**Long-Term Analysis of Minimum Temperature Trends in Nagpur District of Maharashtra, India**

**Abstract**

This study analysed minimum temperature trends in Nagpur, India, from 1985 to 2024, based on daily data from the District Agromet Unit of ICAR - Central Institute for Cotton Research. Temperature data were aggregated into monthly, seasonal, and annual values using Weather Cock15 software, with a focus on evaluating long-term and decadal trends. During 1985-1994, the annual minimum temperature showed a slight, non-significant decrease of 0.014°C, with small declines in both the Southwest (SW) and Northeast (NE) Monsoon seasons, as well as in winter. The most notable change was a 0.133°C decrease in September, which was significant at the 90% confidence level. In the subsequent decade, from 1995-2004, the annual minimum temperature increased by 0.050°C, though this was non-significant. Winter and summer temperatures both showed non-significant increases of 0.200°C, while April stood out with a significant increase of 0.300°C at the 95% confidence level.

During, 2005-2014, the annual minimum temperature decreased slightly by 0.017°C, with the NE Monsoon showing a minor decline. December recorded a significant decrease of 0.250°C at the 95% confidence level. However, in the most recent decade (2015-2024), a clear warming trend emerged, with the annual minimum temperature rising by 0.167°C, significant at the 90% confidence level. The NE Monsoon showed a substantial increase of 0.320°C, and both January and December experienced significant increases, with December showing the largest rise of 0.500°C, significant at the 99% confidence level.

**Keywords**

Minimum temperature, trend analysis, Climate change scenario, Long term trends.

**Introduction**

Minimum temperature plays a crucial role in agriculture, influencing crop growth, development, and overall productivity. It affects several physiological processes in plants, including respiration, photosynthesis, and flowering. Warmer minimum temperatures can increase plant respiration rates, which can reduce the energy available for growth and ultimately lower yields. Crops such as wheat, rice, and maize are particularly sensitive to night time temperatures; elevated minimum temperatures during critical growth phases, like flowering or grain-filling, can lead to reduced grain quality, reduction in yields, and shorter growing seasons.

In addition, minimum temperature impacts the length of frost-free periods, essential for the cultivation of temperature sensitive crops. If minimum temperatures rise, it may reduce the risk of frost damage, potentially extending the growing season in some areas. However, in warmer climates, higher minimum temperatures can also stress plants, increase pest populations, and reduce the effectiveness of certain crop management practices. Monitoring minimum temperature trends helps farmers make informed decisions, such as choosing resilient crop varieties, altering planting schedules, and adjusting water and nutrient management to optimize yield and maintain crop quality under changing climate conditions.

Global studies have consistently observed a warming trend in both minimum and maximum temperatures, with minimum temperatures rising at a faster rate. Karl et al. (1993) found that from 1951 to 1990, minimum temperatures increased by 0.84°C, while maximum temperatures only rose by 0.28°C. This trend of rising minimum temperatures is also noted in various regions, including Europe (Weber et al., 1997), China (Qian & Lin, 2004), and Turkey (Turkes & Sumer, 2004). Similarly, Karl and Easterling (1999) noticed that from 1951 to 1990, global average daily mean temperatures increased by 0.28°C during the day, whereas minimum temperatures rose significantly by 0.84°C, indicating a threefold increase in night time warming compared to daytime warming. These global patterns suggest that climate change has a distinct impact on night time temperatures, with significant implications for ecological and human systems that depend on nocturnal cooling.

In India, multiple studies have documented steady increases in both maximum and minimum temperatures over the last century. Hingane et al. (1985) found a notable warming trend in surface air temperatures from 1901 to 1982. Kothawale and Rupa Kumar (2005) later expanded on this, revealing accelerated warming in both daytime and night time temperatures from 1971 to 2003. Further analysis by Srivastava et al. (2017) revealed that between 1901 and 2010, annual maximum temperatures in India increased by 1.0°C per century, while mean temperatures rose by 0.6°C per century. Minimum temperatures, however, showed a more modest increase of 0.18°C per century, indicating that maximum temperatures in India are warming at a faster rate. Seasonal analyses made by; Kothyari and Singh (1996), along with Kothawale and Kumar (2005) and Rao et al. (2005), reported that post-monsoon minimum temperatures have been rising at 0.012°C per year, whereas minimum temperatures during the monsoon season have decreased at a rate of 0.002°C per year from 1914 to 2003.

Several regional studies within India offer a more nuanced view of temperature and rainfall trends. Palte et al. (2016) examined temperature changes across 16 districts in Arunachal Pradesh, finding that minimum daily temperatures have risen, particularly during the post-monsoon season, followed by the monsoon, with the least warming observed in the pre-monsoon season. In Odisha, Panda and Sahu (2019) found that annual maximum and minimum temperatures are trending upward; however, during the monsoon, both maximum and minimum temperatures have shown a decreasing trend. In Mumbai, Nair and Hosalikar (2013) observed an increase in the frequency of winter hot days, with significant rates of 2.0 days per decade at Colaba and 1.5 days per decade at Santacruz, reflecting greater temperature variability. Gadgil and Dhorde (2005) documented contrasting seasonal changes in Pune, noting a decrease in winter temperatures and a warming trend during the monsoon season. Studies across South Asia also showed the influence of urbanization on temperature trends. Klein Tank et al. (2006) found significant climate variability in central and south Asia, while Qian and Lin (2004) and Chung et al. (2004) reported that urbanization in China and Korea influenced temperature trends. Similarly, Chow (1986) found that urban climate in Shanghai has affected local weather patterns.

Beyond India, regional studies in Southwest Iran have shown similar trends, with Zarenistanak et al. (2014) observing significant summer and spring warming from 1950 to 2007. In East Asia, Fujibe (1995) noted century-long warming trends in Japan, linking these changes with population growth and urban expansion, which influence daily temperature ranges.

The impact of climate change extends beyond temperature, affecting water resources, agricultural productivity, and increasing the risks of droughts and floods. Pal and Mishra (2017) noted that long-term shifts in temperature and precipitation patterns directly influence water availability, exacerbating droughts and flood risks. Singh et al. (2013) emphasized that rainfall and temperature are fundamental climate parameters, essential for maintaining environmental conditions and sustaining agriculture. Studies such as those by Fischer and Ceppi (2012) and Babar and Ramesh (2013) focused the importance of regional analyses, underscoring the need for localized adaptation strategies to mitigate climate impacts. Non-parametric methods like the Mann–Kendall test (Mann, 1945; Kendall, 1975) are frequently applied in these analyses, enabling researchers to identify trends and develop targeted responses to climate variability (Jain & Kumar, 2012).

Sarkar and Gadgil (2005) reported minor seasonal decreases in Nagpur (C) minimum temperatures over the period from 1961 to 1995. During winter and summer, the minimum temperatures each decreased by 0.3°C, while the monsoon season saw a smaller decline of 0.1°C. The most notable change occurred in the post-monsoon season, with a decrease of 0.6°C.

**Material and Methods**

**Study Area and Data Availability**

The daily minimum temperature data for the period from 1985 to 2024, required for this study, was obtained from ICAR - Central Institute for Cotton Research, Nagpur. This dataset of daily maximum and minimum temperatures was then converted into monthly, seasonal, and annual values for detailed analysis. The Weather Cock15 software developed by CRIDA, Hyderabad was utilized to transform the daily data across these various time scales.

**Trend Analysis of Minimum Temperature**

Trend analysis involves examining changes within a time series over a specified period. In this study, temperature, as an independent weather parameter, was analysed for monthly, seasonal, and annual trends using the Mann-Kendall Test and Sen’s Slope Estimator. The Mann-Kendall Test evaluates the presence of a consistent upward or downward trend, indicated by the normalized test statistic (Z) value. Sen’s Slope Estimator, a non-parametric method, quantifies the rate of change in the trend. Details of both methods are outlined below:

**Mann Kendall method**

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

$S= ∑\_{k-1}^{n}\sum\_{j-k-}^{n}sign(Xj-Xk)$ (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.

$Sign=\left\{\begin{array}{c}+1 if xj – xk> 0\\ 0 if xj – xk= 0\\-1 if xj – xk< 0\end{array}\right.$ (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:**

$Variance \left(S\right)=\frac{(n\left(n-1\right)\left(2n+5\right)-∑\_{p=1}^{p=g}(tp(tp-1)(2tp+5)}{18}$ (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

$Z=\frac{(S+1)}{\sqrt{Variance (S)}}, if S>0$ (4)

$Z=0, if S>0$ (5)

$Z=\frac{(S-1)}{\sqrt{Variance (S)}}, if S<0$ (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).**

$Qt=\frac{Xj-Xk}{j-k},i=1, 2, 3, N j>k $ (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;

$Qt=\left\{\begin{array}{c}Q \frac{N+1}{2} If N is odd \\\frac{1}{2} (Q\frac{N}{2}+Q\frac{N+2}{2} If N is even\end{array}\right.$ (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 discussions**

The trend analysis of minimum temperatures in Nagpur from 1985 to 2024 indicates an overall significant increasing trend. This trend is evident annually, seasonally, and in many individual months, with several periods displaying statistically significant increases.

**Minimum Temperature Trends in Nagpur (1985-2024)**

The time series analysis of minimum temperature trends in Nagpur from 1985 to 2024 reveals a general increasing trend, with varying significance across different periods. The annual increase in minimum temperature over the past 40 years is 0.015°C, which is statistically significant at the 95% confidence level. Both the Southwest (SW) and Northeast (NE) Monsoons show significant increases in minimum temperatures. The SW Monsoon saw a rise of 0.018°C, which is statistically significant at the 95% confidence level, while the NE Monsoon experienced an increase of 0.035°C, also significant at the 95% confidence level.

In terms of seasonal trends, the Winter and Summer seasons show non-significant changes in minimum temperatures. Winter saw an increase of 0.005°C, but this trend is non-significant. Similarly, the Summer observed no change in temperature with a non-significant result, suggesting that temperatures during the summer months have remained stable over the past 40 years.

Sarkar and Gadgil (2005) reported seasonal decreases in Nagpur (C) minimum temperatures over the period from 1961 to 1995. During winter and summer, the minimum temperatures each decreased by 0.3°C, while the monsoon season saw a smaller decline of 0.1°C. The most notable change occurred in the post-monsoon season, with a decrease of 0.6°C. These results are non-significant.

For individual months, August and September stand out as months with the most significant increasing trends. August saw an increase of 0.021°C, which is highly significant at the 99% confidence level, while September experienced an increase of 0.027°C, also significant at the 99% confidence level. These months have shown increases in minimum temperatures.

For instance, January showed no change in temperature, while April and May showed slight decreases in minimum temperatures, but these changes were also non-significant. However, December displayed a statistically significant increase of 0.046°C at the 90% confidence level, indicating an increasing trend in the winter month.

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

The annual minimum temperature for the decade from 1985 to 1994 decreased by 0.014°C, but this trend was found to be non-significant. When examining the monsoon seasons, both the Southwest (SW) Monsoon and Northeast (NE) Monsoon periods showed slight decreases in minimum temperatures. The SW Monsoon saw a decline of 0.025°C, and the NE Monsoon experienced a decrease of 0.033°C, but these trends were both non-significant.

For the seasonal trends, Winter saw a slight decrease of 0.020°C, but this change was non-significant. In Summer, there was a modest increase of 0.033°C, but this too was non-significant.

At individual months, January showed no temperature change, reflecting stable conditions during this month. Similarly, February experienced a small increase of 0.013°C, but this was non-significant. March saw a decrease of 0.075°C, with a non-significant result. In April, the temperature decreased by 0.050°C, but again, this was non-significant.

May recorded a small increase of 0.080°C, but this change was still non-significant. June saw no change in temperature. July had a slight increase of 0.050°C, but the trend was non-significant. August experienced a slight decrease of 0.075°C, but this change was also non-significant. The most notable change occurred in September, which showed a decrease of 0.133°C. This trend is statistically significant at the 90% confidence level.

In October, temperatures increased by 0.140°C, but this trend was non-significant. Similarly, November showed a small increase of 0.033°C, but this was also non-significant. December experienced a slight decrease of 0.167°C, but again, this change was non-significant.

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

The analysis of minimum temperature trends for Nagpur from 1995 to 2004 reveals that the annual minimum temperature increased by 0.050°C, but this trend was non-significant.

The Southwest (SW) Monsoon saw a slight decrease of 0.050°C, but this change was non-significant. Similarly, the Northeast (NE) Monsoon showed no temperature change.

Winter temperatures increased by 0.200°C, but the trend was non-significant. In Summer, there was also an increase of 0.200°C, but this was again non-significant. January and February both recorded increases of 0.200°C, but these changes were non-significant. Similarly, March showed a minimal increase of 0.011°C, but this was non-significant, and May had an increase of 0.200°C, also non-significant.

April stood out as the only month with a significant trend, as the minimum temperature increased by 0.300°C, which was statistically significant at the 95% confidence level.

For the other months, June saw a decrease of 0.150°C, but this was non-significant, and July had a slight increase of 0.050°C, also non-significant. August experienced a slight decrease of 0.067°C, but this change was non-significant. September had a minor increase of 0.014°C, which was non-significant. October saw a decrease of 0.050°C, while November recorded a 0.050°C increase, both of which were non-significant. December experienced a small increase of 0.140°C, but again, this was non-significant.

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

The analysis of minimum temperature trends for Nagpur from 2005 to 2014 reveals that the annual minimum temperature during this period decreased slightly by 0.017°C, but this change was non-significant. Similarly, the Southwest (SW) Monsoon showed no trend, with the temperature remaining unchanged. For the Northeast (NE) Monsoon, the minimum temperature decreased by 0.100°C, but this trend was also non-significant.

Winter temperatures decreased by 0.025°C, though this change was non-significant. Similarly, Summer temperatures decreased by 0.013°C, but this trend were also non-significant.

January recorded a slight increase of 0.100°C, but this change was non-significant. February showed a decrease of 0.100°C, though this was also non-significant. March had a small decrease of 0.050°C, which was non-significant, and April experienced a slight decline of 0.012°C, with a non-significant trend. May saw an increase of 0.133°C, but this was non-significant, as were the changes in June (-0.033°C) and July (+0.025°C).

In August, there was no change in temperature, and September had a small decrease of 0.037°C, which was non-significant. October experienced a slight increase of 0.063°C, but this was also non-significant, and November had a 0.060°C decrease, which was non-significant. However, December showed a significant decrease of 0.250°C at the 95% confidence level.

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

The analysis of minimum temperature trends in Nagpur for the period from 2015 to 2024 reveals a general increase in minimum temperatures. The annual minimum temperature increased by 0.167°C over the 10-year period, which was significant at the 90% confidence level. This suggests a clear increasing trend in Nagpur’s minimum temperatures during this period.

During the Southwest Monsoon (SW), the temperature increase was 0.075°C, but this change was non-significant. In contrast, the Northeast Monsoon (NE) showed a significant increase of 0.320°C, which was significant at the 90% confidence level.

For the winter season, minimum temperatures increased by 0.233°C, but this change was non-significant. Similarly, the summer season saw an increase of 0.075°C, which was also non-significant.

January experienced a significant increase of 0.463°C, which was significant at the 90% confidence level. February had a small increase of 0.067°C, but it was non-significant. March saw an increase of 0.163°C, but like February, the trend was non-significant.

In April, there was no change in minimum temperatures, indicating no significant trend. Similarly, May showed a slight decrease of 0.083°C, but this change was non-significant. June had a minor increase of 0.017°C, which was non-significant. Both July and August showed increases of 0.080°C and 0.043°C, respectively, but these trends were also non-significant.

In September, the increase in minimum temperature was 0.083°C, but it remained non-significant. October showed no change. November saw an increase of 0.200°C, but this was non-significant. December, however, experienced the largest increase of 0.500°C, which was highly significant at the 99% confidence level.

|  |
| --- |
| **Table- 1. Times series wise trends statistics of Minimum temperature for the period from 1985-2024 at Nagpur** |
| **Sr. No.** | **Times Series** | **Q****(Sen’s slope)** | **Trends and****significance** | **Test Z****(Mann-Kendall test)** |
|  | Annual | 0.015 | ↑\*( Significant) | 2.28 |
|  | SW Monsoon | 0.018 | ↑\*( Significant) | 2.33 |
|  | NE Monsoon | 0.035 | ↑\*( Significant) | 2.07 |
|  | Winter | 0.005 | ↑(NS) | 0.42 |
|  | Summer | 0.000 | ↑(NS) | 0.16 |
|  | January | 0.000 | ↓(NS) | -0.02 |
|  | February | 0.013 | ↑(NS) | 0.57 |
|  | March | 0.017 | ↑(NS) | 1.36 |
|  | April | -0.004 | ↓(NS) | -0.19 |
|  | May | -0.012 | ↓(NS) | -0.56 |
|  | June | 0.003 | ↑(NS) | 0.27 |
|  | July | 0.009 | ↑(NS) | 1.26 |
|  | August | 0.021 | ↑\*\*\*( Significant) | 3.31 |
|  | September | 0.027 | ↑\*\*\*( Significant) | 4.08 |
|  | October | 0.025 | ↑(NS) | 1.35 |
|  | November | 0.033 | ↑(NS) | 1.60 |
|  | December | 0.046 | ↑+( Significant) | 1.80 |
| ↑ : 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 Minimum temperature for the period from 1985 to 1994 at Nagpur** |
| **Sr. No.** | **Times Series** | **Q****(Sen’s slope)** | **Trends and****significance** | **Test Z****(Mann-Kendall test)** |
|  | Annual | 0.015 | ↑\*( Significant) | 2.28 |
|  | SW Monsoon | 0.018 | ↑\*( Significant) | 2.33 |
|  | NE Monsoon | 0.035 | ↑\*( Significant) | 2.07 |
|  | Winter | 0.005 | ↑(NS) | 0.42 |
|  | Summer | 0.000 | ↑(NS) | 0.16 |
|  | January | 0.000 | ↓(NS) | -0.02 |
|  | February | 0.013 | ↑(NS) | 0.57 |
|  | March | 0.017 | ↑(NS) | 1.36 |
|  | April | -0.004 | ↓(NS) | -0.19 |
|  | May | -0.012 | ↓(NS) | -0.56 |
|  | June | 0.003 | ↑(NS) | 0.27 |
|  | July | 0.009 | ↑(NS) | 1.26 |
|  | August | 0.021 | ↑\*\*\*( Significant) | 3.31 |
|  | September | 0.027 | ↑\*\*\*( Significant) | 4.08 |
|  | October | 0.025 | ↑(NS) | 1.35 |
|  | November | 0.033 | ↑(NS) | 1.60 |
|  | December | 0.046 | ↑+( Significant) | 1.80 |
| ↑ : 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 Minimum temperature for the period from 1995 to 2004 at Nagpur** |
| **Sr. No.** | **Times Series** | **Q****(Sen’s slope)** | **Trends and****significance** | **Test Z****(Mann-Kendall test)** |
|  | Annual | 0.015 | ↑\*( Significant) | 2.28 |
|  | SW Monsoon | 0.018 | ↑\*( Significant) | 2.33 |
|  | NE Monsoon | 0.035 | ↑\*( Significant) | 2.07 |
|  | Winter | 0.005 | ↑(NS) | 0.42 |
|  | Summer | 0.000 | ↑(NS) | 0.16 |
|  | January | 0.000 | ↓(NS) | -0.02 |
|  | February | 0.013 | ↑(NS) | 0.57 |
|  | March | 0.017 | ↑(NS) | 1.36 |
|  | April | -0.004 | ↓(NS) | -0.19 |
|  | May | -0.012 | ↓(NS) | -0.56 |
|  | June | 0.003 | ↑(NS) | 0.27 |
|  | July | 0.009 | ↑(NS) | 1.26 |
|  | August | 0.021 | ↑\*\*\*( Significant) | 3.31 |
|  | September | 0.027 | ↑\*\*\*( Significant) | 4.08 |
|  | October | 0.025 | ↑(NS) | 1.35 |
|  | November | 0.033 | ↑(NS) | 1.60 |
|  | December | 0.046 | ↑+( Significant) | 1.80 |
| ↑ : 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 Minimum temperature for the period from 2005 to 2014 at Nagpur** |
| **Sr. No.** | **Times Series** | **Q****(Sen’s slope)** | **Trends and****significance** | **Test Z****(Mann-Kendall test)** |
|  | Annual | 0.015 | ↑\*( Significant) | 2.28 |
|  | SW Monsoon | 0.018 | ↑\*( Significant) | 2.33 |
|  | NE Monsoon | 0.035 | ↑\*( Significant) | 2.07 |
|  | Winter | 0.005 | ↑(NS) | 0.42 |
|  | Summer | 0.000 | ↑(NS) | 0.16 |
|  | January | 0.000 | ↓(NS) | -0.02 |
|  | February | 0.013 | ↑(NS) | 0.57 |
|  | March | 0.017 | ↑(NS) | 1.36 |
|  | April | -0.004 | ↓(NS) | -0.19 |
|  | May | -0.012 | ↓(NS) | -0.56 |
|  | June | 0.003 | ↑(NS) | 0.27 |
|  | July | 0.009 | ↑(NS) | 1.26 |
|  | August | 0.021 | ↑\*\*\*( Significant) | 3.31 |
|  | September | 0.027 | ↑\*\*\*( Significant) | 4.08 |
|  | October | 0.025 | ↑(NS) | 1.35 |
|  | November | 0.033 | ↑(NS) | 1.60 |
|  | December | 0.046 | ↑+( Significant) | 1.80 |
| ↑ : 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 Minimum temperature for the period from 2015 to 2024 at Nagpur** |
| **Sr. No.** | **Times Series** | **Q****(Sen’s slope)** | **Trends and****significance** | **Test Z****(Mann-Kendall test)** |
|  | Annual | 0.015 | ↑\*( Significant) | 2.28 |
|  | SW Monsoon | 0.018 | ↑\*( Significant) | 2.33 |
|  | NE Monsoon | 0.035 | ↑\*( Significant) | 2.07 |
|  | Winter | 0.005 | ↑(NS) | 0.42 |
|  | Summer | 0.000 | ↑(NS) | 0.16 |
|  | January | 0.000 | ↓(NS) | -0.02 |
|  | February | 0.013 | ↑(NS) | 0.57 |
|  | March | 0.017 | ↑(NS) | 1.36 |
|  | April | -0.004 | ↓(NS) | -0.19 |
|  | May | -0.012 | ↓(NS) | -0.56 |
|  | June | 0.003 | ↑(NS) | 0.27 |
|  | July | 0.009 | ↑(NS) | 1.26 |
|  | August | 0.021 | ↑\*\*\*( Significant) | 3.31 |
|  | September | 0.027 | ↑\*\*\*( Significant) | 4.08 |
|  | October | 0.025 | ↑(NS) | 1.35 |
|  | November | 0.033 | ↑(NS) | 1.60 |
|  | December | 0.046 | ↑+( Significant) | 1.80 |
| ↑ : 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. |

**Conclusions**

The trend analysis of minimum temperatures in Nagpur from 1985 to 2024 reveals an overall significant warming pattern, particularly evident on an annual basis and during specific monsoon seasons. The annual minimum temperature increased by 0.015°C each year, significant at the 95% confidence level, with both the Southwest (0.018°C) and Northeast (0.035°C) Monsoons showing significant increases at the same confidence level. Monthly analysis shows that August and September had the most pronounced trends, with temperature rises of 0.021°C and 0.027°C, respectively, both highly significant at the 99% level, while December also showed a significant increase of 0.046°C at the 90% confidence level.

When examined by decade, distinct patterns emerged: between 1985 and 1994, September experienced a significant decrease of 0.133°C at the 90% confidence level; from 1995 to 2004, April showed a significant warming of 0.300°C at the 95% level. In the period 2005 to 2014, December saw a significant cooling trend of 0.250°C at the 95% confidence level. The most recent decade, 2015 to 2024, exhibited a notable warming trend with the annual minimum temperature increasing by 0.167°C at the 90% level. January displayed a substantial rise of 0.463°C (90% confidence), and December saw the largest increase of 0.500°C, highly significant at the 99% confidence level. Additionally, the Northeast Monsoon in this period showed a marked increase of 0.320°C at the 90% level.

**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. Babar, S. F., & Ramesh, H. (2013). Analysis of Southwest Monsoon Rainfall Trend Using Statistical Techniques over Nethravathi Basin. International Journal of Advanced Technology in Civil Engineering, 2(1), 2231-5721.
2. Chow, S. D. (1986). Some aspects of the urban climate of Shanghai, in: Urban climatology and its applications with special regard to tropical areas. World Meteorological Organization No. 652, 87-109.
3. Chung, U., Choi, J., & Yun, J. I. (2004). Urbanization effect on the observed change in mean monthly temperatures between 1951–1980 and 1971–2000 in Korea. Climatic Change, 66, 127–136.
4. Fischer, A. M., & Ceppi, P. (2012). Revisiting Swiss Temperature Trends 1959–2008. International Journal of Climatology, 32(2), 203–213.
5. Fujibe, F. (1995). Temperature rising trends at Japanese cities during the last hundred years and their relationships with population, population increasing rates and daily temperature ranges. Papers in Meteorology and Geophysics, 46, 35–55.
6. Gadgil, A., & Dhorde, A. (2005). Temperature trends in twentieth century at Pune, India. Atmospheric Environment, 35, 6550–6556.
7. Hingane, L. S., Rupa Kumar, K., & Ramana Murty, V. Bh. (1985). Long-term trends of surface air temperature in India. Journal of Climatology, 5, 521–528.
8. Jain, S. K., & Kumar, V. (2012). Trend Analysis of Rainfall and Temperature Data for India. Current Science, 102, 37–42.
9. Karl, T. R., & Easterling, D. R. (1999). Climate extremes: Selected review and future research directions. Climatic Change, 42, 309–325.
10. 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.
11. Kendall, M. G. (1975). Rank Correlation Methods (4th ed.). Charles Griffin, London.
12. Klein Tank, A. M. G., et al. (2006). Changes in daily temperature and precipitation extremes in central and south Asia. Journal of Geophysical Research, 111(D16105), doi:10.1029/2005JD006316.
13. Kothawale, D. R., & Kumar, K. R. (2005). On the recent changes in surface temperature trends over India. Geophysical Research Letters, 32(1), L01403.
14. Kothawale, D. R., & Rupa Kumar, K. (2005). On the recent changes in surface temperature trends over India. Geophysical Research Letters, 32(L18714), doi:10.1029/2005GL023528.
15. Kothyari, U., & Singh, V. P. (1996). Rainfall and temperature trends in India. Hydrological Processes, 10(3), 357–372.
16. Mann, H. B. (1945). Non-Parametric Tests Against Trend. Econometrica, 13, 163–171.
17. 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.
18. 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.
19. 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, e932. https://doi.org/10.1002/asl.932
20. Qian, W., & Lin, X. (2004). Regional trends in recent temperature indices in China. Climate Research, 27, 119–134.
21. Sarkar, J., and Gadgil, A. S., (2005). Long-term variation of surface temperature in the Vidarbha region. Mausam, 56 (3), 698-702.
22. Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association, 63, 1379–1389.
23. Singh, O., Arya, P., & Chaudhary, B. S. (2013). On Rising Temperature Trends at Dehradun in Doon Valley of Uttarakhand, India. Journal of Earth System Science, 122, 613–622.
24. Srivastava, A. K., Kothawale, D. R., & Rajeevan, M. N. (2017). Observed climate variability and change over the Indian region. In Climate Change and Variability in India (pp. 17–36). Springer.
25. Nair, S., & Hosalikar, K. S. (2013). Trends in surface temperature variability over Mumbai. MAUSAM, 64(2), 251–264.
26. Turkes, M., & Sumer, U. M. (2004). Spatial and temporal patterns of trends and variability in diurnal temperature ranges of Turkey. Theoretical and Applied Climatology, 77, 195–227.
27. Weber, R. O., Talkner, P., Auer, I., Böhm, R., Gajić-Čapka, M., Zaninović, K., & Brázdil, R. F. P. (1997). 20th century changes of temperature in the mountain regions of Central Europe. Climatic Change, 36, 327–344.
28. Zarenistanak, M., Dhorde, A. G., & Kripalani, R. H. (2014). Trend Analysis and Change Point Detection of Annual and Seasonal Precipitation and Temperature Series over Southwest Iran. Journal of Earth System Science, 123(2), 281–295.