



Understanding Climate Change at the Local Scale: A Data-Driven Study of Chandrapur, Maharashtra



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Abstract: This study explores the fluctuations in temperature and precipitation in Chandrapur, Maharashtra, over the last 30 years from 1991 to 2024. The recorded data suggest an increase in temperature, particularly in the summer months from March to May. In addition, winter nights are gradually warmer. Furthermore, the quantity of rainfall is also changing; less rain is observed in June and August, yet an increase is seen in July and September. Not only are these fluctuations evident, but they also showcase the true and escalating impacts of climate change in the area. The Chandrapur district is an industrial and agrarian hub. Therefore, there is an urgent need to devise and prioritize climate adaptation policies.

Keywords: Climate change; Temperature variability; Rainfall; Regional climate analysis; Climate adaptation strategies

1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) [1] refers to climate change as a defining dilemma in the 21st century. It affects ecosystems, economies, and the well-being of humanity globally. Although global climate models are developed as a projection for the forecast to come, the local scale, vulnerable to climate effects models also need to be assessed on an equal scale, as they need more attention. Urbanization at a fast rate has resulted in a large number of impervious surfaces, leading to increased land surface temperature (LST) in urban areas than in surrounding rural areas. This effect, referred to as the urban heat island (UHI) effect, has been extensively reported as a serious environmental and public health concern [2, 3]. Increased urban temperatures increase energy consumption, enhance greenhouse gas emissions, and lead to heat-related diseases and death [4, 5].

India has diverse geography. The country is also super populated, which puts it at risk for sociological challenges; however, it seems to be more advantageous. India is facing the rise of extreme weather, getting hotter, shifting monsoon patterns, and so on [6]. It is also worth mentioning that Chandrapur is a city in India that has captured my climatic attention. This region lies in the Vidarbha region of Maharashtra. In addition to its economic significance, Vidarbha also has a harsh environment. It is infamous for the exploitation of coal via mining, as well as the thermal power produced by improper techniques used by industries. This area lays the foundation for a region that suffers from an added set of intense tropical wet climate modifiers [7]. The area suffers from summer heat, experiences monsoons, and culminates in a mildly cold winter. The change in climate, as well as the rise in extreme climate, puts an inordinate amount of stress on the dual industrial and agricultural socioeconomic structure.

While several studies have examined long-term temperature and rainfall trends across India and Maharashtra, most analyses remain state-level or agro-climatic zone-based, often overlooking districts with complex socio-economic dependencies. Chandrapur represents a distinct and underexplored case due to its dual dependence on industrial activity and agriculture, making it particularly climate-sensitive.

Chandrapur is the venue of extensive coal mining activities, the establishment of thermal power stations, and the development of ancillary industries, all of which do not prevent the area from having a large agrarian community that depends on the monsoon for its water supply and practices sensitive to temperature changes. The coexisting energy-intensive industrial infrastructure and climate-vulnerable agriculture thus raise the impact of the risen temperature and altered precipitation on the respective livelihoods, the water resources, and the sustainability of the environment. Chandrapur's climatic variability does not only affect the productivity of industries and the quantity of agricultural produce to mention human health as well but it does so simultaneously, that is, it has direct and indirect impacts. This research is focusing on Chandrapur thereby moving away from the generalized assessments of the regions and offering a localized, district-scale climate analysis through which the vulnerabilities interacting with each other are captured. The long-term study of temperature and rainfall trends at this scale provides context-specific insights which are extremely important for district-level planning, climate adaptation, and risk management in regions where industry and agriculture are interdependent.

2 Literature Review

2.1 Global and Regional Climate Change Context

The Methodology section should be written concisely, yet provide enough details to allow others to replicate and build on published results. The well-established methods can be introduced briefly with proper citations. Do not describe these published methods in details. In contrast, detailed descriptions are required for new methods. If multiple methods are adopted in the work, this section may be divided into several subsections, each providing details on a specific method. Note that the publication of your manuscript means all materials, data, codes, and protocols associated with the publication must be made available to readers. Remember to disclose restrictions on the availability of materials or information at the submission stage. If your manuscript uses large datasets deposited in an open-source database, please specify where the data have been deposited. If your study requires ethical approval, do not forget to list the authority and code of the ethical approval.

Climate Change is one of the most crucial geopolitical issues of the modern era. The IPCC Working Group I Report published in 2018 infers that the average global temperature has increased by 1.0 °C relative to pre-industrial levels. The burning of fossil fuels was deemed the primary cause. The report also states that Climate Change the world has already reached a level of 1.0 °C mark of temperature without the need for additional human intervention". The report vividly states human inaction towards climate fulfills Changes leaps. The phenomena of "Trigger Climate Fluctuation" is set in motion as a direct result of glacier and sea level the world is pre-emptively witnessing a rise in glacier melt along with severe weather pattern shifts alongside archaic levels of dendritic and shrouded rainfall intertwined with cyclones. In India the sea is the heart of the economy which in the wake would give rise and rampant cyclonic rains alongside internal shifts in tectonic movements within the sea would give rise to abundant levels of internal and bilateral migrations and the consumption of resources constantly along with "renewable energy" becoming the saving grace.

2.2 Climate Change in Maharashtra and Vidarbha

While the "Maharashtra climate" is the heart of the Indian climate. Recent research pertaining to the region suggests that the already changing aspects of weather in the perimiter including a rise in temperature deeply paired with a transformation in the rain pattern including longer hibernation and inter sepolation of rain would give rise to flood prone areas. This leads to a paradoxical environment with the forests becoming the counterpart of dust and the rise in temperature met along with cycling at the "Deep gorges of earth," which would lead to an increase in dust and sand within the air. Maharashtra Climate allows for the acquisition of a warmer climate along with dirt cycles of dust, where the intersection propters fighting would lead to a self-feeding clutch cycle and allow the semi-shrouding iron dish. These paradoxical places would deeply shift alongside the hibernation of semi-dry and hot weather tumbles. Would the intertwining paradox propelling allow the vijarb wites along alongside and the carving of dust would aid in cyclonic rains of hibernating factors allowing the world to sustain a self-feeding sustenance climate?

2.3 Related Work

The main factors which cause increased temperature rise and modified weather patterns in Indian cities are urban development and climate change. Urban areas expand at a fast pace which creates stronger UHI effects because human activities and building materials produce heat, thus making cities more vulnerable to extreme weather conditions which require them to develop their own climate change response plans [8].

Urban development causes temperature changes which affect both daytime high temperatures and nighttime low temperatures, thus changing local climate conditions in cities, which makes it necessary to conduct thorough climate studies for specific areas [9]. Precipitation data requires both accurate measurement and accessible information because temperature records show different patterns for gauge-based and satellite-based datasets that study rainfall variations over different areas and times [10].

Research on meteorological elements which include rainfall and temperature and humidity shows diverse patterns between different areas because some areas experience major climatic changes while other areas keep certain climatic elements constant. The study results show that climate trend analysis requires statistical methods which include the Mann-Kendall test and Theil-Sen estimator to provide trustworthy findings [11].

Rainfall patterns across different regions of India show both increasing and decreasing trends because each area demonstrates its unique precipitation patterns which affect agricultural development and resource allocation [12]. The findings from semi-arid regions demonstrate irregular rainfall patterns which require further research into climate variability and its effects on local ecosystems [13].

Urban areas now prioritize adaptation and mitigation strategies because climate variability continues to increase. The implementation of heat action plans together with awareness initiatives and early warning systems demonstrates effective methods which protect vulnerable groups from heat-related dangers while improving their ability to withstand extreme weather events [14]. The urbanization process creates temperature variations which exist between city centers and their outer regions and these differences demonstrate how UHI effects are increasing costs for energy consumption and public health and economic development [15].

The research demonstrates that green infrastructure functions as an essential solution to reduce urban heat problems because vegetation density helps lower LST which results in better thermal comfort for people in urban areas [16]. Human activities which include deforestation and agriculture expansion and urban development, lead to land use and land cover changes that create environmental impacts which require sustainable land-use planning solutions [17].

The latest studies show how climate change affects public health because extreme temperatures and insufficient green space make health problems worse for communities who need additional protection [18]. Urban areas show different temperature levels because built-up areas and green-blue infrastructure systems create different heat distribution patterns which help urban planners design climate-responsive cities [19]. The results of remote sensing data and modeling techniques, which scientists use to study vegetation and landscape effects on urban heat patterns, demonstrate their key role, especially in semi-arid regions, which enables the creation of successful climate adaptation solutions [20].

The never-ending debates and confusions flowed down along the years on the very grounds relating to the impact of interfaces between green space configuration and urban temperature within urban climate research. A green space configuration would be the spatial arrangement, positioning, and geometrical complexity of the landscapes and influences LST essentially through different respective ways. Certain papers [21–23], showing LST value relation to UGS configurations, claimed certain spatial patterns can either help or at least mitigate temperature; while some other studies [24, 25] contradicted this view claiming that either these parameters of green space configuration are too insignificant to be able to influence LST with regard to temperature change or they might have the tendency to promote this change by amplifying the undesirable influence of weather and physical characteristics of the surface they are investigating. At the regional scale, configuration metrics such as patch density, edge density, and landscape connectivity, rather than composition alone, appear to best reflect cooling power exerted by these UGS. Nevertheless, uncertainty persists regarding whether modifications in landscape configuration can effectively mitigate thermal stress, particularly in arid and semi-arid regions. This discrepancy highlighted the need for further investigation into the role of green space spatial patterns in shaping urban thermal environments under varying climatic conditions.

2.4 Research Gap and Significance

Despite its importance as a city, long-term climate studies in Chandrapur are scanty. Existing literature on climate migration concentrates on state-level or national shifts, leaving policymakers without localized data to plan for adaptation. A joint venture between the Symbiosis Centre for Management Studies and the Symbiosis Institute of Technology, Nagpur, has undertaken this research study to fill this gap. This study is based on 33 years of meteorological data from the India Meteorological Department and its Regional Meteorological Center in Nagpur and shows the detailed effects of temperature and rainfall trends, including changes in switchover patterns of extreme weather. This information will help in planning the climate-resilient development strategy for Chandrapur.

3 Materials and Methods

This research focuses on Chandrapur district, located in the Vidarbha region of Maharashtra, India, approximately 200 km southeast of Nagpur. The district experiences a tropical wet–dry climate, characterized by extreme summer temperatures, a well-defined monsoon season, and comparatively cooler evenings during the rainy period. Outside the monsoon months, prolonged hot and dry conditions are common. Chandrapur's economy exhibits a dual dependency

on heavy industry—particularly coal mining and thermal power generation—and agriculture, making the region highly sensitive to climatic variability and long-term climate change. These characteristics position Chandrapur as a suitable and representative case for examining localized climate change dynamics using a data-driven approach.

3.1 Data Collection

The proposed study is based on a 33-year dataset (1991–2024) comprising temperature and rainfall records for Chandrapur, Maharashtra. The dataset has been obtained from two official sources:

1. India Meteorological Department—Data Services Portal (1991–2015).
2. Regional Meteorological Centre, Nagpur—Supplementary data for 2016–2024.

The dataset includes:

- Monthly Mean Maximum Temperature (°C)
- Monthly Mean Minimum Temperature (°C)
- Total Monthly Rainfall (mm)

The selection of this temporal span enables the identification of long-term climatic trends and seasonal variability. Chandrapur was chosen owing to its dual industrial–agrarian character, making it highly sensitive to climatic fluctuations.

3.2 Data Preprocessing

Data underwent a systematic cleaning and organization process:

- Missing or anomalous values were cross-checked with secondary India Meteorological Department records and corrected where possible.
- Monthly values were aggregated to seasonal (summer, monsoon, winter) and annual scales to capture broad climatic trends.

Standard climatological definitions were applied:

- Summer: March–June
- Monsoon: June–September
- Winter: October–January

For rainfall, total monthly precipitation was used, while for temperature, monthly averages of daily maximum and minimum were analyzed.

3.3 Analytical Framework

The methodology followed a trend-analysis-based climatological approach, structured into three parts:

(a) Temperature trends

- Maximum temperature analysis: Through the study of long-term monthly maxima, the climate change signals were traced through the seasons. The period of March to May was considered the hottest in Chandrapur, which was measured in terms of the intensity and extent of the heatwaves.
- Minimum temperature analysis: Minimum temperature variations were taken to represent nighttime warming and Diurnal Temperature Range changes. Special prominence was kept on December–January for winter warming.
- Seasonal comparison: Maximum and minimum temperatures were analyzed separately for summer (March–June) and winter (October–January) using linear trend lines and plots of both the interannual variability.

(b) Rainfall variability

- Monthly and seasonal rainfall data (June–September) were examined to understand monsoon dynamics.
- Inter-annual variation in rainfall distribution was compared across the four monsoon months (June, July, August, September).
- Special attention was given to rainfall redistribution (declining June and August rainfall vs. increasing July and September rainfall).

(c) Trend estimation

- Regression models were applied to detect long-term trends in temperature and rainfall.
- Moving averages (5-year window) were used to smooth inter-annual fluctuations and emphasize underlying patterns.
- Comparative analysis between decades (1991–2000, 2001–2010, 2011–2020, 2021–2024) highlighted intensification of warming and rainfall redistribution.
- To assess the statistical significance of long-term trends in temperature and rainfall, non-parametric trend tests were applied in addition to linear trend analysis and moving averages. The Mann-Kendall test was specifically used for revealing the presence of monotonic trends in the time series, while Sen’s slope estimator was used to represent in numbers both the amount and the direction of the change. The Mann-Kendall test is very common in climate studies because of the non-normality assumption it does not make and thus it is quite strong against outliers as well as missing data. Sen’s slope gives a median-based value for how much change from one year to the next has occurred, which is a

dependable indicator of the size of the trend. These tests were performed on the yearly and seasonal series (maximum and minimum) of temperature and rainfall at the location of the study. The 5% significance level ($p < 0.05$) was set for determining the statistical significance. The combination of descriptive trend visualization (linear trends and moving averages) with non-parametric statistical testing strengthens the reliability of the detected climate trends and ensures that observed changes represent statistically significant climatic signals rather than short-term variability.

- Results from the Mann-Kendall test indicates statistically significant increasing trends in temperature variables, while rainfall trends exhibit greater variability with selective seasonal significance. Sen’s slope estimates further quantify the rate of change, reinforcing the long-term warming signal observed in Chandrapur.

3.4 Visualization

The results were presented using statistical graphs and visual analytics to capture temporal fluctuations:

- Mean monthly maximum temperature profiles—to compare seasonal maxima across years.
- Seasonal temperature trends (Summer and Winter)—highlighting warming trends in critical months.
- Mean monthly minimum temperature profiles—for insights into night-time warming.
- Rainfall distribution—showing redistribution of rainfall during the monsoon season.

All visualizations were generated using Python (Matplotlib & Pandas libraries), ensuring replicability and transparency in data analysis.

4 Result and Discussion

4.1 Mean Monthly Maximum Temperature

Analysis over the 33-year period reveals a clear upward trend in the summer temperatures. March and April showed steady increases in maximum temperature, with May consistently recording the highest values, often above 45 °C. June shows greater variability due to the onset of the monsoon but still exhibits a gradual upward trend in recent years (Figure 1). These findings suggest not only intensifying heatwaves, but also an earlier onset of summer conditions in Chandrapur.

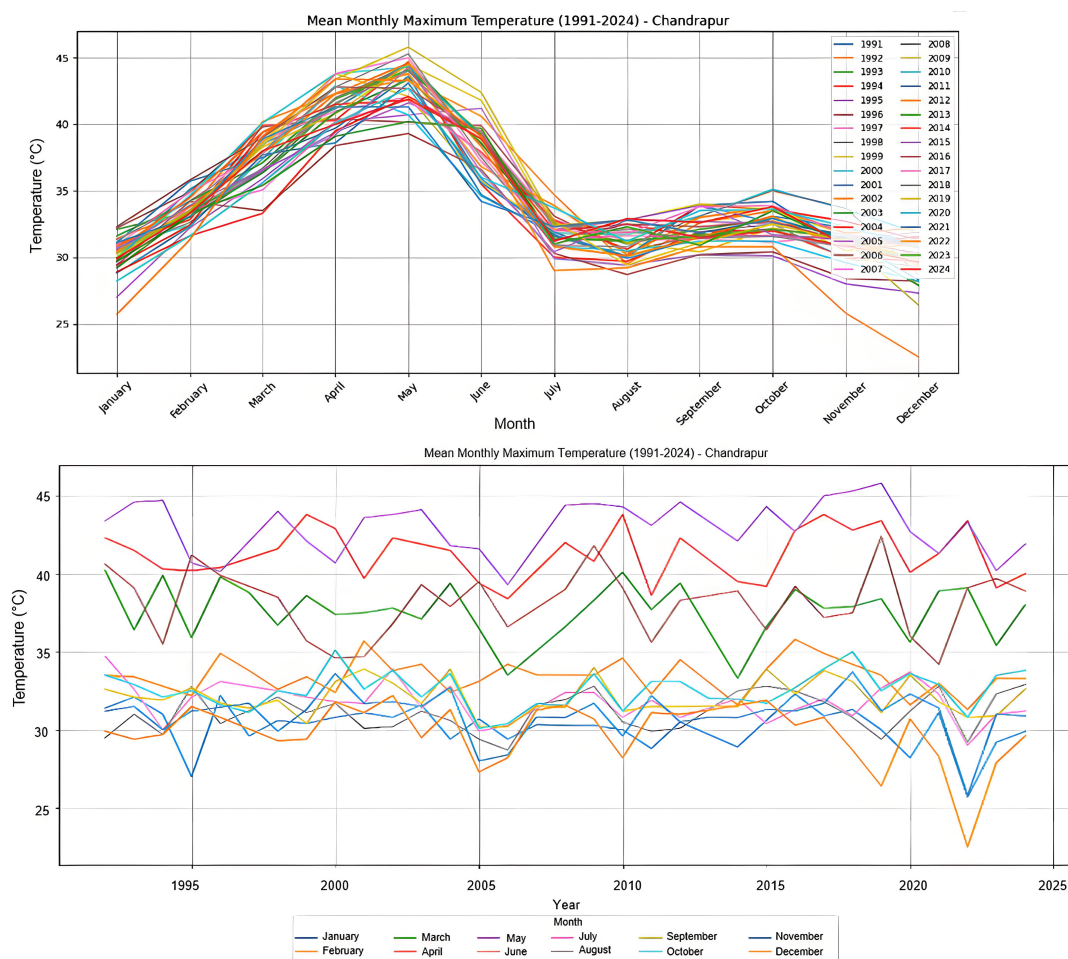


Figure 1. Variations in mean monthly maximum temperatures in Chandrapur during 1991–2024

In the case of winter months, January and December showed relatively stable temperatures, with a slight cooling trend in recent years. October and November exhibited more variability, with warmer years in the early 2000s and the mid-2010s. The lowest winter temperatures were observed in 2022, particularly in December and January (Figure 2). In fact, winter months show less pronounced warming than the summer months. In fact, recent years have suggested slight cooling, possibly owing to changing seasonal patterns or increased variability.



Figure 2. Variations in mean monthly maximum temperatures in Chandrapur in summer and winter months

4.2 Mean Monthly Minimum Temperature

The graph showing variations in the mean monthly minimum temperature in Chandrapur during 1991-2024 is shown in Figure 3.

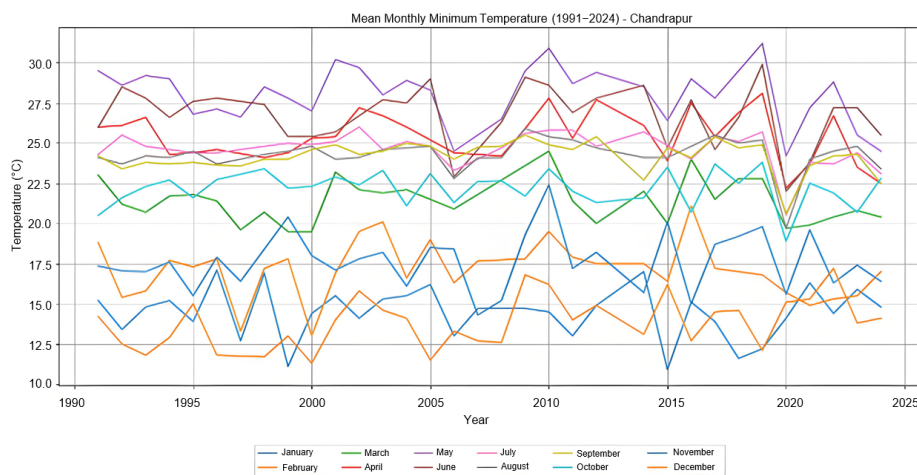


Figure 3. Variations in mean monthly minimum temperatures in Chandrapur in summer and winter months

The analysis of the mean monthly minimum temperature shows that May and June consistently record the highest minimum temperatures, indicating warm nights during peak summer; December and January are the coldest months, with minimum temperatures often below 15 °C. There is a visible warming trend in the summer and monsoon months, while winter months show more variability. Increasing nights do not allow sufficient cooling, which may result in health problems in marginalized sections of society that do not have sufficient cooling amenities. The warming trend was more pronounced in the core winter months of December and January (Figure 4). This means that winters are becoming warmer, and summers are expanding.

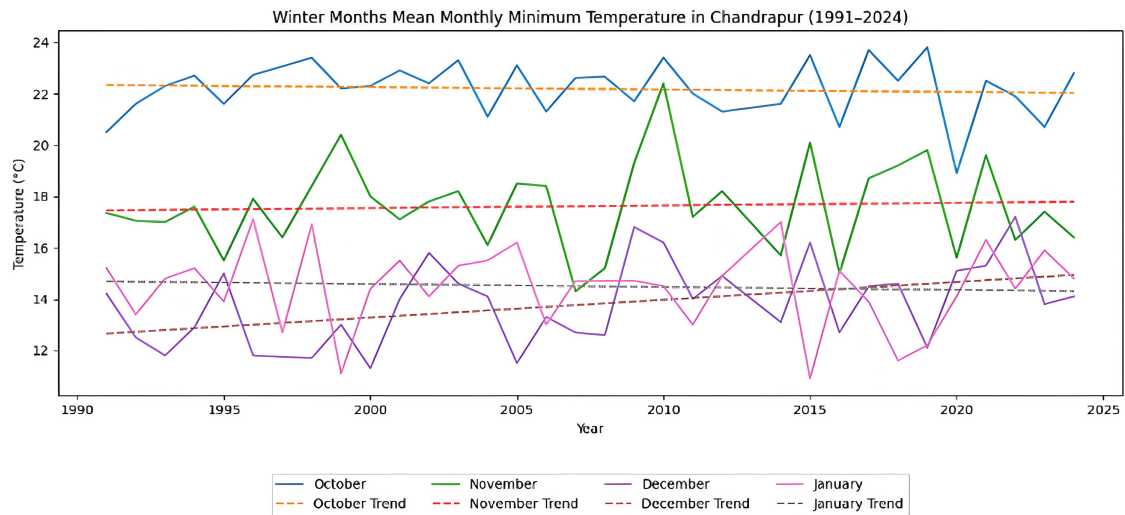


Figure 4. Variations of mean monthly minimum temperature in Chandrapur during 1991–2024 in winter months of October–January

4.3 Rainfall

The monthly rainfall variability over the years has been shown in Figure 5. As we can see, July and August consistently received the highest rainfall, with averages well above the other months. June and September also showed significant rainfall, confirming a strong monsoon influence. We further analyzed the rainfall over these four months to understand the rainfall pattern over the years (Figure 6).

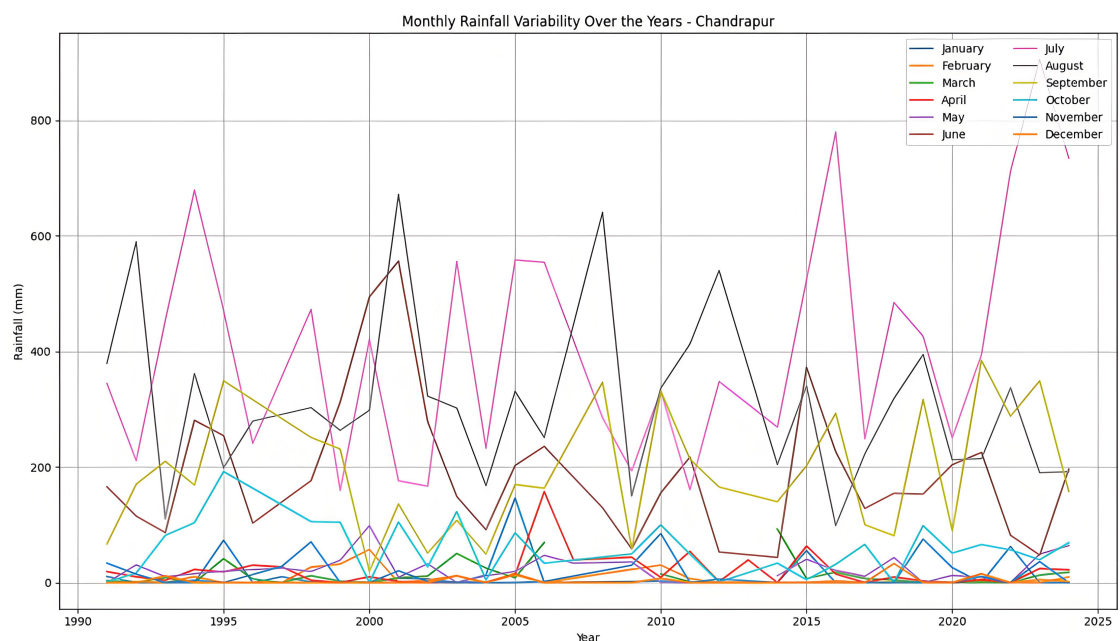


Figure 5. Variation in mean monthly rainfall in Chandrapur during 1991–2024

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months. June and September also showed significant rainfall, confirming a strong monsoon influence. We further analyzed the rainfall over these four months to understand the rainfall pattern over the years (Figure 6).

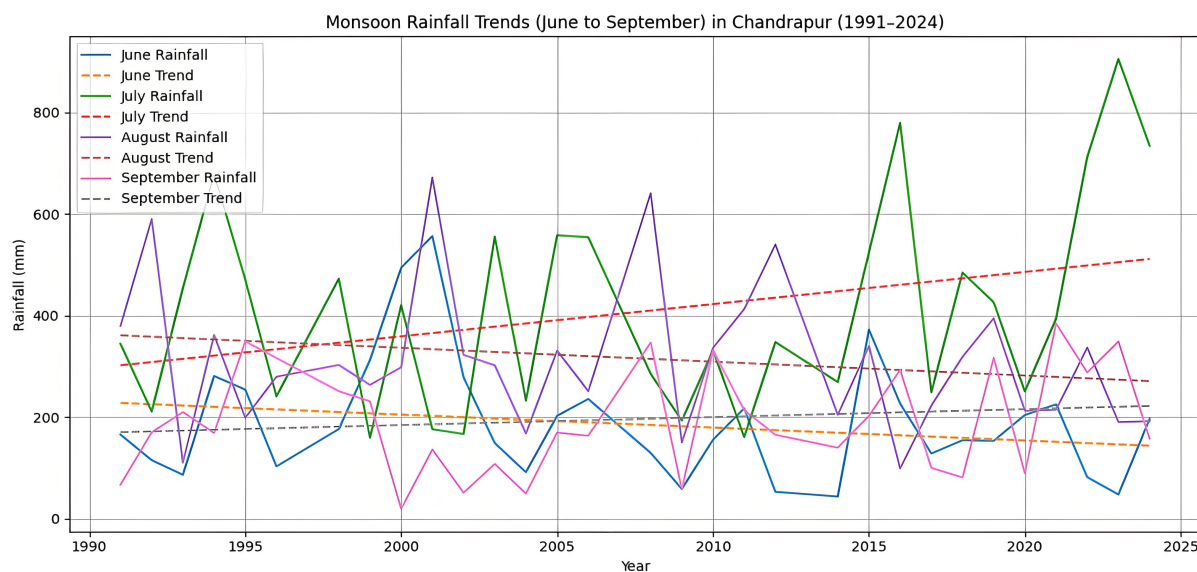


Figure 6. Variation in mean monthly rainfall in June to September months in Chandrapur during 1991–2024

This analysis revealed a noteworthy shift in the monsoon rainfall patterns in Chandrapur. August, the month of maximum rainfall during the monsoon season, has displayed a definite diminishing trend (Figure 6), while June, which is usually the month of initiation of the rainy season, has also experienced a drop in the amount of rain. This can be interpreted as the summer conditions gradually shifting towards the early monsoon period. July, on the other hand, is a month of different features since it has very high rainfall, and this suggests that the majority of the seasonal rain is gathered in this month alone. This new arrangement is reflected in the total monsoon rainfall as it suppresses it and at the same time increases the probability of the prolonged dry periods interspersed by heavy rains, which is the scenario when global warming is actively cutting off the total monsoon rainfall and giving rise to prolonged dry situations followed by heavy rains, which is a typical phenomenon of global warming. The rainfall behavior during September also trends similarly, but to a lesser extent and pace, supporting or indicating some change in monsoon dynamics. The findings of the study point out the trend of diversity in precipitation that is becoming more pronounced along with the necessity of conducting further research to properly resolve the issue of causes behind and coping with the risks of such factors as agriculture, water management, and flood risk in the area.

The warming trends noticed in Chandrapur are probably the result of a mix of different factors like local land-use change, urbanization, and industrial activity. The area’s surface becoming less porous and the vegetation being cut down can lead to retention of heat and reduction of evaporative cooling, thereby causing surface and air temperatures to rise. Such changes are like UHI-type effects, even in semi-urban and industrialized areas. Apart from that, industrial activities such as coal mining and power generation may also contribute to the warming of the area as they produce waste heat continuously and release aerosols and particulate matter that can alter the local radiative balance. Changes in the distribution of rainfall might be connected to the shifts in monsoon dynamics which can be affected by land–atmosphere interactions and local aerosol loading. These factors combined indicate that the climatic changes noticed in Chandrapur are the result of a mix of regional climate variability and localized anthropogenic activities, thereby showing the need for district-scale climate assessments.

5 Conclusions and Implications

5.1 Conclusions

This study presents a localized assessment of climate change in Chandrapur using a 33-year (1991–2024) meteorological dataset. The examination shows a clear rise in maximum and minimum temperatures, with summer (March–May) being hotter and longer, and the gradual warming of winter nights. Such transitions result in an increase of heat stress, power requirement, and public health and agricultural risks. The shifts in precipitation are reflected in the monsoon rains, with a decrease of rains in June and August along with an increase of rainfall in July as if the wet season is going to be shorter but more intense. Such shifts pose challenges for agricultural planning, water resource management, and flood risk. The results, though being in line with the larger national climate patterns, still point to

Chandrapur's increased susceptibility due to its industrial and agricultural nature that makes the planning of climate resilience specifically for the location more necessary.

5.2 Implications for Local Climate Adaptation

The observed trends emphasize the need for targeted heat-adaptation measures, including strengthened heat-action plans, early warnings, and protection for vulnerable populations during extreme summer periods. The changes in monsoon rains require alternative water management, for instance, better rainwater harvesting, groundwater recharge, and flood readiness. In farming, changing the calendars according to new climates and promoting towards climatic-resilient practices would be an effective way to alleviate or completely avoid risks related to climate. In the case of Chandrapur with its industrial setting, skills like integrating climate-responsive industrial planning and green cover protection can also release the area from the stress of local climate more. Such actions are proving that the evidence of local climate is capable of providing the basis for practical adaptation strategies.

Author Contributions

Conceptualization, L.P. and G.K.; methodology, L.P., P.A., G.K., N.R., M.K., and S.K.; software, L.P., P.A., G.K., N.R., M.K., and S.K.; validation, G.K., S.K., and M.K.; formal analysis, M.K.; investigation, L.P. and P.A.; resources, N.R. and S.K.; data curation, L.P., P.A., G.K., N.R., M.K., and S.K.; writing—original draft preparation, L.P., P.A., and G.K.; writing—review and editing, N.R., M.K., and S.K.; visualization, L.P. and P.A.; supervision, N.R.; funding acquisition, L.P., P.A., G.K., N.R., M.K., and S.K. All authors have read and agreed to the published version of the manuscript.

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Data Availability

The data used to support the research findings are available from the corresponding author upon request.

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Conflicts of Interest

The authors declare no conflict of interest.

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