



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(2): 307-311
Received: 02-10-2025
Accepted: 04-12-2026

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Climatic and its variability in Tarai regions of Uttar Pradesh

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i2e.4871>

Abstract

This study uses a 31-year dataset (1993-2023) of daily temperature and rainfall data from NASA power data to examine the long-term climate variability in the Tarai region of Uttar Pradesh, India. Using statistical methods like the Mann-Kendall test and Sen's slope estimator, the investigation sought to assess seasonal and annual changes in maximum and minimum temperatures as well as rainfall. The findings showed that the rainfall minimum temperature is trending upward while the maximum temperature is trending downward. This regional climate assessment adds to the larger conversation on climate adaptation and sustainable agriculture in the area.

Keywords: Climatic variability, Tarai region, Uttar Pradesh, weather parameters

Introduction

The Tarai region of Uttar Pradesh is a fertile, marshy lowland belt (10-20 km wide) stretching along the Himalayan foothills, acting as a transition zone with rich biodiversity and alluvial soil. It is a major agricultural hub for sugarcane, rice, and wheat, supported by high rainfall.

Global temperatures have risen by roughly 0.5-0.6 °C, according to observational data, and are expected to rise by an additional 0.3-0.7 °C by 2035 (Jaswal *et al.*, 2015) ^[11]. Anthropogenic changes to land cover, vegetation dynamics, and surface moisture regimes are the main causes of these warming trends, which are ascribed to changes in radiative forcing mechanisms (Thomas *et al.*, 2012) ^[13]. The examination of long-term patterns and fluctuations in temperature and precipitation is a crucial aspect of climate change study. Statistically significant changes in these characteristics have been reported in many studies around the world, including the United States (Vose *et al.*, 2017), India (Prasad *et al.*, 2017) ^[14, 15], and Brazil (Rosso *et al.*, 2015) ^[16]. The Intergovernmental Panel on Climate Change (IPCC, 2007) predicts that temperatures in South Asia would increase by 0.5 to 1.2 °C by 2020, 0.88 to 3.16 °C by 2050, and 1.56 to 5.44 °C by 2080. India is expected to warm at a pace of about 0.57 °C per century, which is consistent with worldwide trends (Dash *et al.*, 2007) ^[4].

Unfortunately, increasing human activities like mining, urbanization, deforestation, and so on may affect the territorial climate-balance and, consequently, alter the course and pace of ongoing geomorphic processes, or the modifications to the Earth's surface configuration brought about by physical stresses and chemical reactions.

According to regional estimates, India has warmed by roughly 1.0 °C during the previous century, with considerably larger rises seen in the winter and after the monsoon season (Jain & Kumar, 2012) ^[10]. Maximum temperatures during the 1914-2003 period increased by 0.008 °C ⁻¹ during the monsoon, 0.014 °C ⁻¹ during the post-monsoon, and 0.008 °C ⁻¹ during the yearly periods, according to seasonal assessments conducted at eight locations in the Tarai Region of Uttar Pradesh. According to Subash *et al.* (2011) ^[17], minimum temperatures likewise showed a minor decrease (0.002 °C ⁻¹) during the monsoon season but an increase (0.012 °C ⁻¹) during the post-monsoon season. To guarantee reliable trend detection in climate datasets, such temporal analyses frequently use non-parametric statistical techniques such as the Mann-Kendall test (Mann, 1945; Kendall, 1955) ^[18, 19]. For example, yield reductions of up to 5 million tonnes may occur from a 1 °C increase in mean temperature during the wheat-growing season (Aggarwal, 2007) ^[1].

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However, adaption techniques including changing the dates of planting and choosing crop varieties that can withstand heat have demonstrated promise in reducing these effects.

Precipitation trends also exhibit spatial heterogeneity: the peninsular east and northeastern regions have shown an opposite trend to Northern India, which has seen a decrease in the frequency of heavy rainfall events (Rajeevan *et al.*, 2008; Guhathakurta *et al.*, 2011; Duhan & Pandey, 2013) [20, 8, 6]. Sea-level rise patterns also correspond with worldwide measurements, with the Indian Ocean witnessing an accelerated

rise from 1.7 mm yr⁻¹ (1901-2010) to 3.2 mm yr⁻¹ (1993-2010). Mid-century (2050s) projections predict a temperature increase of 2-4 °C throughout India. In light of this, the current study attempts to evaluate the long-term trend and variability of seasonal and yearly patterns of rainfall and temperature throughout Uttar Pradesh's Tarai Zone. Planning for climate-resilient agriculture and developing localized mitigation and adaptation plans that are sensitive to changing climate threats both benefit greatly from this kind of analysis.

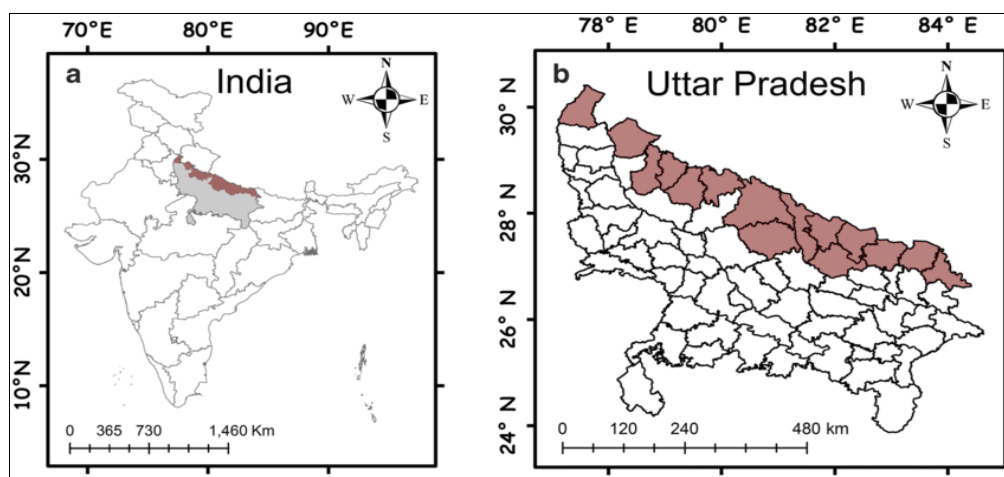


Fig 1: Map of Tarai region Uttar Pradesh

Materials and Methods

Study area and data collection

The Tarai zone in Uttar Pradesh, which roughly lies between latitudes 28.0°N and 36.0°N and longitudes 79.4°E and 81.0°E, was the focus of the current study. The years 1993-2023 were the main focus of the analysis.

Utilizing a 31-year dataset of daily meteorological observations that included rainfall, maximum temperature (Tmax), and minimum temperature (Tmin) obtained from NASA power data, this study looked into long-term trends and variability in area climate. First, using Weather Cock from the Crida website, the daily records were combined into monthly values so that regular seasonal and annual comparisons could be made. Using the MS Excel application software, the statistical analysis was performed with the following parameters:

To assess geographic temporal variability, statistical analysis was performed on the monthly records for each climate variable. For each of the three parameters, descriptive statistics such as the arithmetic mean, standard deviation (SD), and coefficient of variation (CV) were calculated. In particular, the CV provides information about the degree of dispersion in relation to the mean, making it easier to evaluate comparative variability across various seasons and characteristics. (Kaur and Hundal, 2002) [21]

Mean: The mean is the average or the most common value in a collection of numbers

$$\text{Mean} = \sum_{i=1}^n X_i / n$$

Where,

X_i is the data for i^{th} term and n is the total number of data.

(i) Standard Deviation: It is defined as the positive square root of the arithmetic mean of the squares of the deviations of the given values from the arithmetic mean. A measure of a group of values' degree of variance or dispersion is the standard deviation.

$$SD = \frac{\sqrt{\sum (X_i - X_{\text{mean}})^2}}{n - 1}$$

(ii) Coefficient of Variation: The coefficient of variation (CV) is a statistical measure of how individual data points vary about the mean values.

$$CV = SD / \text{Mean} * 100$$

For the purpose of researching the aforementioned climatic parameters and variability in the Tarai region of Uttar Pradesh, statistical parameters such as mean, maximum, minimum, standard deviation, and coefficient of variation for the various weather parameters, such as maximum temperature, minimum temperature, and rainfall, are calculated.

Results and Discussion

Season-wise Analysis of Climatic Parameter of Tarai region (1993-2023): Pilibhit District The present study analysed annual and seasonal climatic parameters of Pilibhit district for the period 1993-2023 using statistical indicators such as mean values, ranges, and inter-annual variability. The results indicate gradual warming along with comparatively higher rainfall and humidity levels, reflecting the moist sub-humid climatic conditions of the Tarai region.

Table 1: Annual trend analysis using Mann Kendall

Parameter	Z value	p-value	Sen's slope	Trend	Significance ($\alpha=0.05$)	Significance ($\alpha=0.01$)
TMax	-0.37	0.70	-0.065	Decreasing	Not Significant	Not Significant
TMin	-0.06	0.94	-0.004	Decreasing	Not Significant	Not Significant
RF	0.30	0.75	16.03	Increasing	Not Significant	Not Significant

Table 2: North East Monsoon trend analysis using Mann kendall

Parameter	Z value	p-value	Sen's slope	Trend	Significance ($\alpha=0.05$)	Significance ($\alpha=0.01$)
TMax	-0.30	0.75	-0.078	Decreasing	Not Significant	Not Significant
TMin	-0.20	0.83	-0.017	Decreasing	Not Significant	Not Significant
RF	0.07	0.94	1.186	Increasing	Not Significant	Not Significant

Table 3: summer season trend analysis using mann kendall

Parameter	Z value	p-value	Sen's slope	Trend	Significance ($\alpha=0.05$)	Significance ($\alpha=0.01$)
TMax	-0.30	0.76	-0.060	Decreasing	Not Significant	Not Significant
TMin	0.031	0.97	0.003	Increasing	Not Significant	Not Significant
RF	0.20	0.83	2.741	Increasing	Not Significant	Not Significant

Table 4: south west monsoon trend analysis

Parameter	Z value	p-value	Sen's slope	Trend	Significance ($\alpha=0.05$)	Significance ($\alpha=0.01$)
TMax	-0.27	0.78	-0.061	Decreasing	Not Significant	Not Significant
TMin	-0.07	0.94	-0.006	Decreasing	Not Significant	Not Significant
RF	0.21	0.83	9.324	Increasing	Not Significant	Not Significant

Table 5: winter season trend analysis using mann kendall

Parameter	Z value	p-value	Sen's slope	Trend	Significance ($\alpha=0.05$)	Significance ($\alpha=0.01$)
TMax	-0.28	0.77	-0.068	Decreasing	Not Significant	Not Significant
TMin	0.058	0.95	0.006	Increasing	Not Significant	Not Significant
RF	0.28	0.78	2.78	Increasing	Not Significant	Not Significant

Temperature Trends

Both maximum and minimum temperatures show a steady increasing tendency across annual and seasonal scales.

- Annual maximum temperature varies approximately between 31.8 °C and 34.6 °C, with a long-term mean close to 33.1-33.5 °C, indicating moderate but consistent warming.
- Annual minimum temperature ranges from about 17.2 °C to 20.6 °C, with higher values observed in recent decades.
- During the summer season, maximum temperature frequently exceeds 38 °C, occasionally reaching 40-41 °C, while minimum temperature generally remains above 22 °C, indicating increasing heat stress.
- In the winter season, minimum temperature shows an increase from nearly 10-11 °C in the early years to around 13-14 °C in recent years, suggesting a reduction in cold intensity.

The concurrent rise in Tmax and Tmin confirms an overall warming trend in Pilibhit district.

Rainfall Characteristics

Rainfall analysis reveals comparatively high totals with substantial inter-annual variability.

- Annual rainfall ranges approximately from 850 mm to 1900 mm, with a long-term mean of about 1350-1450 mm, making Pilibhit one of the wetter districts in the study region.
- Southwest monsoon rainfall, contributing the major share of annual precipitation, varies widely between ~600 mm and ~1500 mm, with an average close to 950-1050 mm.
- Summer rainfall ranges from ~70 mm to ~320 mm, while winter rainfall varies between ~40 mm and ~280 mm,

indicating notable year-to-year fluctuations.

- Northeast monsoon rainfall ranges from approximately ~50 mm to ~300 mm, reflecting frequent post-monsoon rainfall events.

These results indicate high rainfall variability despite overall wetter conditions, increasing the risk of both flooding and short dry spells.

Seasonal Climatic Behaviour

Seasonal analysis highlights distinct climatic behaviour:

- Summer season shows moderate to strong warming combined with relatively high humidity, enhancing heat stress conditions.
- Southwest monsoon season exhibits high rainfall and humidity with large inter-annual variability, increasing the likelihood of flood events.
- Winter season reflects gradual warming through rising minimum temperatures, indicating moderation of cold extremes.

Overall Inference

The numerical and statistical assessment clearly indicates that Pilibhit district has experienced gradual warming along with high and variable rainfall during the period 1993-2023. While temperature trends show a consistent rise, rainfall remains abundant but increasingly variable. These changes increase the region's vulnerability to extreme rainfall events, flooding, and humidity-related stress.

In conclusion, the climatic regime of Pilibhit district is shifting toward a warmer and more variable humid climate, with important implications for agriculture, water management, and climate adaptation strategies in the Terai region.

Table 6: Annual statistical analysis

Parameter	Mean	SD	CV (%)
MAXT(C)	31.93	0.97	3.03
MINT(C)	19.46	0.35	1.82
RF(MM)	1161.13	292.01	25.15

Final Conclusion and Observed Climatic Trends with Numerical Results (1993-2023): Pilibhit District

The present study analysed annual and seasonal climatic parameters of Pilibhit district for the period 1993-2023 using statistical indicators such as mean values, ranges, and inter-annual variability. The results indicate gradual warming along with comparatively higher rainfall and humidity levels, reflecting the moist sub-humid climatic conditions of the Terai region.

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Acknowledgements

We are really appreciative of the many sources of assistance that have enabled this research. Sam Higginbottom University of Agriculture, Technology, and Sciences Prayagraj's resources and response. Colleagues and other researchers' encouragement and support would be greatly valued. Statement of the Author This manuscript benefited greatly from the contributions of both writers. Shraddha Rawat assisted with supervision, while Ritika Singh oversaw database administration and analysis. Both authors also carefully went over and polished the material. Statement on Conflicts of Interest Regarding this paper's publication, the authors state that they have no conflicts of interest.

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