 0.23°C.

January and February observed non-significant downward trends, with decreases of 0.10°C and 0.13°C, respectively. March shows a slight non-significant upward trend (Z = 0.18) with a rise of 0.07°C, whereas April and May both observed non-significant decreasing trends with reductions of 0.32°C and 0.23°C, respectively.

June shows a non-significant increasing trend (Z = 0.54) with a small increase of 0.11°C, and August also showed a slight non-significant increasing trend (Z = 0.80) with an increase of 0.09°C. July and September both exhibit non-significant decreasing trends, with decreases of 0.10°C and 0.08°C, respectively. October, November, and December all observed non-significant decreasing trends, with November showed decrease of 0.11°C. The values for the time series trends in maximum temperature at Nagpur from 2015 to 2024, including the Mann-Kendall test Z statistics and Sen's slope (Q), are provided in Table-5.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Table. 1. Times series wise trends statistics of Maximum temperature for the period from 1985-2024 at Nagpur** | | | | |
| **Sr. No.** | **Times Series** | **Test Z**  **(Mann-Kendall test)** | **Trends and**  **significance** | **Q**  **(Sen’s slope)** |
|  | Annual | 0.66 | ↑(NS) | 0.004 |
|  | SW Monsoon | -0.09 | ↓(NS) | 0.000 |
|  | NE Monsoon | 1.75 | ↑+ (S) | 0.025 |
|  | Winter | -0.29 | ↓(NS) | -0.004 |
|  | Summer | -0.63 | ↓(NS) | -0.012 |
|  | January | -0.36 | ↓(NS) | -0.006 |
|  | February | 0.08 | ↑(NS) | 0.000 |
|  | March | -0.66 | ↓(NS) | -0.017 |
|  | April | -0.48 | ↓(NS) | -0.010 |
|  | May | -1.29 | ↓(NS) | -0.027 |
|  | June | 0.00 | No trend | 0.000 |
|  | July | -0.21 | ↓(NS) | -0.003 |
|  | August | 1.15 | ↑(NS) | 0.015 |
|  | September | -0.80 | ↓(NS) | -0.012 |
|  | October | 0.90 | ↑(NS) | 0.020 |
|  | November | 1.95 | ↑+(S) | 0.024 |
|  | December | 1.29 | ↑(NS) | 0.027 |
| ↑ : Increasing, ↓ : Decreasing, NS- Non-Significant, S : Significant, + : Significant at 90 per cent confidence level, \* : Significant at 95 per cent confidence level, \*\* : Significant at 99 per cent confidence level, - : No trends. | | | | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Table. 2. Times series wise trends statistics of Maximum temperature for the period from 1985 to 1994 at Nagpur** | | | | |
| **Sr. No.** | **Times Series** | **Test Z**  **(Mann-Kendall test)** | **Trends and**  **significance** | **Q**  **(Sen’s slope)** |
|  | Annual | 0.00 | No trend | 0.000 |
|  | SW Monsoon | -0.09 | ↓(NS) | -0.025 |
|  | NE Monsoon | 0.36 | ↑(NS) | 0.033 |
|  | Winter | 0.72 | ↑(NS) | 0.088 |
|  | Summer | 0.00 | No trend | 0.000 |
|  | January | 0.80 | ↑(NS) | 0.238 |
|  | February | 0.36 | ↑(NS) | 0.062 |
|  | March | 0.00 | No trend | 0.100 |
|  | April | -1.34 | ↓(NS) | -0.100 |
|  | May | 0.45 | ↑(NS) | 0.088 |
|  | June | -0.18 | ↓(NS) | -0.083 |
|  | July | 0.27 | ↑(NS) | 0.050 |
|  | August | -0.98 | ↓(NS) | -0.100 |
|  | September | -0.98 | ↓(NS) | -0.213 |
|  | October | 0.27 | ↑(NS) | 0.067 |
|  | November | -0.36 | ↓(NS) | -0.043 |
|  | December | 0.00 | No trend | -0.044 |
| ↑ : Increasing, ↓ : Decreasing, NS- Non-Significant, S : Significant, + : Significant at 90 per cent confidence level, \* : Significant at 95 per cent confidence level, \*\* : Significant at 99 per cent confidence level, - : No trends. | | | | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Table. 3. Times series wise trends statistics of Maximum temperature for the period from 1995 to 2004 at Nagpur** | | | | |
| **Sr. No.** | **Times Series** | **Test Z**  **(Mann-Kendall test)** | **Trends and**  **significance** | **Q**  **(Sen’s slope)** |
|  | Annual | 1.97 | ↑\*(S) | 0.100 |
|  | SW Monsoon | -1.25 | ↓(NS) | -0.150 |
|  | NE Monsoon | 1.70 | ↑+(S) | 0.220 |
|  | Winter | 1.34 | ↑(NS) | 0.200 |
|  | Summer | 1.88 | ↑+(S) | 0.214 |
|  | January | 1.52 | ↑(NS) | 0.350 |
|  | February | 0.27 | ↑(NS) | 0.040 |
|  | March | 0.63 | ↑(NS) | 0.220 |
|  | April | 1.97 | ↑\*(S) | 0.267 |
|  | May | 0.45 | ↑(NS) | 0.080 |
|  | June | -1.25 | ↓(NS) | -0.425 |
|  | July | -0.54 | ↓(NS) | -0.150 |
|  | August | -1.70 | ↓+(S) | -0.167 |
|  | September | 0.36 | ↑(NS) | 0.080 |
|  | October | 1.16 | ↑(NS) | 0.125 |
|  | November | 2.24 | ↑\*(S) | 0.200 |
|  | December | 1.25 | ↑(NS) | 0.217 |
| ↑ : Increasing, ↓ : Decreasing, NS- Non-Significant, S : Significant, + : Significant at 90 per cent confidence level, \* : Significant at 95 per cent confidence level, \*\* : Significant at 99 per cent confidence level, - : No trends. | | | | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Table. 4. Times series wise trends statistics of Maximum temperature for the period from 2005 to 2014 at Nagpur** | | | | |
| **Sr. No.** | **Times Series** | **Test Z**  **(Mann-Kendall test)** | **Trends and**  **significance** | **Q**  **(Sen’s slope)** |
|  | Annual | -0.18 | ↓(NS) | -0.013 |
|  | SW Monsoon | 0.00 | No trend | 0.000 |
|  | NE Monsoon | -0.27 | ↓(NS) | -0.033 |
|  | Winter | -1.88 | ↓+(S) | -0.100 |
|  | Summer | 0.36 | ↑(NS) | 0.040 |
|  | January | -1.07 | ↓(NS) | -0.125 |
|  | February | -1.34 | ↓(NS) | -0.133 |
|  | March | 0.09 | ↑(NS) | 0.017 |
|  | April | 0.00 | No trend | -0.029 |
|  | May | 0.63 | ↑(NS) | 0.125 |
|  | June | 0.00 | No trend | -0.086 |
|  | July | 1.43 | ↑(NS) | 0.125 |
|  | August | 0.00 | No trend | 0.014 |
|  | September | -0.09 | ↓(NS) | -0.011 |
|  | October | -0.36 | ↓(NS) | -0.050 |
|  | November | 0.63 | ↑(NS) | 0.050 |
|  | December | -0.45 | ↓(NS) | -0.100 |
| ↑ : Increasing, ↓ : Decreasing, NS- Non-Significant, S : Significant, + : Significant at 90 per cent confidence level, \* : Significant at 95 per cent confidence level, \*\* : Significant at 99 per cent confidence level, - : No trends. | | | | |

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Table. 5. Times series wise trends statistics of Maximum temperature for the period from 2015 to 2024 at Nagpur** | | | | |
| **Sr. No.** | **Times Series** | **Test Z**  **(Mann-Kendall test)** | **Trends and**  **significance** | **Q**  **(Sen’s slope)** |
|  | Annual | -0.27 | ↓(NS) | -0.02 |
|  | SW Monsoon | 0.36 | ↑(NS) | 0.02 |
|  | NE Monsoon | -0.63 | ↓(NS) | -0.10 |
|  | Winter | -0.63 | ↓(NS) | -0.04 |
|  | Summer | -0.89 | ↓(NS) | -0.23 |
|  | January | -0.36 | ↓(NS) | -0.10 |
|  | February | -0.45 | ↓(NS) | -0.13 |
|  | March | 0.18 | ↑(NS) | 0.07 |
|  | April | -0.80 | ↓(NS) | -0.32 |
|  | May | -0.89 | ↓(NS) | -0.23 |
|  | June | 0.54 | ↑(NS) | 0.11 |
|  | July | -0.54 | ↓(NS) | -0.10 |
|  | August | 0.80 | ↑(NS) | 0.09 |
|  | September | -0.54 | ↓(NS) | -0.08 |
|  | October | -0.18 | ↓(NS) | -0.03 |
|  | November | -1.61 | ↓(NS) | -0.11 |
|  | December | -0.27 | ↓(NS) | -0.03 |
| ↑ : Increasing, ↓ : Decreasing, NS- Non-Significant, S : Significant, + : Significant at 90 per cent confidence level, \* : Significant at 95 per cent confidence level, \*\* : Significant at 99 per cent confidence level, - : No trends. | | | | |

**Conclusion**

The analysis of maximum temperature trends in Nagpur, Maharashtra, from 1985 to 2024 showed important patterns for agriculture and climate adaptation. Over the long term, annual maximum temperatures have shown a slight but non-significant warming trend, aligning with broader climate change patterns and suggesting a need for on-going adaptation. Notably, the Northeast Monsoon (1995-2004) experienced a significant temperature increase, which may have stressed crops reliant on cooler monsoon conditions and emphasized the importance of adaptive practices. Winter months from 2005 to 2014 exhibited a significant decline in maximum temperatures, potentially impacting winter crop yields and pointing to the need for frost-resistant varieties or adjusted planting schedules. The recent period (2015-2024) shows relative temperature stability, allowing more predictable planning but requiring continued monitoring for future shifts. Together, these findings provide essential for farmers and policymakers to make informed decisions, safeguard crop productivity, and ensure resilience in agriculture amidst climate variability. Further research should focus on understanding these trends' long-term impacts on crop yields and agricultural productivity.

**Acknowledgement**

The authors are thankful to the Director, ICAR-Central Institute for Cotton Research, Nagpur, for providing the necessary facilities and support. The authors also extend their gratitude to Krishi Vigyan Kendra, ICAR-CICR, Nagpur, the Agromet Advisory Services Division, IMD, New Delhi, the Agrimet Division, IMD, Pune, and the Regional Meteorological Centre (RMC), Nagpur.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

ChatGpt was used for minor editing of manuscript.

**References**

1. Abaurrea, J., & Cerian, A. C. (2001). Trend and variability analysis of rainfall series and their extreme events.
2. Abrol, P. Y., Gandhi, S., & Pant, G. B. (2003). Climate Variability and Agriculture. Narosha Publishing House, New Delhi, India, 1, 252.
3. Aggarwal, P. K. (2003). Impact of climate change on Indian agriculture. Journal of Plant Biology, 30, 189–198.
4. Aggarwal, P. K. (2008). Global climate change and Indian agriculture: Impacts, adaptation, and mitigation. Indian Journal of Agricultural Sciences, 78(10), 911–919.
5. Alexander, L. V., Zhang, X., Peterson, T. C., Caesar, J., Gleason, B., Klein Tank, A. M. G., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F., Tagipour, A., Kumar, K., Revadekar, J., Griffiths, G., Vincent, L., Stephenson, D. B., Burn, J., Aguilar, E., Brunet, M., Taylor, M., New, M., Zhai, P., Rusticucci, M., & Aguirre, J. L. (2006). Global observed changes in daily climate extremes of temperature and precipitation. Journal of Geophysical Research, 111, D05109. https://doi.org/10.1029/2005JD006290
6. Angell, J. K. (1988). Variations and trends in tropospheric and stratospheric global temperatures, 1958–87. Journal of Climate, 1, 1296–1313.
7. Arora, M., Goel, N. K., & Singh, P. (2005). Evaluation of temperature trends over India. Hydrological Sciences Journal, 50, 81–93.
8. Bhattacharya, A., Thomas, A., Soni, V. K., Roy, P. S., Sarangi, C., & Kanawade, V. P. (2023). Opposite trends in heat waves and cold waves over India. Journal of Earth System Science, 132, 67.
9. Chahal, S. S. (2010). Climate change: Challenges and researchable issues for agricultural sustainability. University News, 48(24), 73–79.
10. Colin, P., Silas, M., Stylianos, P., & Pinhas, A. (1999). Long-term changes in diurnal temperature range in Cyprus. Atmospheric Research, 51, 85–98.
11. Deshmukh, D. T., & Lunge, H. S. (2013). Trend assessment in climatic variables by Mann-Kendall and t-test: A case study of Yavatmal District in Vidarbha, India. International Journal of Current Research, 2(5), 597–600.
12. Dhorde, A., & Gadgil, A. (2009). Long-term temperature trends at four largest cities of India during the twentieth century. Journal of Indian Geophysical Union, 13(2), 85–97.
13. Easterling, D. R., Evans, J. L., Groisman, P. Y., Karl, T. R., Kunkel, K. E., & Ambenje, P. (2000). Observed variability and trends in extreme climate events: A brief review. Bulletin of the American Meteorological Society, 81, 417–425.
14. Easterling, D. R., Horton, B., Jones, P. D., Peterson, T. C., Karl, T. R., Parker, D. E., Salinger, M. J., Razuvayev, V., Plummer, N., Jamason, P., & Folland, C. K. (1997). Maximum and minimum temperature trends for the globe. Science, 277(5324), 364–367.
15. Fulekar, M. H., & Kale, R. K. (2010). Impact of climate change: Indian scenario. University News, 48(24), 15–23.
16. IPCC. (2007). Climate change: Climate change impacts, adaptation, and vulnerability. Working Group II Contribution to the Intergovernmental Panel on Climate Change, Fourth Assessment Report, Summary for Policymakers, 23.
17. IPCC. (2007). Climate Change - A Synthesis Report of the IPCC. Intergovernmental Panel on Climate Change, Technical Report.
18. IPCC. (2018). Global warming of 1.5 °C. Intergovernmental Panel on Climate Change (IPCC), WMO.
19. Karanurun, A., & Kara, F. (2011). Analysis of spatially distributed annual, seasonal and monthly temperatures in Istanbul from 1975 to 2006. World Applied Sciences Journal, 12(10), 1662–1675.
20. Karl, T. R., & Easterling, D. R. (1999). Climate extremes: Selected review and future research directions. Climatic Change, 42, 309–325.
21. Karl, T. R., Janes, P. D., Knight, R. W., Kukla, J., Plummer, N., Razuvayev, V., Gallo, K. P., Lindesay, J., Charlson, R. J., & Peterson, T. C. (1993). A symmetric trend of daily maximum and minimum temperatures: Empirical evidence and possible causes. Bulletin of the American Meteorological Society, 74(6), 1007–1023.
22. Kothawale, D. R., & Rupa Kumar, K. (2005). On the recent changes in surface temperature trends over India. Geophysical Research Letters, 32, L18714. https://doi.org/10.1029/2005GL023528
23. Kothyari, U., & Singh, V. P. (1996). Rainfall and temperature trends in India. Hydrological Processes, 10(3), 357–372.
24. Kumar, K. R., Kumar, K. K., & Pant, G. B. (1994). Diurnal asymmetry of surface temperature trends over India. Geophysical Research Letters, 21(6), 677–680.
25. Kumar, R., & Gautam, H. R. (2014). Climate change and its impact on agricultural productivity in India. Journal of Climatology and Weather Forecasting, 2, 109. https://doi.org/10.4172/2332-2594.1000109
26. Kumar, V., Jain, S. K., & Singh, Y. (2010). Analysis of long-term rainfall trends in India. Hydrological Sciences Journal, 55(4), 484–496.
27. Mahlstein, I., Daniel, J. S., & Solomon, S. (2013). Pace of shifts in climate regions increases with global temperature. Nature Climate Change, 3, 739–743.
28. Mann, H. B. (1945). Non-parametric tests against trend. Econometrica, 13, 163–171.
29. Meehl, G. A., Zwiers, F., Evans, J., Knutson, T., Mearns, L., & Whetton, P. (2000). Trends in extreme weather and climate events: Issues related to modelling extremes in projections of future climate change. Bulletin of the American Meteorological Society, 81, 427–436.
30. Meshram, S. G., Singh, S. K., Meshram, C., Deo, R. C., & Ambade, B. (2018). Statistical evaluation of rainfall time series in concurrence with agriculture and water resources of Ken River basin, Central India (1901–2010). Theoretical and Applied Climatology, 134, 1231–1243.
31. Naveena, N., Satyanarayana, G. C., Dharma Raju, A., Rao, K., Sivasankara, & Umakanth, N. (2021). Spatial and statistical characteristics of heat waves impacting India. AIMS Environmental Science, 8(2), 117–134.
32. Pal, A. B., & Mishra, P. K. (2017). Trend analysis of rainfall, temperature, and runoff data: A case study of Rangoon Watershed in Nepal. International Journal of Students' Research in Technology & Management, 5(3), 21–38.
33. Palte, G. T., Libang, A., & Ahuja, S. (2016). Analysis of rainfall and temperature variability and trend detection: A non-parametric Mann-Kendall test approach. 3rd International Conference on Computing for Sustainable Global Development, 16–18 March, New Delhi, India.
34. Panda, A., & Sahu, N. (2019). Trend analysis of seasonal rainfall and temperature pattern in Kalahandi, Bolangir, and Koraput districts of Odisha, India. Atmospheric Science Letters, 20(10), 933.
35. Pant, G. B., & Rupa Kumar, K. (1997). Climates of South Asia. John Wiley & Sons.
36. Peterson, T. C., & Manton, M. J. (2008). Monitoring changes in climate extremes: A tale of international collaboration. Bulletin of the American Meteorological Society, 89, 1266–1271.
37. Sarkar, J., and Gadgil, A. S., (2005). Long-term variation of surface temperature in the Vidarbha region. Mausam, 56 (3), 698-702.
38. Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall’s tau. Journal of the American Statistical Association, 63(324), 1379–1387.
39. Sen Roy, S., & Balling, R. C. (2004). Trends in extreme daily precipitation indices in India. International Journal of Climatology, 24(4), 457–466.
40. Sinha, A. K., & Swaminathan, M. S. (2009). Climate change and food security in South Asia. Indian Journal of Agricultural Sciences, 79, 17–26.
41. Singh, N., & Sontakke, N. A. (2002). On climatic fluctuations and environmental changes of the Indo-Gangetic plains, India. Climatic Change, 52, 287–313.