A Statistical Analysis of Temperature Variability and Seasonal Pattern in India

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Abstract:

Temperature variability and changing temperature patterns are important aspects of climate variability, with implications for environmental conditions and climate-related planning. This study statistically examines annual temperature variability and seasonal patterns in India during the period 2010–2024. The analysis is based on the India Meteorological Department (IMD) dataset All India Monthly and Seasonal Mean Temperature (°C) Series. Annual temperature behaviour was examined using descriptive statistics, year-to-year changes, and linear trend analysis, while seasonal patterns were assessed using descriptive measures of central tendency and variability across Winter, Pre-Monsoon, Monsoon, and Post-Monsoon seasons. The findings highlight the coexistence of a broader increasing temperature tendency with short-term fluctuations and distinct seasonal characteristics in India during the study period. The study demonstrates the usefulness of basic statistical methods for summarizing and examining temperature variability and provides a foundation for more detailed investigations of India's temperature patterns.

1. Introduction:

Climate change and climate variability have emerged as major environmental concerns across the world, with changes in temperature being one of the most prominent indicators of a changing climate. Increasing concentrations of greenhouse gases due to human activities have contributed to changes in the Earth's climate at both global and regional scales. Observational evidence has shown a long-term increase in global temperature.(Arora et al., 2005)

Temperature is an important climatic variable because it reflects the thermal state of the Earth's surface and provides useful information about changes occurring within the climate system. Changes in temperature may be associated with both large-scale climatic influences and regional factors such as urbanization, industrialization, and changes in land-use patterns. Furthermore, changes in temperature can influence other climatic processes, including precipitation, evaporation, and wind patterns. Therefore, analysing temperature behaviour provides an important basis for understanding climate variability and change.(Tomar et al., 2017)

Although global warming represents a broad-scale phenomenon, its manifestation is not uniform across geographical regions. Different regions may experience different magnitudes and patterns of temperature change because of variations in topography, climatic conditions, land characteristics, and other regional influences. India is particularly important in this context because of its diverse geographical features and climatic zones.(Prusty et al., 2025)

Studies conducted over India have reported increasing tendencies in annual as well as maximum and minimum temperatures. However, temperature changes are not limited to changes in annual mean values. The spatial and temporal variability of temperature provides additional information about how climatic conditions are changing. The changes in temperature can have consequences for agriculture, energy demand, water resources, human health, and other socio-economic activities.(Kothawale et al., 2010; Revadekar et al., 2012)

Seasonal analysis is particularly relevant for understanding temperature behaviour in India. Temperature does not remain constant throughout the year, and different seasons experience distinct climatic conditions. The pre-monsoon period, for example, is recognized as the warmest season in India, and variations in temperature during particular seasons may have important implications for human health and other socio-economic activities. (Kothawale et al., 2010) The diverse geographical and climatic characteristics of India make continued analysis of temperature variability and seasonal behaviour valuable, particularly when examining a defined recent period using consistent national-level data.(Prusty et al., 2025)

The present study focuses on the statistical analysis of temperature variability and seasonal patterns in India. The analysis focuses on examining the overall variability of temperature, identifying seasonal patterns, assessing year-to-year changes, and examining the overall pattern or trend during the study period. Descriptive statistical measures and simple trend analysis are employed to provide a clear statistical understanding of temperature behaviour. The study is intended to provide a concise statistical assessment of recent temperature behaviour in India and to contribute to a better understanding of how temperature varies across years and seasons.

2. Literature Review:

Several studies used Mann–Kendall and Sen's slope methods to examine long-term temperature and rainfall trends across India using annual, seasonal and monthly data. (Tomar et al., 2017;Nandi et al., 2026) examined monthly, seasonal and annual temperature behaviour at Agartala and Kailashahar for the period 1969–2014. Analysing climate variables across multiple time scales gives much clearer picture instead of annual averages. These bodies of research indicate that seasonal analysis can reveal patterns that annual averages alone may not fully describe changes in temperature behaviour. (Mondal et al., 2015; Kerketta & Singh, 2020)

(Kothawale & Rupa Kumar, 2005) examined all-India temperature trends using data covering 1901–2003. The studies examined shifts in how maximum and minimum temperatures contributes to overall warming reveal distinct seasonal changes, particularly during the monsoon. These findings demonstrate that temperature trends can differ according

to the period and season considered. The study (Kothawale et al., 2010) noted that the pre-monsoon period is the warmest part of the year over much of the region and that changes in daily temperature behaviour can have important implications for human health and other socio-economic activities.

(Arora et al., 2005) investigated temperature trends using observations from 125 stations distributed throughout India and analysed annual and seasonal temperature series using the Mann–Kendall test. The studies emphasized that temperature and climate change can have different effects at regional scales and that information on temperature trends is important for understanding climate-related impacts across different geographical and climatic regions over India. India's heterogeneous topography and diverse climatic zones can produce different patterns of climatic variability across regions. (Prusty et al., 2025; Tomar et al., 2017)

The reviewed literature demonstrates the application of both descriptive and inferential statistical approaches to climate data. Overall, the existing literature provides strong evidence that temperature analysis at different temporal scales is essential for understanding climate variability in India. However, the reviewed studies differ considerably in their geographical coverage, study periods, temperature variables and analytical objectives. The present study builds upon this literature by bringing together recent annual and seasonal temperature behaviour within a single national-level analysis for 2010–2024.

3. Research Methodology:

3.1 Research Design:

The present study acquires a quantitative, descriptive and analytical research design based on secondary time-series data. The study is observational in nature and focuses on examining temperature variability and seasonal patterns in India over the selected study period. The analysis is designed to provide a concise statistical assessment of annual and seasonal temperature behaviour without employing complex forecasting or advanced climate-modelling techniques.

The study uses temperature data for the period 2010–2024, providing a 15-years period for examining recent variations and patterns in India's temperature. The data are analysed using the Python programming environment, which is used for data organization and statistical calculations.

3.2 Research Objectives:

The study is guided by the following objectives:

1. To examine the overall variability in India's annual temperature during 2010 – 2024.

2. To examine year-to-year changes in India's annual temperature during 2010–2024.
3. To assess the overall linear trend in India's annual temperature during the study period.
4. To analyse the seasonal pattern of temperature in India during the study period.
5. To compare temperature variability across the four seasons.

3.3 Data Source and Collection:

The study is based entirely on secondary data obtained from the India Meteorological Department (IMD). The dataset used is titled All India Monthly and Seasonal Mean Temperature (°C) Series. The dataset contains temperature observations for India at monthly and seasonal levels over a long historical period.

The dataset provides monthly, seasonal and annual mean temperature observations. The seasonal observations correspond to Winter (January–February), Pre-Monsoon (March–May), Monsoon (June–September), and Post-Monsoon (October–December), as defined in the IMD dataset.

For the present study, observations corresponding to the period 2010–2024 were selected for analysis. The selection of this period enables the study to focus on relatively recent temperature behaviour while maintaining a consistent period of observation. The year 2025 is not included in the present analysis and may be considered in future research when appropriate data become available.

4. Data Analysis and Interpretation:

Table: 1. Annual Descriptive Statistics

Statistic	Value (°C)
Mean	25.30108667
Standard Deviation	0.242927458
Minimum	24.9473
Maximum	25.7431
Range	0.7958

Interpretation:

The descriptive analysis of annual temperature for India during 2010–2024 indicates a mean annual temperature of 25.30°C, with a standard deviation of 0.24°C. The observed annual mean temperature ranged from 24.95°C to 25.74°C, resulting in an overall range of 0.80°C. Overall, the descriptive statistics indicate limited dispersion in annual mean temperature during the study period.

Table: 2. Year-to-year Annual temperature changes

Year	Annual Temperature	Annual Change in Temperature
2010	25.4804	-
2011	24.9695	-0.5109
2012	24.9473	-0.0222
2013	24.993	0.0457
2014	25.0679	0.0749
2015	25.281	0.2131
2016	25.6305	0.3495
2017	25.4721	-0.1584
2018	25.3285	-0.1436
2019	25.2692	-0.0593
2020	25.1274	-0.1418
2021	25.3097	0.1823
2022	25.4295	0.1198
2023	25.4672	0.0377
2024	25.7431	0.2759

Interpretation:

The year-to-year analysis reveals considerable fluctuations in India's annual mean temperature during 2010–2024 rather than a continuous increase. The largest decrease was observed between 2010 and 2011, when the annual mean temperature declined by 0.51°C, while the largest increase occurred between 2015 and 2016, with an increase of 0.35°C. Annual temperature increased continuously from 2012 to 2016, followed by a declining phase from 2017 to 2020. A renewed increasing pattern was observed from 2021 to 2024, with temperature increasing in each successive year and reaching the highest observed value of 25.74°C in 2024. These results demonstrate the presence of considerable year-to-year fluctuations within the study period.

Table: 3. Annual linear trend

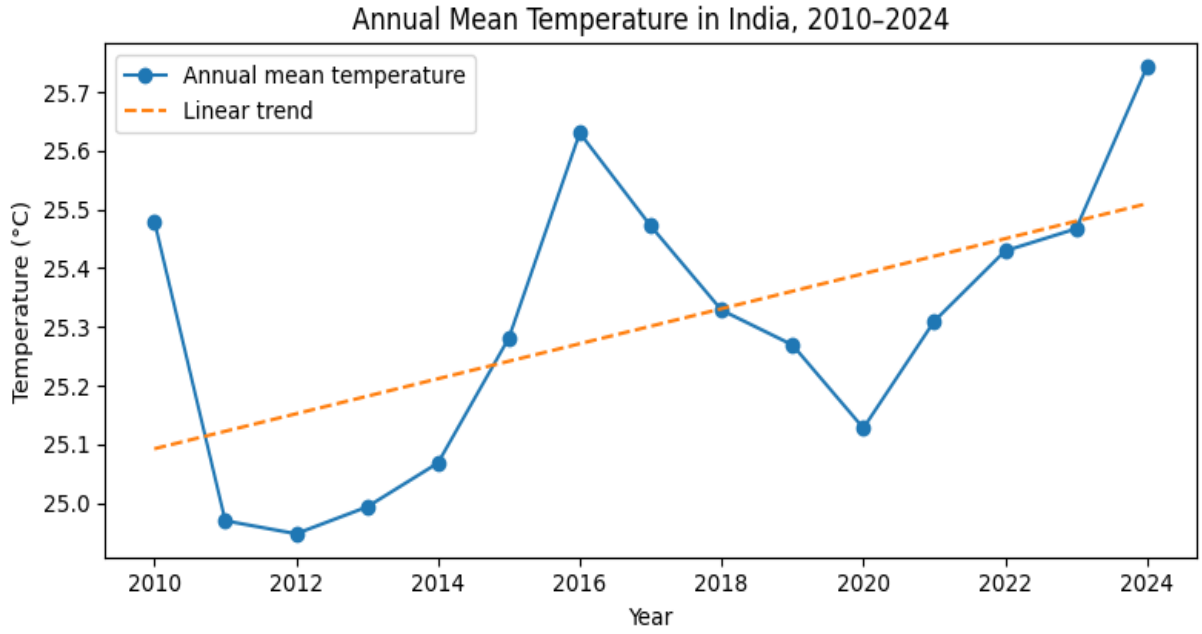
Measure	Value
Slope (°C per year)	0.029842143
Intercept	-34.89051548
R-squared	0.301812202
P-value	0.03389945
Standard error of slope	0.01258856

Interpretation:

Linear regression analysis indicated a positive trend in India's annual mean temperature during 2010–2024. The estimated slope was 0.0298°C per year, corresponding to an increase of approximately 0.30°C per decade. The positive slope was statistically significant at the 5% level ($p = 0.0339$), indicating evidence of an overall increasing linear trend in annual mean

temperature during the study period. The coefficient of determination R2 was 0.3018, suggesting that approximately 30.2% of the observed variation in annual temperature was explained by the linear relationship with time. These results indicate that although substantial year-to-year fluctuations occurred, as observed in the preceding analysis, the overall temperature series exhibited a statistically significant positive linear trend during the study period.

Figure 1. Annual mean temperature and fitted linear trend in India, 2010–2024.



Interpretation:

The annual temperature series exhibited considerable interannual fluctuations; however, the fitted linear trend showed an overall upward direction (Figure 1). This visual pattern is consistent with the statistically significant positive slope obtained from the linear regression analysis (Table 3).

Table: 4. Seasonal Descriptive Statistics

Season	Mean (°C)	SD (°C)	Minimum (°C)	Maximum (°C)	Range (°C)
Winter Season	19.53448	0.482602	18.8347	20.4229	1.5882
Pre- Monsoon Season	27.986827	0.531843	27.2939	28.9272	1.6333
Monsoon Season	28.219627	0.251032	27.7906	28.7166	0.926
Post-Monsoon season	22.592753	0.319299	22.1172	23.1724	1.0552

Interpretation:

The seasonal descriptive analysis revealed distinct differences in temperature levels and variability across the four seasons during 2010–2024. The Monsoon Season recorded the highest mean temperature (28.22°C), followed closely by the Pre-Monsoon Season (27.99°C), whereas Winter recorded the lowest mean temperature (19.53°C). In terms of variability, the Pre-Monsoon Season exhibited the highest standard deviation (0.53°C), followed by Winter (0.48°C), while the Monsoon Season showed the lowest standard deviation (0.25°C). The range also indicated comparatively greater variability during the Pre-Monsoon and Winter seasons and lower variability during the Monsoon and Post-Monsoon seasons. Thus, the results demonstrate that seasonal differences exist not only in the level of temperature but also in the magnitude of interannual variability. Interestingly, the Monsoon Season had the highest average temperature but the lowest variability among the four seasons. Based on standard deviation and range, pre-monsoon exhibited the greatest variability, whereas Monsoon showed the least.

5. Conclusion:

This study provided a statistical assessment of temperature variability and seasonal patterns in India during 2010–2024. The analysis indicates that India's temperature during the study period was characterized by an overall increasing tendency, while also exhibiting noticeable year-to-year fluctuations. The seasonal analysis further demonstrated clear differences in temperature levels and variability across the four seasons, highlighting the distinct nature of India's seasonal temperature behaviour.

The findings suggest that temperature change over the study period cannot be understood solely through its long-term direction; the associated interannual variability and seasonal differences are also important components of the observed temperature pattern. The study demonstrates how basic statistical methods can effectively summarize and examine temperature behaviour using observed climate data.

As a preliminary statistical assessment, this study provides a foundation for more detailed investigations of India's temperature dynamics. Future research may extend the analysis to longer historical periods, monthly temperature behaviour, temperature extremes, spatial variations, and more advanced statistical trend and variability techniques.

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