EPH – International Journal of Mathematics and Statistics
ISSN:2208-2212
https://eijms.com/index.php/ms/issue/archive

CLIMATE VARIABILITY AND HYDROCLIMATIC CHANGE IN RANCHI, JHARKHAND, INDIA: TRENDS IN RAINFALL AND TEMPERATURE DURING 2000-2025

[1*]Sandeep Minz, [2]Anamol Kumar Lal, [3]Uma Shankar Singh
[1*]St. Columba's College, Hazaribagh, India-825302, sandeepminz2k10@gmail.com, orchid id: 0009-0003-2572-0354
[2]Simdega College, Simdega, India-83400, lal305400@gmail.com, Orcid-0009-000-7643-0144
[3]I.F.S. (Retd.), U.P., India, Umashankar.87@gmail.com, Orcid-0000-0003-1743-7017
Corresponding author: sandeepminz2k10@gmail.com

ARTICLE INFO

Received: 14/02/2026
Revised: 26/03/2026
Accepted: 10/04/2026
Published:24/04/2026

DOI: https://doi.org/10.69980/6vq1th24
Volume:12, Issue:1, April, 2026

Abstract

Climate change is one of the most severe environmental challenges of the twenty first century that has been affecting the regional climate systems, hydrological processes, ecosystem dynamics and the human livelihoods. Information on long-term climatic variations at the regional scale is needed to facilitate the development of effective adaptation and mitigation strategies. This study examines the variations in monthly climatic parameters of rainfall and temperature over Ranchi District of Jharkhand, India for the period 2000 to 2025. Rainfall variability and dependence on the monsoons, temperature trends and climate anomalies were assessed using annual, seasonal and monthly analysis. The results show that annual rainfall has increased slowly by no more than 22.3 mm per year while mean temperature has increased by no more than 0.038 °C per year. The mean annual rainfall for the study period was 1468.6 mm with almost 81.5% of it falling in the southwest monsoon season. There was large interannual variation, with the highest recorded in 2025 (2553.3 mm) and the lowest was recorded in 2014 (854.7 mm). The data analysis of the temperature showed an increase in mean temperatures during recent years, especially after 2015. The period-wise analysis revealed that 2021 – 2025 had the highest average rainfall and 2021 – 2025 had the highest average temperature. The results presented here suggest the increasing climatic variability and the possible effect of climatic change on the hydroclimatic conditions in the region. The observed changes have implications for agriculture, water resources, forest ecosystems and conservation of biodiversity, and planning for climate adaptation in Jharkhand.

Keywords: Climate Change, Rainfall Variability, Temperature Trend, Monsoon Dynamics, Ranchi, Jharkhand, Climate Adaptation

1. Introduction

Climate change is well known as one of most important environmental issues that impacts natural and human systems internationally. Global energy balances have changed, due to increasing concentrations of greenhouse gases, which has led to an increase in temperature, changes in precipitation, and more severe weather. The IPCC reports a marked increase in global surface temperature over the last century, resulting in substantial impacts on ecosystems, water resources, agriculture and human health.

India's vulnerability to climate variability stems from its reliance on climate dependent monsoon rains and the high climate vulnerability of its population involved in climate sensitive sectors like agriculture and forestry. Variability in distribution of precipitation and temperature can have substantial impacts on crop productivity, water supply, forest health and disaster frequency. Climate change has brought more variability to the climate of eastern India, where Jharkhand is also seeing a rise in climatic fluctuations, thus requiring an assessment of climate change impacts at the regional level.

The Chotanagpur Plateau is an ecologically and socioeconomically significant region with moderate temperature and monsoon dominated rainfall with the city of Ranchi. Significant forest resources are present within the district, and the agricultural economy is dependent upon this resource. The changes in rainfall and temperature have direct impacts on both productivity of agricultural crops and groundwater recharge, biodiversity, and the frequency of forest fires.

Although India is increasingly aware of the effects of climate change, there are still very few long-term studies on climate change effects in Ranchi. The present study is therefore aimed at investigating trends in Rainfall and temperature over extended period and evaluating the effects of the observed climatic changes on sustainability of environment and resource management.

The goal of present study is to examine the long-term climatic changes in Ranchi district by analysing the rainfall and temperature data of the years 2000-2025. In particular, this study analyzes trends in annual rainfall and assesses changes in minimum, maximum and mean temperature over the years. It also analyzes the climate parameters variation on seasonal and monthly scales to explore the level of climatic variability in the region. The study aims to derive evidence of climate change and the impacts on regional climatic conditions by analysing these long-term patterns. Moreover, the research examines the implications of the observed climatic changes for environmental management, sustainable use of the resources and development of climate adaptation strategies in Ranchi and the surrounding areas.

2. Study Area

The Ranchi district lies in central part of Jharkhand state of India between latitude 23°00′–23°50′ N and longitude 84°50′–85°50′ E. The district is the part of the Chotanagpur Plateau with an average elevation of approximately 650 m above mean sea level.

The climate of Ranchi is tropical monsoonic with 3 distinct seasons: summer (March-June), monsoon (June–September) and winter (November–February). The summer season is hot and dry, monsoon season gets significant amount of rainfall from the southwest monsoon system. It is relatively cool and dry in the winter, with cooler weather throughout the area. The rainfall is highly seasonal and over 80% of annual rain falls during monsoon season in Ranchi, thus making the southwest monsoon the most important variable influencing the water availability in the region. The district is endowed with large areas of agriculture, a variety of forest ecosystem and fast growing urban settlements which are significantly affected by climatic conditions. The region is thus vulnerable to changes in climate and climatic variability, which can significantly affect agriculture, water resources, biodiversity, ecosystem function and urban sustainability.

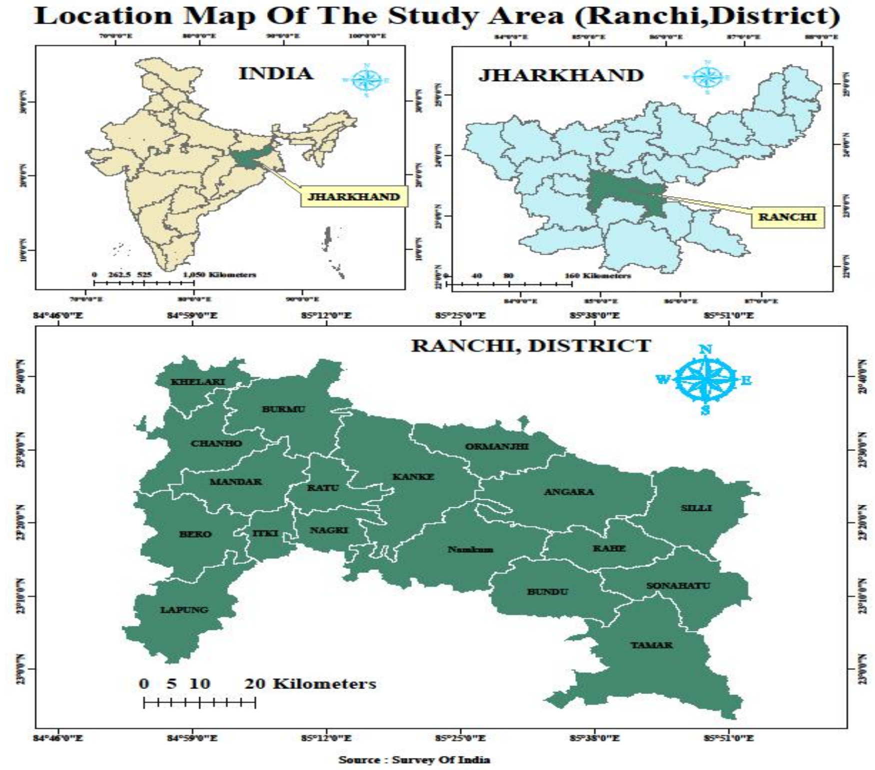

Figure 1: Location map of study area (Ranchi District)

3. Materials and Methods

3.1 Data Collection

Monthly rainfall and temperature data for the Ranchi district for the years 2000-2025 were collected from the meteorological records and analysis of climatic variability and trends in the district was done. The data included monthly precipitation (in mm), minimum, maximum and mean temperature (in °C). The parameters included were chosen as they are the main climatic parameters that affect regional hydrological processes, agricultural productivity, ecosystem functioning, and environmental sustainability. The monthly data were then converted into annual and seasonal data to allow for the analysis of the distribution of rainfall, temperature fluctuations, climatic trends and potential indicators of climate change over the 26 year study period.

3.2 Data Processing

The monthly rainfall and temperature values were added together to give annual totals and season averages to evaluate long-term climatic patterns and trends for analysis. The rainfall was also divided into monsoonal and non-monsoonal rainfall to assess the contribution of southwest monsoon to the annual rainfall.In order to assess the relative contribution of southwest monsoon to the overall annual rainfall rainfalls were further subdivided into monsoonal rainfall (June–Sept.) and non-monsoonal rainfall (Oct–May). This seasonal classification enabled a detailed analysis of the distribution of rainfall and dependence upon the monsoonal activity. Rainfall anomalies were derived by subtracting the annual rainfall from the long-term mean rainfall for study period to identify wet and dry years, and to evaluate variability from the normal climatic condition. Positive anomalies represented years with above-average rainfall while negative anomalies represented years with below-average rainfall. The analyses gave insights into interannual variations in rainfall and into possible changes in rainfall patterns due to climate change.

3.3 Statistical Analysis

Data of rainfall and temperature has been subjected to various statistical and graphical analyses to comprehensively assess the climatic variability and long-term changes at Ranchi location. The data is summarized using descriptive statistics which shows the basic data characteristics of average value, variation, minimum value and maximum value.

Mean Value

The mean value was calculated by adding all observed values and dividing by total number of observations.

Mean = Sum of all observed values / Total number of observations

Rainfall and temperature variations were evaluated by standard deviation (SD) which is a measure of the amount of variation or dispersion from mean value. If standard deviation is high, it means that the data is more spread out from the mean value, and if the standard deviation is low, the data is closer to the mean value.

The standard deviation was calculated using the following formula:

$$SD = \sqrt{\frac{\sum(X - \bar{X})^2}{n - 1}}$$

where X represents an individual observation, Xrepresents the mean of the observations, n is total number of observations, and ∑(X−X)2is the sum of the squared deviations from the mean. The standard deviation measures the dispersion of observations around the mean and indicates the degree of variability present in the dataset.
Thus, the standard deviation represents the square root of the average squared deviation of observations from the mean, adjusted by the sample size n1.

Coefficient of Variation (CV)
The CV was used to compare relative variability among different climatic parameters. The coefficient of variation (CV) is a measure of variability relative to the mean value, unlike the standard deviation, which is an absolute measure of variability and thus cannot be directly compared between two variables. A higher CV means that the data are more variable from the mean, and a lower CV means that the data are more consistent.
The coefficient of variation was calculated using following formula:

$$CV(\%) = \frac{SD}{\bar{X}} \times 100$$

where CV is the Coefficient of Variation (%), SD is the Standard Deviation and X ¯is the mean of the observations. CV is a measure of variability of climatic parameters presented as a percentage of the mean and is used to compare the variability of different climatic parameters in a standardized manner.
Linear Regression Analysis
To find the long-term trends of rainfall and temperature over study period, linear regression analysis was used. This technique is used to study a climatic variable and time to see if there is an upward or downward trend. The following general regression equation was used:

$$Y = a + bX$$

The climatic variable (rainfall or temperature) is Y, the years of data are X, a is estimated value of variable when X is zero, and b is rate of change and gradient of the line. Positive b values are indicative of a general upward trend and negative b values are indicative of a general downward trend in the climatic variable through the study period.

Rainfall Anomaly Analysis
The rainfall anomaly analysis was conducted to determine whether rainfall was higher or lower than the LT average. The rainfall anomaly was calculated as:

Rainfall Anomaly=Annual Rainfall−Long-term Mean Rainfall

Positive anomaly values indicate wetter-than-average years, while negative anomaly values indicate drier-than-average years.

Standardized Rainfall Anomaly
Standardized rainfall anomaly was computed to determine extent of rainfall deviations from the natural variability as follows:

$$\text{Standardized Rainfall Anomaly} = \frac{\text{Annual Rainfall} - \text{Mean Rainfall}}{\text{Standard Deviation}}$$

Numbers above zero in the standardized anomaly indicate above average precipitation while numbers below zero indicate below average precipitation. This approach enables comparisons of rainfall variability in different years on a common scale.

Seasonal Rainfall Contribution Analysis
Numbers above zero in the standardized anomaly indicate above average precipitation while numbers below zero indicate below average precipitation. This approach enables comparisons of rainfall variability in different years on a common scale.

$$\text{Seasonal Rainfall Contribution } (\%) = \frac{\text{Seasonal Rainfall}}{\text{Total Annual Rainfall}} \times 100$$

This analysis helps in understanding seasonal distribution of rainfall and dependence of the region on monsoon precipitation.

Monthly Climatological Analysis
Monthly climatological analysis was done to look at the annual cycle and seasonal pattern of rainfall and temperature. Monthly mean values were calculated using the following formula:

$$\text{Monthly Mean} = \frac{\text{Sum of values for a particular month over all years}}{\text{Number of years}}$$

The resulting monthly averages provide a representative picture of normal climatic conditions and seasonal variations throughout the year.

Correlation Analysis
Pearson's correlation analysis was used to study relationship between rainfall and temperature. The Pearson's correlation coefficient is a measure of the strength and direction of the relationship between two variables, and is defined as:

$$r = \frac{\text{Covariance (Rainfall, Temperature)}}{\text{SD of Rainfall} \times \text{SD of Temperature}}$$

Where, r= Pearson's correlation coefficient.
The value of r is between −1 and +1. Positive numbers represent positive correlation between rainfall and temperature and negative numbers represent negative correlation between rainfall and temperature. Numbers near zero indicate that there is little or no linear correlation.
Heatmap Visualization
The monthly and annual changes in rainfall and temperature were visualized using heatmap. In this method, climatic data were put in a matrix year by year and month by month, and the intensities of the colours were used to indicate the magnitude of the climatic values. This visualization technique enables the identification of the wet/dry and hot/cold periods throughout the study period.
Period-wise Climatic Analysis
To evaluate temporal changes in climatic conditions, study period was divided into five intervals: 2000–2005, 2006–2010, 2011–2015, 2016–2020, and 2021–2025. The average value of each interval was computed as:

$$\text{Period-wise Mean} = \frac{\text{Sum of climatic values within a period}}{\text{Number of years in that period}}$$

This period-wise classification enabled systematic comparison of rainfall and temperature characteristics across different phases of the study period and helped identify gradual climatic

4. Results

4.1 Main Climatic Characteristics

The annual rainfall were highly variable during the study period with average of 1468.6 mm, from 854.7 mm in 2014 to 2553.3 mm in 2025. The average annual mean temperature was 23.1 °C.

Table 1. Summary of key climatic indicators for Ranchi (2000–2025).

Indicator	**Value**
Study Period	2000–2025
Average Annual Rainfall	1468.6 mm
Highest Annual Rainfall	2553.3 mm (2025)
Lowest Annual Rainfall	854.7 mm (2014)
Average Monsoon Contribution	81.5%
Rainfall Trend	+22.3 mm year^{-1}
Average Mean Temperature	23.1 °C
Mean Temperature Trend	+0.038 °C year^{-1}

The analysis of trends in climatic data showed positive rainfall and increasing mean temperature trends of 22.3 mm/yr and 0.038 °C/yr respectively for the period of 2000-2025. The positive trend in rainfall is an indication of a gradual rise in the annual rainfall over the period of study, but significant inter-annual variability was noted. In the same way, the trend of temperature increase indicates a regional warming trend. All these trends indicate the continued climatic change in Ranchi and suggest that there are appreciable changes in climatic conditions both in terms of precipitation and in terms of thermal conditions in the past two and a half decades. The rise in rainfall and temperature occurred at the same time, and is in line with the trends observed across various regions of India, which underscores impact of climate variability on the environmental conditions, water resources, agricultural productivity, and ecosystem dynamics of the region.

4.2 Annual Rainfall Variability

There is a high degree of interannual variability in the annual rainfall series. Rainfall over past few years has been significantly higher than the average, such as in 2006, in 2011, 2021, 2022, 2024 and 2025. However, 2012–2015 and 2018 saw significant rainfall shortages.

The very high rainfall that was recorded during 2025 suggests enhanced rainfall extremes and may represent enhanced monsoon activity. Positive long-term rainfall trend indicates that the moisture availability in the region will be gradually increasing.

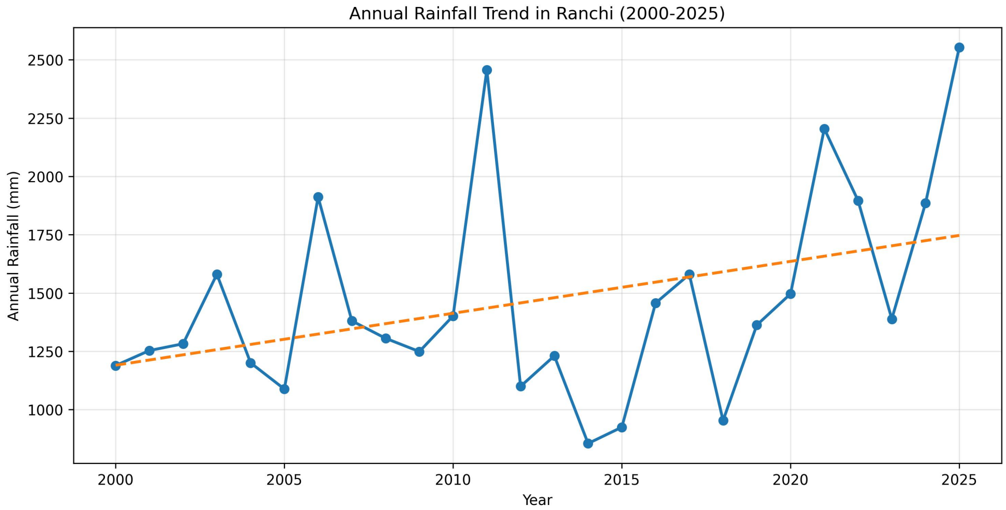

Figure 2. Annual rainfall trend in Ranchi during 2000–2025.

4.3 Rainfall Anomalies

Rainfall anomaly analysis revealed that there were wet and dry spells during study period. The positive anomalies were more significant during 2011, 2021, 2022 and 2025 whereas strong negative anomalies were observed during 2014 and 2015.

An increase in extreme positive and negative anomalies suggests greater climatic variability, which has been frequently reported to be a result of climate change.

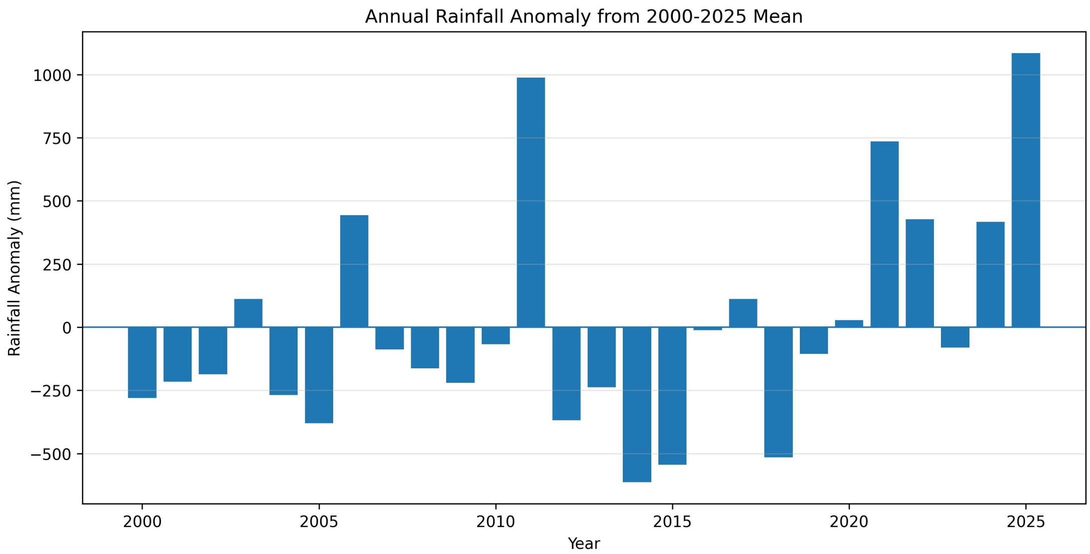

Figure 3. Annual rainfall anomalies relative to the long-term mean (2000–2025).

4.4 Monsoonal and Non-Monsoonal Rainfall

Monsoonal rainfall was identified as the major type of rainfall in the annual precipitation. The analysis of seasonal distribution of rainfall showed that the southwest monsoon is the chief contributing season for the rainfall received at Ranchi with 81.5% of the annual rainfall while remaining 18.5% of the annual rainfall is received during non-monsoonal period. The high seasonal rainfall concentration highlights the high seasonality of rainfall in the region. The results also showed that years with an abnormally high annual rainfall were most often linked to more intense monsoon activity and higher precipitation amounts in June–September. Weaker monsoons, on the other hand, often were correlated with less than average annual rainfall. The results highlight the critical influence of Southwest monsoon on hydrological regime of Ranchi and water availability in this region for agriculture, recharge of ground water resources, forest ecosystem and for domestic use. This means that changes in the intensity, duration or distribution of the monsoons due to global warming could greatly affect environmental and socioeconomic sustainability in the region.

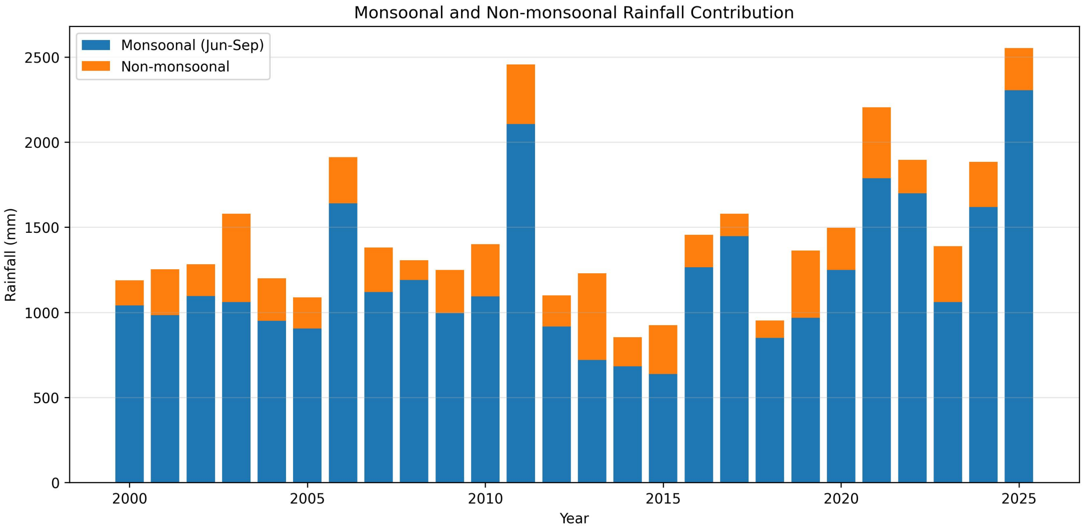

Figure 4. Contribution of monsoonal and non-monsoonal rainfall in Ranchi (2000–2025).

4.5 Temperature Trends

The analysis of temperature showed that the temperature was increasing gradually during the study period. There was large interannual temperature variability and a general warming trend during the study period, as detected by temperature analysis. The highest average maximum temperature was in 2021 (31.2 °C) and lowest average minimum temperature was in 2018 (15.5 °C), which suggests very warm conditions in 2021 and very cool conditions in 2018. Based on long-term trend analysis, average mean temperature increased by ~0.038 °C per year, indicating a gradual warming in the region from 2000 to 2025. This warming trend has increased markedly since 2015 when the annual mean temperature often registered above the long-term average. This is the long-term rise in temperature which could be seen as part of the climate warming trend for India as well as the rest of world. The potential effects of climate change on environmental sustainability and socioeconomic development in the Ranchi region are also evident through its impact on evapotranspiration rates, soil moisture availability, agricultural productivity, ecosystem functioning, climate change and human health.

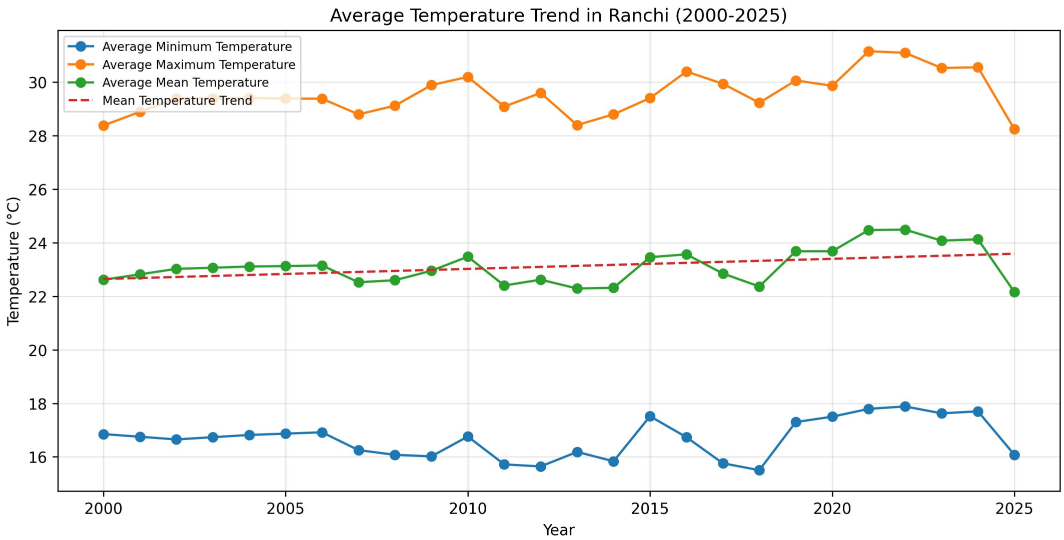

Figure 5. Trends in annual minimum, maximum, and mean temperatures in Ranchi (2000–2025).

4.6 Monthly Climatic Pattern

A seasonal cycle is clearly illustrated in monthly climatology. The tropical monsoon climate of Ranchi is highly seasonal with strong variations in rainfall and temperature during different seasons as shown in figure 5. The rainfall during November to April is very low (usually less than 30 mm/month) which means dry winter and pre-monsoon conditions. May marks the start of the increasing rain, and then a sudden increase in June when the southwest monsoon season starts. The main part of annual rainfall occurs during monsoon season with July having the highest average rainfall of around 355 mm, followed by August (325 mm) and September (285 mm). The following months (October onwards) rainfall decreases sharply while winter (November to March) is dry.

There is an inverse seasonal relationship between the temperature pattern and rainfall. The average maximum temperature gradually increases from 24°C in January to almost 37°C in May and the average minimum temperature increases from nearly 7°C in January to almost 23°C in May-June. As the rains of the monsoon season begin, the daytime high and low temperatures become more moderate because of the greater cloudiness, humidity and precipitations. During the months of July – September, maximum temperatures drop to about 30°C with still high minimum temperatures, resulting in a decrease in diurnal temperature range. The figure represents the prevailing climatic regime in the city of Ranchi during the winter season with the minimum temperature dropping below 10°C, and the pattern clearly shows the dominance of the southwest monsoon, which also affects the distribution of rainfall, as well as temperatures. The timing of precipitation with significant amounts over a few months of the monsoon and the moderation in temperatures over that period reflect the high sensitivity of this region to monsoons and the impact of changes in the monsoon behavior caused by climate change.

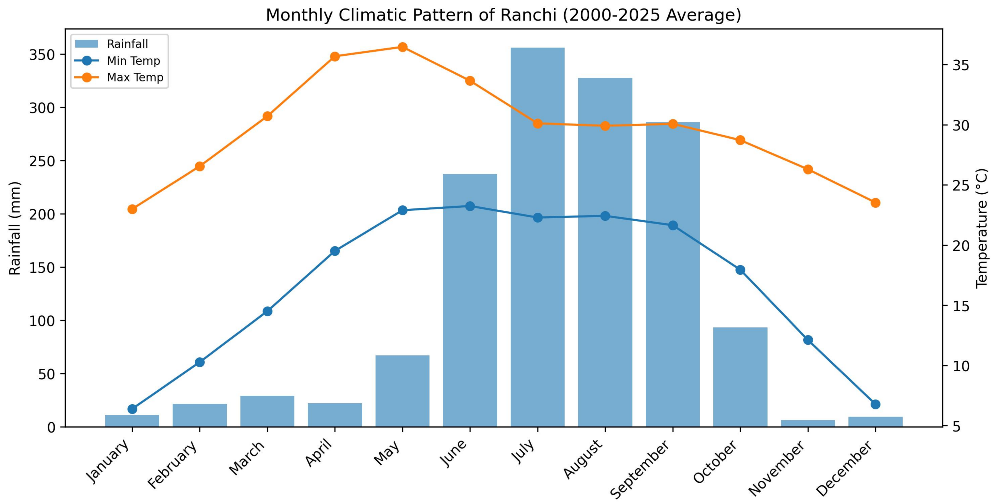

Figure 6. Average monthly rainfall and temperature pattern in Ranchi (2000–2025).

4.6 Heatmap-Based Climate Variability

Rainfall heat map indicates the distribution of rainfall in monsoon months, July, August and September, in which there are a number of high rainfall cells. The heatmap also reveals the year-to-year variation, including very wet months like July 2017, August 2022 and June 2025. The temperature heatmap displays temporal variations clearly with higher values during the spring months (April-June) and lower values during the winter months (December-January).

The monthly distribution of rainfall was analysed and it was found that there is a typical monsoon type rainfall pattern in Ranchi. The winter months (November–February) were very dry, with rainfall below the norm, indicative of the dryness of this region during this time of the year. Increase in precipitation was seen during the pre-monsoon months with a fast rise after June as the southwest monsoon started. The highest rainfall intensities occurred in the summer and autumn months (July through September) and the most of the annual rainfall occurred during these months. After October, rainfall dropped significantly following the withdrawal of the monsoon and there was comparatively less rain in post monsoon and winter seasons. The noticeable seasonal rainfall pattern indicates a high reliance on the monsoonal rains in the region and the importance of the southwest monsoon for supporting the local agriculture and water supply, forest systems and environmental sustainability.

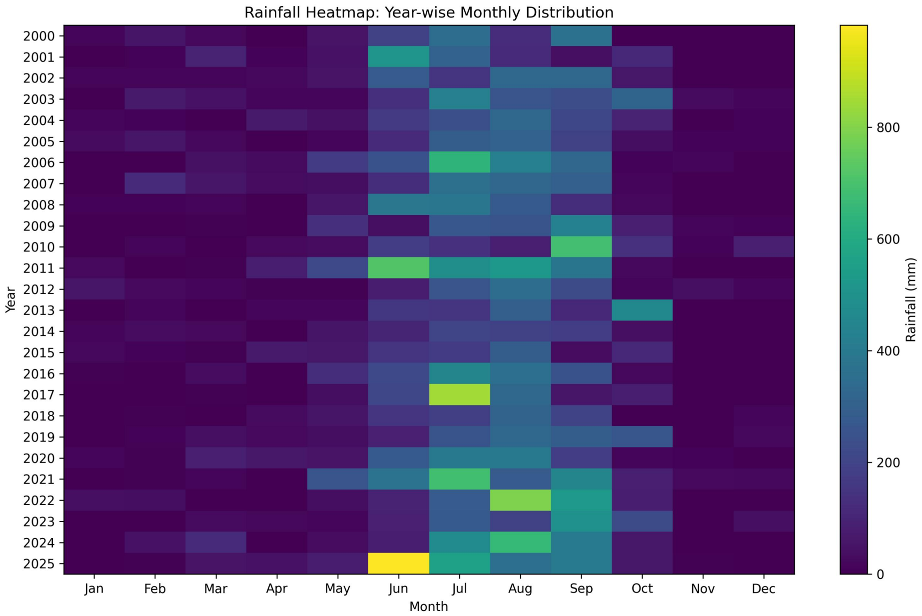

Figure 7. Monthly rainfall heatmap showing interannual variability (2000–2025).

The seasonal cycle of the monthly temperature in Ranchi was well pronounced during the entire period of study. During the summer months (April to June), temperatures were generally higher due to strong solar radiation and less rainfall, which increased the maximum temperatures. During the monsoon season (June onwards) the temperature eased off with more cloud cover, higher humidity and more frequent rainfall events and was comparatively lower during the monsoon season. The coldest periods were in the winter (December-January) when colder continental air masses dominated the region. This seasonal variation shows strong influence of the southwest monsoon on the thermal regime of Ranchi and indicate the influence of monsoon on temperature distribution within the region apart from its role in rainfall distribution and climatic regulation.

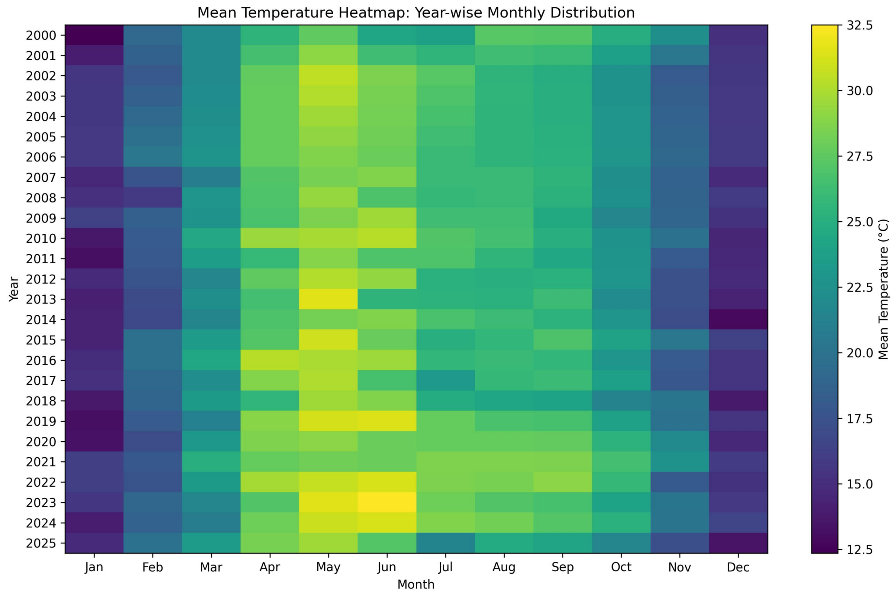

Figure 8. Monthly mean temperature heatmap showing interannual variability (2000–2025).

4.7 Period-Wise Climate Change Assessment

The 26-year period was broken up into 5 intervals for thesis interpretation. Period-wise analysis helps to determine the rainfall and temperature changes in the phases, which is not possible by looking at individual years. Rainfall and temperature data revealed climatic variations during the period of the study, when analysed on a periodical basis. It was noticed that when comparing the five assessment intervals, the most recent one (2021-2025) had significantly higher rainfall and temperature compared to the previous intervals. The highest average annual rainfall and the highest AMT were recorded during this interval, which represented an overall increase in precipitation and warming over the region. In addition, a higher variability in annual rainfall and temperature was noticed in this time span, indicating more extreme climate variability and more extreme weather events. An increase in rainfall and temperature has also been observed along with increased variability, indicating effects of climate change are more pronounced in recent years. The results are in line with the broader regional and global trends in the shifts of climatic patterns and indicate that Ranchi is becoming increasingly vulnerable to environmental and socioeconomic impacts of climate change.

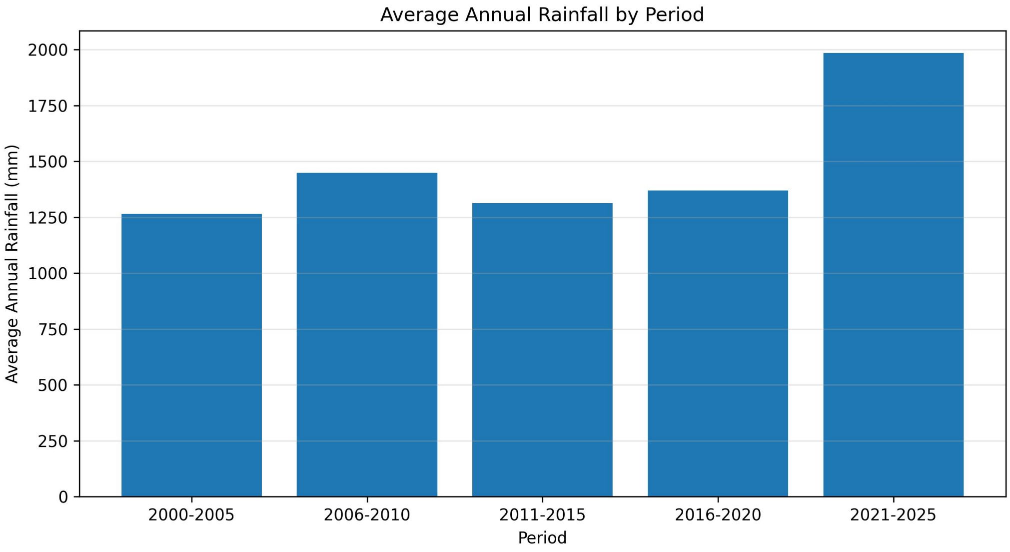

Figure 9. Average annual rainfall during different study periods.

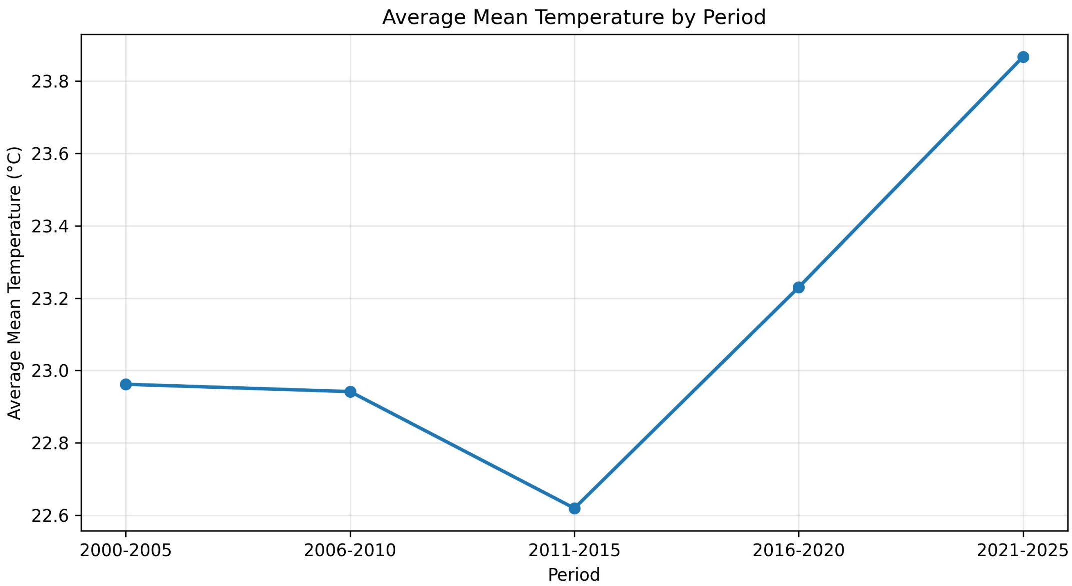

Figure 10. Average mean temperature during different study periods.

4.8 Rainfall–Temperature Relationship

It was found that there is a weak relationship between annual rainfall and mean temperature using scatter plot analysis. The analysis of the relationship between annual rainfall and mean temperature showed that the highest amounts of rainfall did not always coincide with the highest mean temperatures. This means that in Ranchi, the strength, onset and duration of the southwest monsoon play a more significant role in determining the variability in rainfall than the mean annual temperature. Precipitation variability is still driven mainly by the monsoonal dynamics, as indicated by the low association with temperature. But the apparent long-term rise in temperature could cause major environmental impacts. Warming of the climate may increase the evapotranspiration rates and thus the moisture demand of the atmosphere as well as the moisture loss from the soil and vegetation. These shifts could impact soil moisture availability, groundwater recharge, crop water needs, and hydrology. Therefore, despite the lack of direct evidence of a link between annual precipitation and temperature, further warming could also change the water balance and the functioning of the ecosystems in the regions, which may contribute to overall effects of climate change likely in Ranchi.

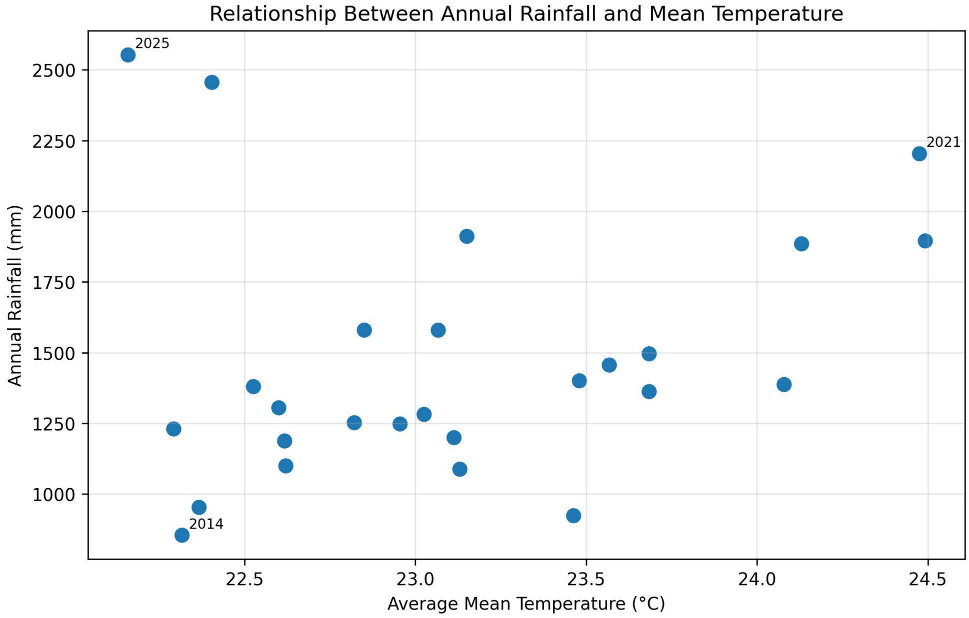

Figure 11. Relationship between annual rainfall and annual mean temperature in Ranchi (2000–2025).

5. Conclusion

This study explored the long term variation of climatic parameters rainfall and temperature from 2000 to 2025 for the location Ranchi, Jharkhand, India. Data analysis showed significant variation in the climate as well as gradual climate change in the region. There were large interannual variations in rainfall with a positive trend of about 22.3 mm per year, ranging from 854.7 mm in 2014 to 2553.3 mm in 2025. The results show that the southwest monsoon is the most important factor that controls the rainfall variability over Ranchi, accounting for an average of 81.5% of total annual rainfall over study period. Extremely severe years of rainfall were typically linked with good monsoon performance, indicating the importance of monsoonal processes in modulating regional hydrology.

The analysis of temperature showed a gradual warming trend, at a rate of about 0.038 °C per year. The maximum temperature was at its highest average value of 31.2 °C in 2021, and the minimum temperature was at its lowest average value of 15.5 °C in 2018. Annual mean temperatures have started to rise sharply since 2015, when annual mean temperatures were generally above the long-term average. Seasonal and monthly analyses also showed significant climatic variations, with high precipitation in the months of July–September and high temperatures during April–June. A rise in climatic variability was observed in the heatmap visualization and the period-wise evaluation, particularly in the recent period (2021-2025) with the highest average rainfall, highest average temperature and maximum climatic variability.

The analysis of rainfall–temperature relationship suggested that the years with high rainfall were not necessarily the warmest years, implying that the interannual variability of precipitation was driven more by monsoon dynamics than by annual mean temperature. However, these increases in temperature could have a considerable impact on evapotranspiration, soil moisture, recharge of groundwater and hydrological processes. The concurrent rise in rainfall with temperature along with intensification of climatic variability indicates the current climate change influences in the Ranchi region.

The observed climatic changes have significant impacts on agriculture, water resources, forest ecosystems, biodiversity conservation as well as urban development. These changes in precipitation patterns can increase likelihood of flooding and drought, and the warming climate can lead to greater heat stress, water requirements, and ecosystem damage. Thus the results stress the importance for climate change resilient agricultural practices, sustainable water resource management, watershed conservation, afforestation programs, and strategic planning for policy-building with consideration to climate change. To strengthen environmental sustainability and environmental resilience in the region of Ranchi and other parts of Jharkhand in the future, continuous monitoring of climatic parameters and integration of climate adaptation measures in regional development frameworks will be needed.

References

1. Intergovernmental Panel on Climate Change (IPCC). (2023). Climate Change 2023: Synthesis Report. Geneva: IPCC.
2. World Meteorological Organization (WMO). (2024). State of the Global Climate 2023. Geneva: WMO.
3. India Meteorological Department (IMD). (2024). Annual Climate Summary of India. New Delhi: Ministry of Earth Sciences.
4. Kumar, V., Jain, S. K., & Singh, Y. (2022). Analysis of rainfall variability and trends over India. Theoretical and Applied Climatology, 147(1–2), 341–356.

5. Dash, S. K., Jenamani, R. K., Kalsi, S. R., & Panda, S. K. (2021). Some evidence of climate change in twentieth-century India. Climatic Change, 85(3–4), 299–321.
6. Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanan, M. S., & Xavier, P. K. (2006). Increasing trend of extreme rain events over India. Science, 314(5804), 1442–1445.
7. Rajeevan, M., Bhate, J., & Jaswal, A. K. (2008). Analysis of variability and trends of extreme rainfall events over India. International Journal of Climatology, 28(14), 1837–1847.
8. Guhathakurta, P., Sreejith, O. P., & Menon, P. A. (2011). Impact of climate change on extreme rainfall events and flood risk in India. Journal of Earth System Science, 120(3), 359–373.
9. Pai, D. S., Sridhar, L., Rajeevan, M., Sreejith, O. P., Satbhai, N. S., & Mukhopadhyay, B. (2014). Development of a new high spatial resolution rainfall dataset for India. Mausam, 65(1), 1–18.
10. Krishnan, R., Shrestha, A. B., Ren, G., et al. (2020). Climate Change and Land: IPCC Special Report. Cambridge University Press.
11. Singh, D., Tsiang, M., Rajaratnam, B., & Diffenbaugh, N. S. (2014). Observed changes in extreme wet and dry spells during the South Asian monsoon season. Nature Climate Change, 4(6), 456–461.
12. Mishra, V., Kumar, D., & Ganguly, A. R. (2020). Climate change and hydrologic extremes in India. Journal of Hydrology, 589, 125–142.
13. Jain, S. K., Kumar, V., & Saharia, M. (2013). Analysis of rainfall and temperature trends in northeast India. International Journal of Climatology, 33(4), 968–978.
14. Chattopadhyay, S., & Edwards, D. R. (2016). Long-term trends in precipitation and temperature in eastern India. Atmospheric Research, 178–179, 146–157.
15. Pattanaik, D. R., Mohanty, U. C., & Kumar, A. (2019). Climate variability and changing monsoon characteristics over eastern India. Meteorological Applications, 26(3), 450–462.

EPH – International Journal of Mathematics and Statistics
https://eijms.com/index.php/ms/index