Trend Analysis of Temperature Variations in Bihar: Assessing Climate Change Impacts and Deceleration Patterns

Keshav Kumar[1*], Mani Bhushan[2], Mansi Ranjan[3], Prava Gupta[4], Akash Ranjan[3], Supriya Sinha[3], Ashok Kumar Chaudhary[3]

[1] Assistant Professor, Dept. of Civil Engineering, Nalanda College of Engineering Chandi, DSTTE, Gov. of Bihar (India)
[2] Principal in Charge, Government Engineering College Khagaria, DSTTE, Gov. of Bihar (India)
[3] Assistant Professor, Nalanda College of Engineering Chandi, DSTTE, Gov. of Bihar (India)
[4] Assistant Professor (Assistant Director), DSTTE, Gov. of Bihar (India)
[*]Corresponding author: Keshav Kumar; Email: keshav151008@nitp.ac.in

Abstract
This study analyses long-term temperature trends in Bihar, India, with a specific focus on identifying potential deceleration patterns. Bihar, a region with significant agricultural and climatic variability, is highly sensitive to temperature changes, making trend analysis crucial for understanding climate change impacts, formulating mitigation strategies, and ensuring sustainable development.
To assess these trends, Mann-Kendall and Sen's Slope Estimator tests were applied to temperature data from the India Meteorological Department (IMD) in Patna for a 70-year period (1951–2021). Monthly, seasonal, and annual temperature trends were computed for selected districts, and the correlation between observed data and IMD datasets was analysed. The Mann-Kendall test results varied across districts, with values ranging from -0.258 to 0.442, while p-values ranged from 0.002 to 1.00, indicating varying levels of statistical significance.
The findings suggest minimal temperature variation across the selected districts, with a notable increase in warm days and a greater rise in minimum temperatures compared to maximum temperatures. Significant trends were observed in seasonal and annual minimum temperatures, potentially leading to an increased incidence of heat stress-related diseases and urban warming. This comprehensive analysis of temperature variation indices provides valuable insights into regional climate dynamics, which can aid policymakers and stakeholders in climate adaptation and resilience planning.

Keywords: Temperature Trends, Climate Change, Mann-Kendall Test, Sen's Slope Estimator

Introduction

Bihar, located in eastern India, is characterized by a subtropical climate with distinct seasonal variations, including hot summers and cool winters. Bordered by Nepal to the north, West Bengal to the east, Uttar Pradesh to the west, and Jharkhand to the south, the state has a predominantly agrarian economy that is highly sensitive to climatic variations (Kumar et al., 2021). In recent decades, climate change has emerged as a critical challenge, influencing regional temperature patterns and leading to potential socioeconomic and environmental consequences.
Global temperature rise and changing weather patterns have significant implications for Bihar, affecting agriculture, water resources, and public health. Long-term temperature trend analysis is essential for understanding climate change impacts and developing effective mitigation and adaptation strategies (IPCC, 2021). Historical temperature data from meteorological stations and satellite observations provide valuable insights into these changes, enabling researchers to assess trends and variability.
Trend analysis of temperature data helps identify patterns, including potential deceleration in warming trends, which is crucial for understanding climate variability and its broader implications (Brunetti et al. 2001; Chauche et al. 2010; Gebert and Krug 1996; Kampata et al. 2008; Marengo 2004). In Bihar, such analyses can offer insights into climate change vulnerabilities, particularly concerning agricultural productivity, hydrological cycles, and human health (Singh & Pandey, 2020). The winter season in Bihar is characterized by notably low temperatures, often ranging from 5°C to 10°C (Solomon 2007). This study investigates long-term temperature trends in Bihar, focusing on whether warming trends have decelerated over recent decades and the potential implications of these trends.
Understanding the deceleration of temperature trends in Bihar holds significant implications across multiple domains. This study contributes to the broader understanding of regional climate change by identifying long-term temperature variations and their potential deceleration patterns, thereby enhancing scientific knowledge and informing strategies to mitigate climate change impacts (Sharma et al., 2019). Shifts in temperature patterns directly affect ecosystems, biodiversity, and natural resources, making trend analysis crucial for identifying vulnerable regions and species, supporting conservation efforts, and promoting sustainable resource management (IPCC, 2021; Pant et al, 1999; mirza et al 1998). Given Bihar's strong reliance on agriculture, temperature fluctuations can impact crop yields, farming practices, and water availability. Recognizing trends and assessing the potential deceleration of temperature increases can aid in developing climate-resilient agricultural strategies, ensuring food security, and safeguarding rural livelihoods (Mishra & Tiwari, 2020). Furthermore, socioeconomic

consequences of rising minimum temperatures include increased heat stress-related illnesses and exacerbation of the urban heat island effect, necessitating adaptive strategies for urban planning, public health preparedness, and infrastructure resilience (Ghosh et al., 2022). The findings of this study also hold policy relevance by providing critical insights for evidence-based decision-making in climate adaptation, urban development, and disaster preparedness (Singh & Pandey, 2020). Additionally, situating Bihar's temperature trends within a broader regional and global context strengthens climate change discourse and fosters collaboration on climate resilience strategies at national and international levels (IPCC, 2021; Singh et al. 2008; Shrestha et al. 1999). By addressing these interconnected aspects, this research enhances scientific understanding of Bihar's climate dynamics and supports efforts to mitigate and adapt to climate change impacts effectively.

STUDY AREA

The study focuses on five districts in Bihar—Araria, Siwan, Aurangabad, Darbhanga, and Katihar—each selected for their distinct geographical and climatic characteristics. Bihar, located in eastern India, experiences a subtropical climate with significant seasonal variations, making it a critical region for analysing temperature trends and their potential deceleration. Araria, situated in the northeastern part of Bihar along the Nepal border, is characterized by fertile alluvial plains, where agriculture forms the backbone of the economy. The district, covering approximately 2,830 km², experiences substantial monsoonal influence, impacting both agricultural productivity and flood risks. Siwan, located in western Bihar, borders Uttar Pradesh and spans 2,219 km², with its economy primarily driven by the cultivation of paddy, wheat, maize, and sugarcane. The district's temperature trends are influenced by the monsoon and the climatic conditions of the Gangetic plains. Aurangabad, positioned in central Bihar, covers 10,100 km² and is one of the larger districts in the study area. The region's climate plays a vital role in its agricultural output and historical tourism significance. Darbhanga, known for its rich cultural heritage and Mithila art, occupies 2,279 km² in northern Bihar, where significant monsoonal rainfall impacts both agriculture and flood occurrences. Lastly, Katihar, located in northeastern Bihar near the West Bengal border, covers 3,056 km² and is traversed by the Ganges and its tributaries, contributing to its fertile plains and extensive agricultural activities. These districts represent diverse climatic conditions, ranging from flood-prone areas to relatively stable agricultural zones, making them ideal for studying regional temperature trends. Analysing the deceleration of temperature trends across these regions provides critical insights into climate variability, agricultural sustainability, and socio-economic resilience in Bihar. Geographical Details of the selected districts in Bihar are shown in Table 1.

Table 1: Geographical Details of Selected Districts in Bihar

District Name	Latitude (°N)	Longitude (°E)	Area (km²)	% of Total Area
Darbhanga	26.15	85.89	2,279	2.42%
Katihar	25.53	87.58	3,056	3.25%
Araria	26.15	87.52	2,830	3.00%
Aurangabad	19.88	75.32	10,100	10.73%
Siwan	26.22	84.36	2,219	2.36%

Data Collection

The temperature trend analysis in this study is based on data obtained from the India Meteorological Department (IMD), Patna. The provided dataset was in NetCDF (.nc) format, which was subsequently processed and converted into the required format using ArcGIS tools to facilitate analysis. Historical temperature data were collected for five districts in Bihar—Aurangabad, Siwan, Araria, Darbhanga, and Katihar—covering a 70-year period from 1951 to 2021. The dataset includes both monthly and annual temperature records to enable a comprehensive trend analysis.

This study primarily relies on secondary data sources to achieve its research objectives. The collected data were systematically extracted and processed to ensure consistency and reliability in trend detection. The use of long-term temperature records enhances the robustness of the analysis, allowing for an in-depth examination of temperature variations and potential deceleration patterns over time.

Methodology

To analyse temperature trends in Bihar, this study employs the Mann-Kendall (MK) Test to detect the presence of trends and the Sen's Slope Estimator to determine the magnitude of changes in the time series data. These non-parametric methods are widely used for hydro-climatic trend analysis due to their robustness against non-normal data distributions and missing values.

1. Mann-Kendall Test

The Mann-Kendall (MK) test is a non-parametric statistical test used to detect trends in hydro-climatic time series (Kendall, 1938). It is particularly useful for identifying monotonic trends, which represent consistent increases or decreases over time (Adamowski and Bougadis 2003; Hamed and Rao 1998; Kumar et al. 2022). The MK test statistic, denoted as M, is computed using the following equation :

$$M = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \operatorname{sgn}(Y_j - Y_i)$$

where, Y represents the time series data, and N is the number of data points. The sign function $\operatorname{sgn}(\Delta)$ is defined as:

$$\operatorname{sgn}(\Delta) = \begin{cases} +1, & \text{if } \Delta > 0 \\ 0, & \text{if } \Delta = 0 \\ -1, & \text{if } \Delta < 0 \end{cases}$$

The variance of the test statistic M is given by:

$$\operatorname{Var}(M) = \frac{N(N-1)(2N+5) - \sum_t t(t-1)(2t+5)}{18}$$

where, t represents the number of tied values in the dataset.

The standardized test statistic Z_M is then calculated as:

$$Z_M = \begin{cases} \frac{M-1}{\sqrt{\operatorname{Var}(M)}}, & \text{if } M > 0 \\ 0, & \text{if } M = 0 \\ \frac{M+1}{\sqrt{\operatorname{Var}(M)}}, & \text{if } M < 0 \end{cases}$$

If $|Z_M|$ is greater than 1.96, the null hypothesis (i.e., no trend in the time series) is rejected at a 95% confidence level, indicating the presence of a significant trend.

.

2. Sen's Slope Estimator

To quantify the magnitude of a detected trend, the non-parametric Sen's Slope Estimator is employed (Sen, 1968). This method assumes a linear trend in the time series, and calculates the slopes S_i of all possible data pairs:

$$S_i = \frac{Y_j - Y_k}{j - k}, \quad \forall i = 1, \ldots, P$$

where Y_j and Y_k and are data values at times j and k (where j > k). The Sen's slope estimator β is obtained by computing the median of all S_i values:

$$\beta = \operatorname{median}(S_i)$$

A positive β value indicates an increasing trend, whereas a negative β signifies a decreasing trend in the dataset. This combined methodology ensures a robust assessment of temperature trends in Bihar, providing both statistical significance and trend magnitude for a comprehensive analysis.

Results and Discussion

The trend analysis of temperature variations in Bihar from 1951 to 2021 was conducted using the Mann-Kendall test and Sen's slope estimator, applied to a dataset collected from five districts: Aurangabad, Siwan, Araria, Darbhanga, and Katihar. The analysis aims to assess significant temperature trends and potential deceleration patterns in the region due to climate change.

Both monthly and annual temperature data were analysed to compute key statistical parameters, including mean, standard deviation, and coefficient of variation, along with minimum and maximum temperature values. The results are presented in Tables 2 and 3. Additionally, the basic statistical attributes of the selected variables are provided in subsequent tables, categorized by month for each of the five districts separately.

The summary statistics for annual maximum temperature across five districts in Bihar (1951–2021) indicate notable spatial and temporal variations. May exhibits the highest mean maximum temperature, ranging from 30.87°C (Araria) to 37.43°C (Siwan), while January records the lowest values. Standard deviation (SD) and coefficient of variation (CV) suggest temperature variability, with February showing the highest CV in Araria

(10.12%), implying greater fluctuation. Comparatively, Siwan and Aurangabad experience higher maximum temperatures, while Araria and Darbhanga show greater variability. These variations highlight regional climatic differences, influencing hydro-meteorological conditions and necessitating district-specific climate adaptation strategies.

Table 2: Summary Statistics for Annual Maximum Temperature (°C) in Bihar (1951–2021)

Month	Araria (Mean ± SD, CV%)	Darbhanga (Mean ± SD, CV%)	Aurangabad (Mean ± SD, CV%)	Katihar (Mean ± SD, CV%)	Siwan (Mean ± SD, CV%)
January	20.41 ± 2.04, 9.98%	22.59 ± 2.26, 9.42%	22.96 ± 2.24, 9.75%	23.95 ± 2.04, 8.52%	22.35 ± 2.54, 11.35%
February	23.08 ± 2.34, 10.12%	26.19 ± 2.64, 10.08%	26.19 ± 2.83, 10.63%	27.27 ± 2.47, 9.05%	26.10 ± 2.73, 10.47%
March	27.53 ± 2.48, 9.01%	31.79 ± 2.91, 9.14%	31.93 ± 3.01, 9.31%	32.33 ± 2.60, 8.05%	31.81 ± 3.02, 9.50%
April	30.55 ± 2.41, 7.90%	36.36 ± 2.44, 6.71%	36.77 ± 2.53, 6.72%	35.53 ± 2.50, 7.04%	36.70 ± 2.46, 6.70%
May	30.87 ± 2.36, 7.64%	37.04 ± 2.62, 7.07%	35.15 ± 2.63, 6.73%	35.15 ± 2.47, 7.03%	37.43 ± 2.71, 7.24%
June	30.34 ± 2.07, 6.81%	35.63 ± 2.82, 7.92%	36.91 ± 3.47, 9.40%	34.07 ± 2.26, 6.63%	36.00 ± 3.11, 8.63%
July	29.33 ± 1.52, 5.17%	33.00 ± 1.69, 5.13%	32.67 ± 1.85, 5.67%	32.45 ± 1.46, 4.51%	33.06 ± 1.89, 5.71%
August	29.58 ± 1.50, 5.08%	32.85 ± 1.45, 4.42%	32.08 ± 1.36, 4.24%	32.33 ± 1.44, 4.41%	32.86 ± 1.48, 4.50%
September	29.30 ± 1.64, 5.60%	32.60 ± 1.66, 5.09%	31.99 ± 1.65, 5.16%	32.61 ± 1.43, 4.39%	31.71 ± 1.54, 5.24%
October	28.53 ± 1.67, 5.85%	31.76 ± 1.68, 5.37%	31.35 ± 1.68, 5.37%	31.63 ± 1.65, 5.18%	31.92 ± 1.67, 5.22%
November	25.94 ± 1.65, 6.38%	28.85 ± 1.59, 5.51%	28.42 ± 1.68, 5.89%	29.33 ± 1.54, 5.24%	28.91 ± 1.68, 5.82%
December	22.30 ± 1.86, 8.33%	24.42 ± 2.13, 8.74%	24.38 ± 1.90, 7.81%	25.65 ± 1.86, 7.24%	24.29 ± 2.32, 9.57%

Table 3: Summary Statistics for Annual Minimum Temperature (1951–2021) in Bihar Districts

Month	Siwan (Mean ± SD, CV%)	Aurangabad (Mean ± SD, CV%)	Darbhanga (Mean ± SD, CV%)	Araria (Mean ± SD, CV%)	Katihar (Mean ± SD, CV%)
January	8.98 ± 2.01, 22.41%	8.99 ± 2.12, 23.60%	9.65 ± 1.82, 18.83%	8.25 ± 1.46, 17.69%	10.58 ± 1.61, 15.18%
February	11.43 ± 2.14, 18.76%	11.72 ± 2.26, 19.30%	12.10 ± 2.04, 16.86%	10.40 ± 1.76, 16.95%	13.18 ± 1.89, 14.33%
March	15.86 ± 2.31, 14.56%	16.24 ± 2.25, 13.86%	16.55 ± 2.35, 13.58%	14.29 ± 1.90, 13.28%	17.54 ± 2.06, 11.76%
April	21.21 ± 1.99, 9.36%	21.61 ± 1.93, 8.91%	21.62 ± 1.85, 8.56%	18.19 ± 1.52, 8.36%	22.02 ± 1.61, 7.33%
May	24.40 ± 1.55, 6.34%	24.78 ± 1.48, 5.98%	24.59 ± 1.50, 6.10%	20.39 ± 1.33, 6.53%	24.19 ± 1.36, 5.64%
June	25.91 ± 1.16, 4.48%	25.81 ± 1.15, 4.45%	26.11 ± 1.03, 3.94%	22.02 ± 0.85, 3.84%	25.65 ± 0.86, 3.34%
July	25.82 ± 0.83, 3.20%	24.84 ± 0.75, 3.01%	26.06 ± 0.75, 2.86%	22.41 ± 0.63, 2.83%	25.83 ± 0.62, 2.41%
August	25.71 ± 0.70, 2.70%	24.61 ± 0.60, 2.44%	26.00 ± 0.66, 2.55%	22.53 ± 0.63, 2.79%	25.94 ± 0.61, 2.35%
September	24.98 ± 0.87, 3.47%	23.95 ± 0.78, 3.26%	25.35 ± 0.82, 3.24%	21.83 ± 0.74, 3.41%	25.28 ± 0.75, 2.96%
October	21.50 ± 2.22, 10.33%	20.42 ± 2.18, 10.70%	22.00 ± 2.07, 9.37%	19.00 ± 1.69, 8.88%	22.49 ± 1.78, 7.91%
November	15.02 ± 2.19, 14.57%	14.36 ± 2.15, 14.99%	15.36 ± 2.03, 13.36%	13.80 ± 1.71, 12.39%	16.66 ± 1.92, 11.53%
December	10.29 ± 1.87, 18.23%	9.90 ± 1.91, 19.27%	10.90 ± 1.74, 15.98%	9.69 ± 1.44, 14.83%	11.96 ± 1.57, 13.10%

Table 3 presents the summary statistics for annual minimum temperature (1951–2021) across five districts in Bihar. The lowest mean temperature occurs in January (8.25°C–10.58°C), while the highest is in July (24.84°C–26.06°C). Seasonal trends indicate cooler winters and warmer summers. The standard deviation (SD) is higher in winter months, indicating greater interannual variability, while lower SD in summer suggests more stable temperatures. The coefficient of variation (CV%) is highest in January (15.18%–23.60%), highlighting pronounced fluctuations, whereas July and August exhibit minimal variation (2.35%–3.20%). These variations provide insights into climate variability and regional temperature patterns.

TEMPERATURE VARIATION IN DIFFERENT DISTRICT OF BIHAR

The graphical representations across Figures 1 to 5 illustrate long-term trends (1951–2021) in maximum, minimum, and average temperatures across five districts of Bihar: Siwan, Araria, Aurangabad, Katihar, and Darbhanga. These plots offer insights into the regional climate variability and changing thermal profiles that could influence agricultural productivity, water resources, and broader ecosystem stability.

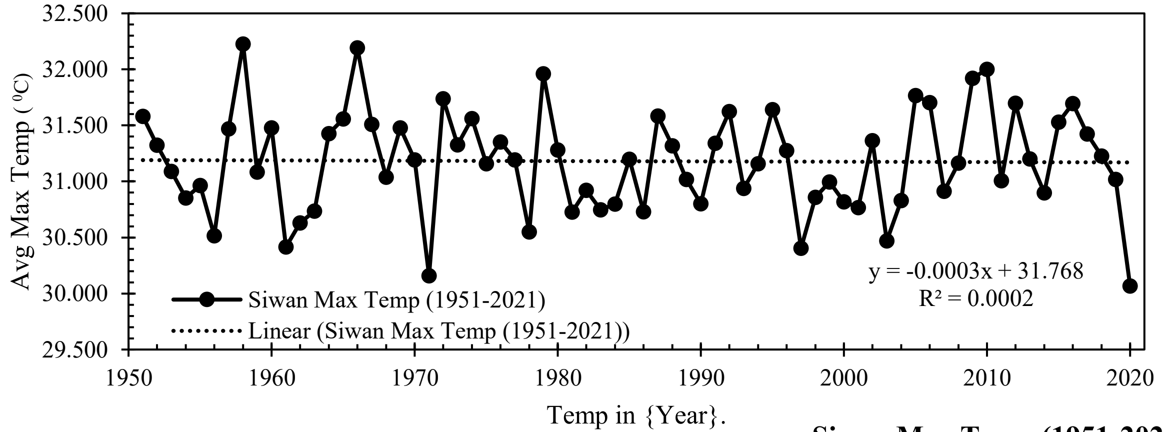
In Siwan, both maximum and minimum temperatures demonstrate slight declining trends with very low coefficients of determination ($R^2 = 0.0002$ for Tmax and $R^2 = 0.002$ for Tmin), indicating negligible correlation. The average of Tmax and Tmin also shows a minor decreasing trend ($R^2 = 0.0102$), suggesting marginal cooling.

Contrastingly, Araria exhibits significant warming trends, particularly in minimum temperature (Tmin), with a positive slope of 0.0057x and a relatively stronger R^2 value of 0.0351. Maximum temperature (Tmax) and average temperature (Tavg) also trend upwards, with R^2 values of 0.0687 and 0.1339 respectively, indicating a more consistent warming pattern in this region.

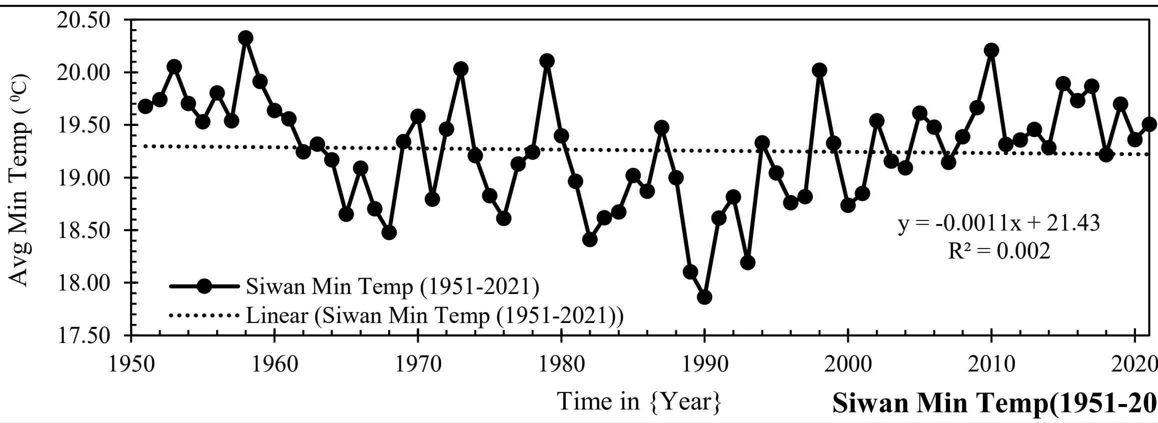
In Aurangabad, the Tmax and Tmin trends are weakly positive, with R^2 values of 0.0119 and 0.0126, respectively. However, the average temperature trend slightly decreases, indicating a mixed temperature behaviour possibly influenced by local microclimates or land-use changes.

Katihar shows a consistent warming trend with more pronounced increases in Tmax (slope = 0.0087x, R^2 = 0.1199) and Tmin (slope = 0.0036x, R^2 = 0.0147). The average temperature also increases, suggesting a warming climate scenario in this district.

In Darbhanga, the temperature trends are subtle. While Tmax shows a marginal increase (R^2 = 0.0045), Tmin and Tavg display relatively stronger warming signals with R^2 values of 0.0236 and 0.1339 respectively, especially for the average temperature.



Siwan Max Temp (1951-2021)



Siwan Min Temp(1951-2021)

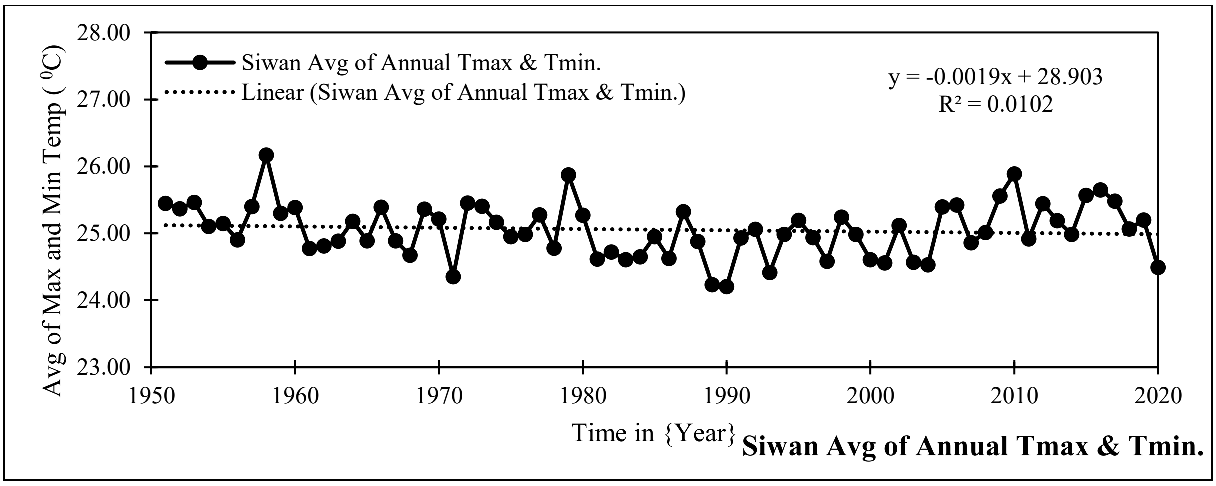
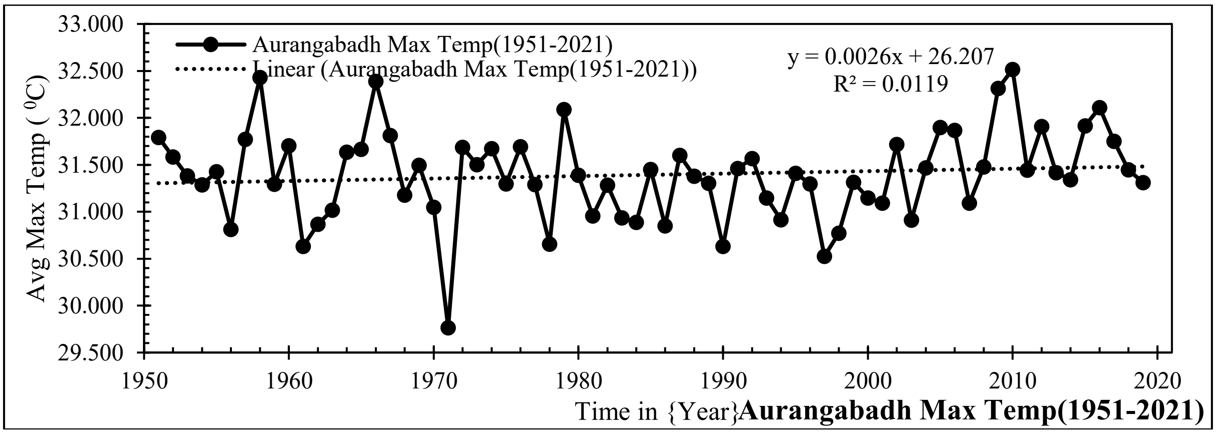
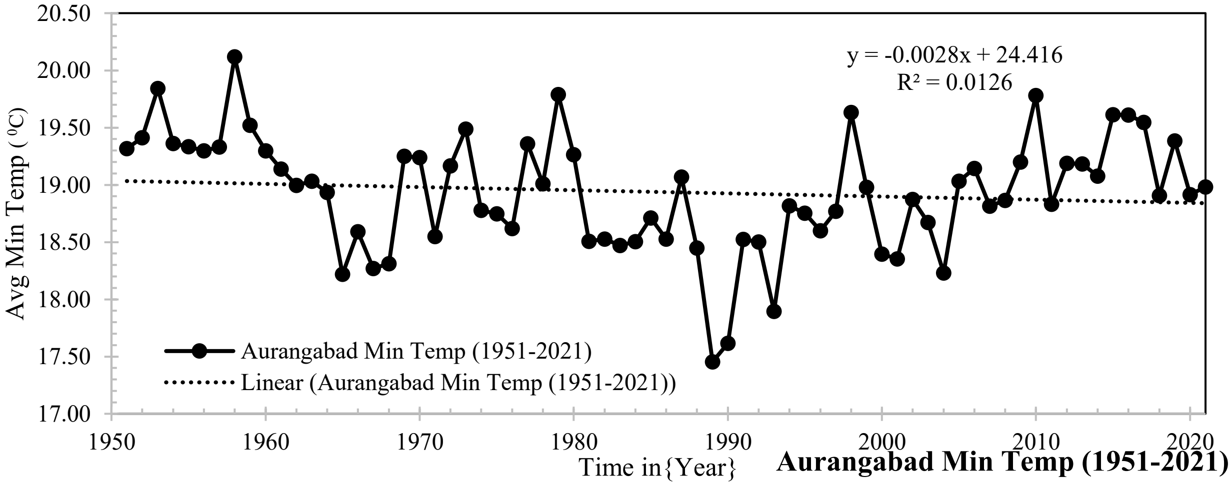


Figure 1: Graphical representation of Min, Max and Avg. of Min and Max temperature trend of Siwan for period (1951-2021)

Overall, the analysis reveals heterogeneity in temperature trends across these districts. Araria and Katihar exhibit more robust warming trends, particularly in Tmin, possibly due to increased urbanization or reduced nocturnal cooling. In contrast, Siwan and Aurangabad display either weak or declining trends, indicating potential regional cooling effects. These findings are crucial for climate adaptation planning and for understanding the spatial variability of climate change impacts within Bihar.





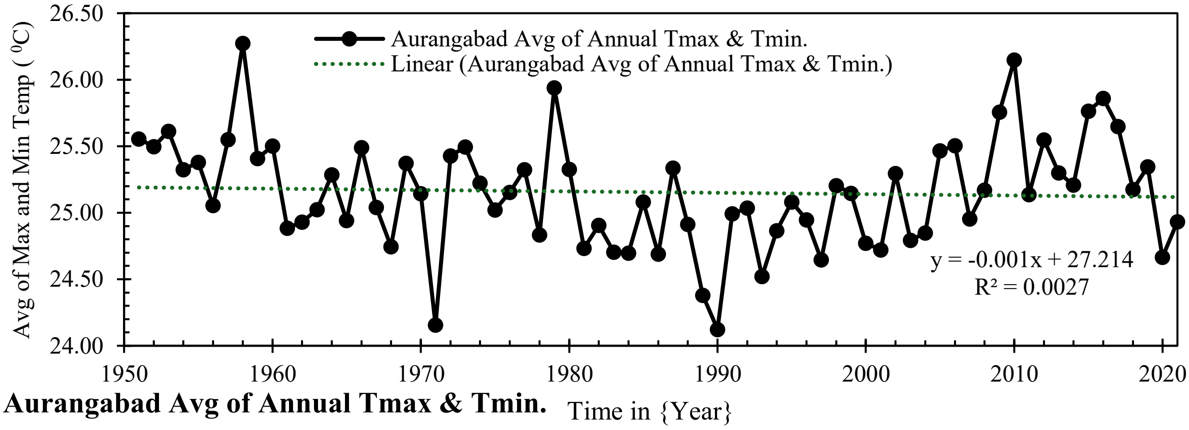


Figure 2: Graphical representation of Min, Max and Avg. of Min and Max temperature trend of Aurangabad for period (1951-2021)

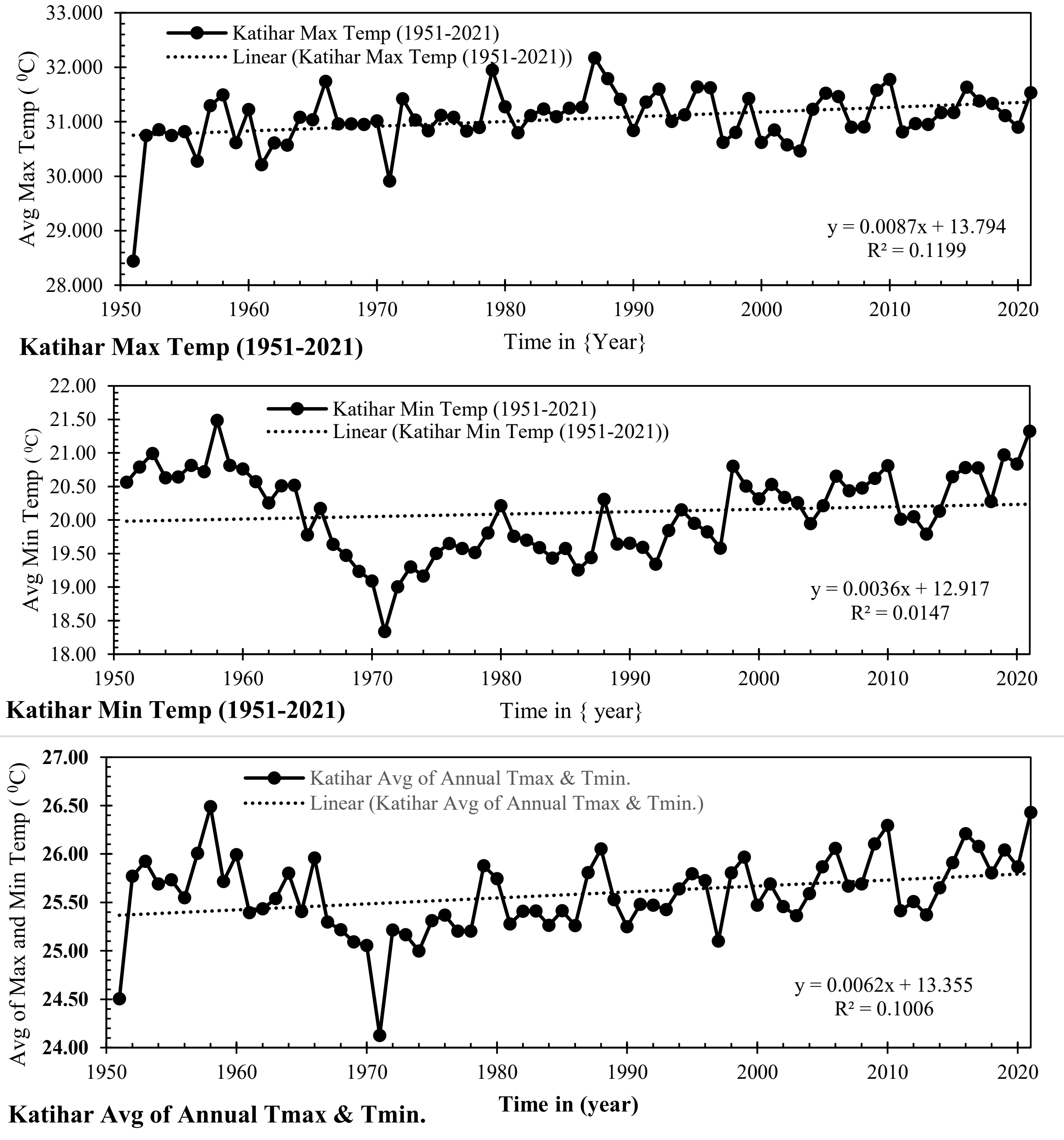


Figure 3: Graphical representation of Min, Max and Avg. of Min and Max temperature trend of Katihar for period (1951-2021)

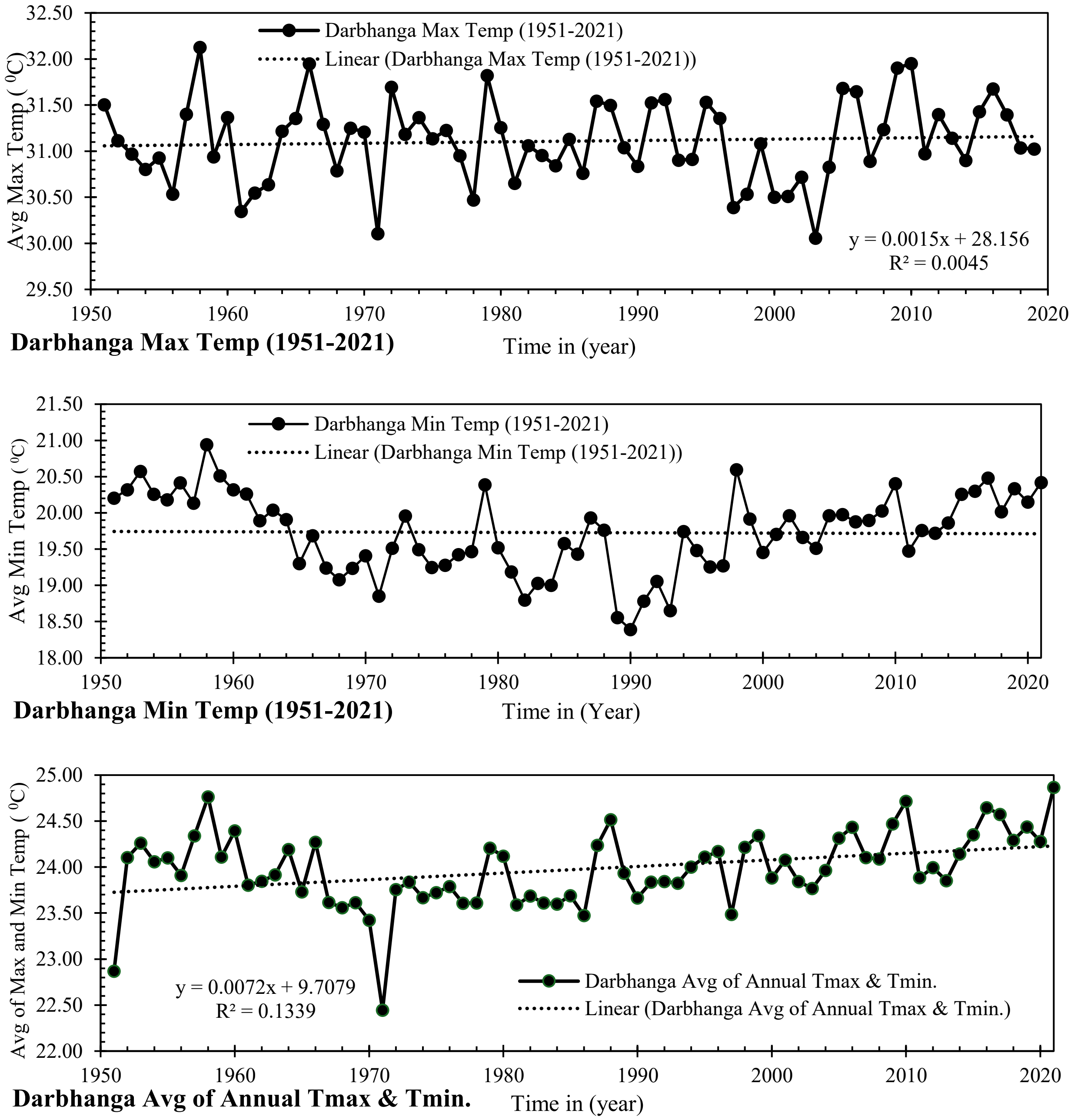
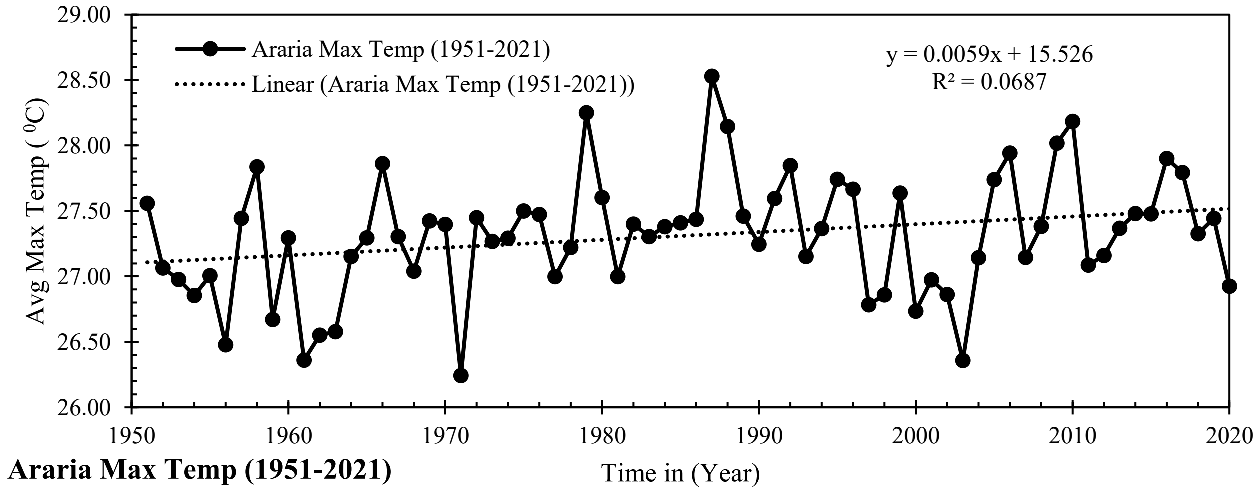


Figure 4: Graphical representation of Min, Max and Avg. of Min and Max temperature trend of Darbhanga for period (1951-2021)



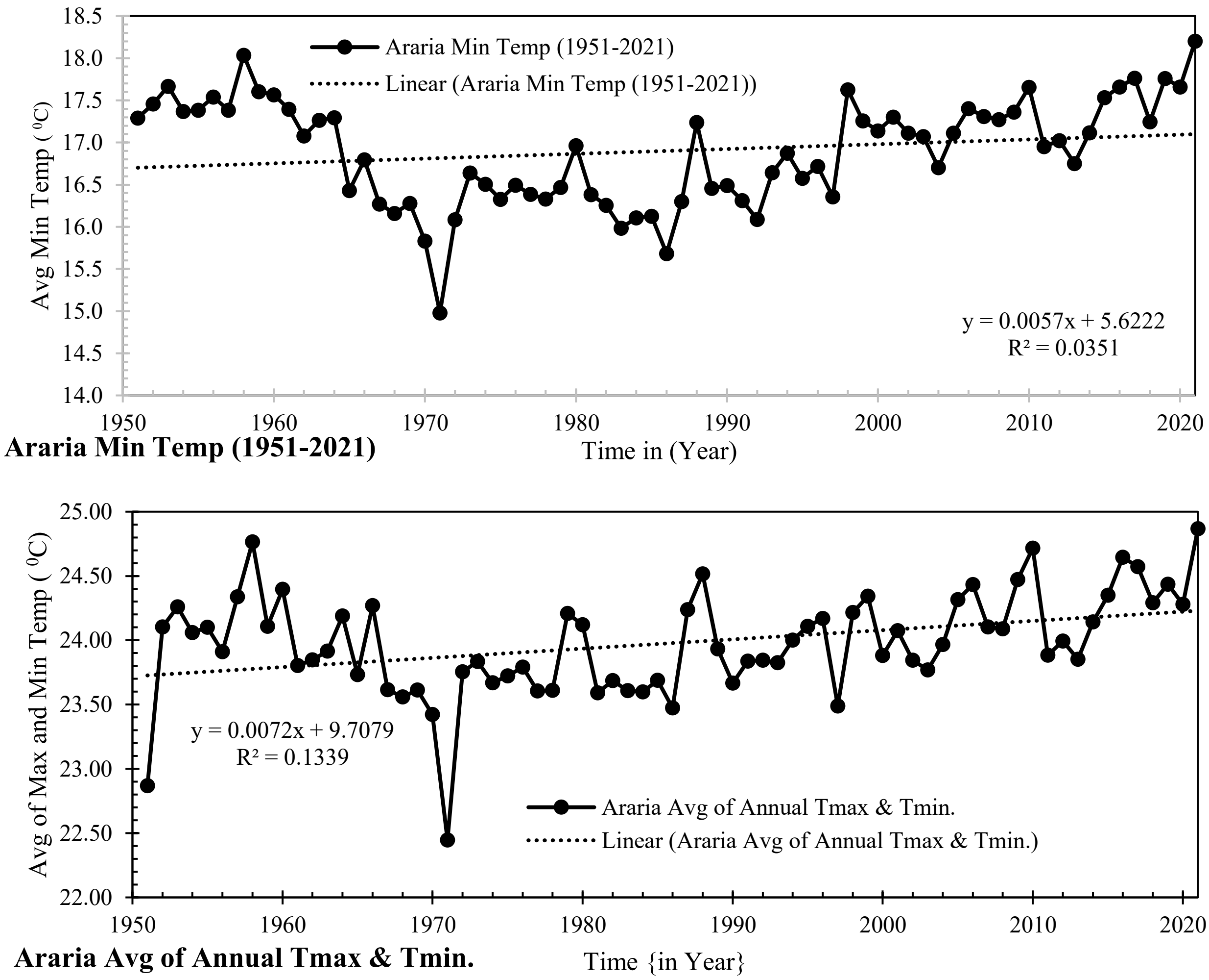


Figure 5: Graphical representation of Min, Max and Avg. of Min and Max temperature trend of Araria for period (1951-2021)

The monthly trend analysis using the Mann–Kendall test and Sen's slope estimator for the districts of Siwan, Araria, Darbhanga, Aurangabad, and Katihar provides insight into temporal variations in hydro-meteorological parameters, potentially influenced by climate change in Table 4 to 8. The analysis spans 12 months and evaluates trend direction, magnitude, and statistical significance at a 95% confidence level.

Table 4: Monthly Trend Analysis Using Mann-Kendall Test and Sen's Slope Estimator of Siwan District

Month	P-Value	Mann-Kendall τ	Sen's Slope	Trend Direction	Significance at 95%
January	0.003	-0.239	-0.015	Decreasing	Insignificant
February	0.484	0.058	0.006	No Trend	Insignificant
March	0.976	-0.003	0.000	No Trend	Insignificant
April	0.287	-0.087	-0.006	No Trend	Insignificant
May	0.002	-0.248	-0.020	Decreasing	Insignificant
June	0.429	-0.065	-0.006	No Trend	Insignificant
July	0.287	0.087	0.004	No Trend	Insignificant
August	0.001	0.265	0.009	Increasing	Insignificant
September	0.061	0.153	0.007	No Trend	Insignificant
October	0.323	0.081	0.004	No Trend	Insignificant
November	0.003	0.240	0.013	Increasing	Insignificant
December	0.481	-0.058	-0.003	No Trend	Insignificant

In Siwan district, decreasing trends were observed in January and May, while August and November exhibited increasing trends. However, all trends were statistically insignificant, indicating the absence of robust monthly changes over the assessed period.

For Araria district, an overall tendency toward increasing trends was noted from June to November. Particularly from June to October, positive Mann–Kendall values and Sen's slopes suggested upward trends, though these were not statistically significant at the 95% level. This suggests potential intra-annual variability but lacks strong evidence of significant change.

Table 5: Monthly Trend Analysis Using Mann-Kendall Test and Sen's Slope Estimator of Araria District

Month	P-Value	Mann-Kendall τ	Sen's Slope	Trend Direction	Significance at 95%
January	0.047	-0.163	-0.010	Decreasing	Insignificant Trend
February	0.260	0.092	0.008	No Trend	Insignificant Trend
March	0.181	0.110	0.008	No Trend	Insignificant Trend
April	0.356	-0.076	-0.006	No Trend	Insignificant Trend
May	0.260	-0.092	-0.007	No Trend	Insignificant Trend
June	0.009	0.215	0.012	Increasing	Insignificant Trend
July	0.008	0.395	0.017	Increasing	Insignificant Trend
August	0.005	0.442	0.016	Increasing	Insignificant Trend
September	0.002	0.293	0.011	Increasing	Insignificant Trend
October	0.004	0.236	0.012	Increasing	Insignificant Trend
November	0.000	0.307	0.016	Increasing	Insignificant Trend
December	1.000	0.000	0.000	No Trend	Insignificant Trend

Darbhanga district revealed a similar pattern, where July to November showed weak increasing trends. Decreasing trends were evident in January and May, with all trends classified as insignificant. This reflects stable hydro-meteorological behaviour without notable monthly shifts.

In Aurangabad district, January and May showed decreasing tendencies, while August and November indicated slight increases. Despite some variation in Sen's slope values, trends remained statistically insignificant across all months. This suggests relatively stable monthly patterns over the study period, with no strong monotonic changes.

Table 6: Monthly Trend Analysis Using Mann-Kendall Test and Sen's Slope Estimator of Darbhanga District

Month	P-Value	Mann-Kendall τ	Sen's Slope	Trend Direction	Significance at 95%
January	0.002	-0.251	-0.015	Decreasing	Insignificant Trend
February	0.577	0.046	0.004	No Trend	Insignificant Trend
March	0.951	0.005	0.000	No Trend	Insignificant Trend
April	0.136	-0.122	-0.008	No Trend	Insignificant Trend
May	0.008	-0.217	-0.017	Decreasing	Insignificant Trend
June	0.919	-0.009	-0.001	No Trend	Insignificant Trend
July	0.034	0.173	0.008	Increasing	Insignificant Trend
August	0.000	0.290	0.009	Increasing	Insignificant Trend
September	0.071	0.148	0.006	No Trend	Insignificant Trend
October	0.287	0.087	0.004	No Trend	Insignificant Trend
November	0.001	0.273	0.013	Increasing	Insignificant Trend
December	0.598	-0.043	-0.002	No Trend	Insignificant Trend

Katihar district presented the most dynamic pattern among the five. From June to November, consistent increasing trends were observed with highly significant p-values (<0.05), especially in July, August, and September ($p < 0.0001$), indicating a statistically significant increasing trend in these months. This highlights Katihar as a hotspot for monthly-scale changes, possibly linked to intensified rainfall or runoff during monsoonal months.

Table 7: Monthly Trend Analysis Using Mann-Kendall Test and Sen's Slope Estimator of Aurangabad District

Month	P-Value	Mann-Kendall τ	Sen's Slope	Trend Direction	Significance at 95%
January	0.019	-0.192	-0.013	Decreasing	Insignificant Trend
February	0.459	0.061	0.459	No Trend	Insignificant Trend
March	0.708	0.031	0.003	No Trend	Insignificant Trend
April	0.400	-0.069	-0.005	No Trend	Insignificant Trend
May	0.002	-0.258	-0.020	Decreasing	Insignificant Trend
June	0.491	-0.057	-0.007	No Trend	Insignificant Trend
July	0.201	0.105	0.005	No Trend	Insignificant Trend
August	0.012	0.207	0.007	Increasing	Insignificant Trend
September	0.055	0.157	0.006	No Trend	Insignificant Trend
October	0.584	0.045	0.002	No Trend	Insignificant Trend
November	0.005	0.228	0.014	Increasing	Insignificant Trend
December	0.497	-0.056	-0.003	No Trend	Insignificant Trend

Table 8: Monthly Trend Analysis Using Mann-Kendall Test and Sen's Slope Estimator of Katihar District

Month	P-Value	Mann-Kendall τ	Sen's Slope	Trend Direction	Significance at 95%
January	0.006	-0.225	-0.015	Decreasing	Insignificant

February	0.423	0.066	0.005	No Trend	Insignificant
March	0.367	0.074	0.006	No Trend	Insignificant
April	0.159	-0.116	-0.009	No Trend	Insignificant
May	0.136	-0.122	-0.01	No Trend	Insignificant
June	0.03	0.178	0.011	Increasing	Insignificant
July	<0.0001	0.376	0.015	Increasing	Insignificant
August	<0.0001	0.427	0.016	Increasing	Insignificant
September	0	0.287	0.01	Increasing	Insignificant
October	0.009	0.215	0.01	Increasing	Insignificant
November	0.001	0.261	0.014	Increasing	Insignificant
December	0.53	-0.052	-0.003	No Trend	Insignificant

Spatial Temperature Distribution Map

The Figure 6 to Figure 8 illustrate the monthly variation in minimum, maximum, and average temperatures across five districts in Bihar—Katihar, Araria, Darbhanga, Siwan, and Aurangabad—using spatial temperature distribution maps. These visuals offer valuable insights into seasonal patterns and regional climatic behaviour, critical for environmental monitoring, agricultural planning, and climate resilience initiatives.

Minimum Temperature Trends:

From January to December, the minimum temperature maps reveal a strong seasonal pattern. During winter months (December–February), temperatures drop significantly, particularly in the northern and northeastern districts such as Katihar and Araria, where values often fall below 10°C. These areas are depicted in cooler shades (yellow to light green), indicating relatively lower temperatures. As the seasons progress towards summer (April–June), minimum temperatures increase steadily across all districts, with most regions showing values above 25°C during peak summer. The spatial gradient shifts, showing warmer conditions extending across central and southern regions.

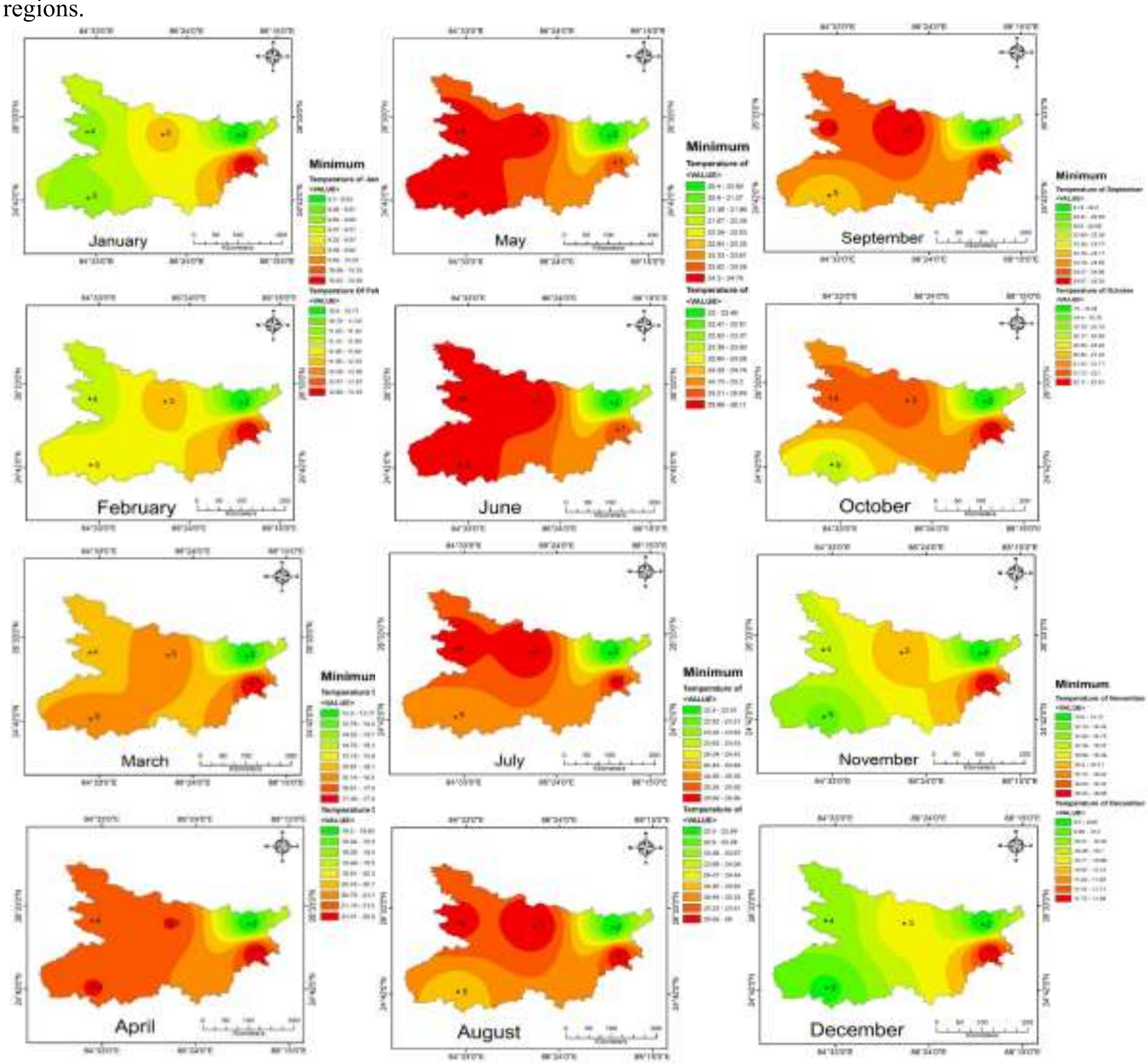
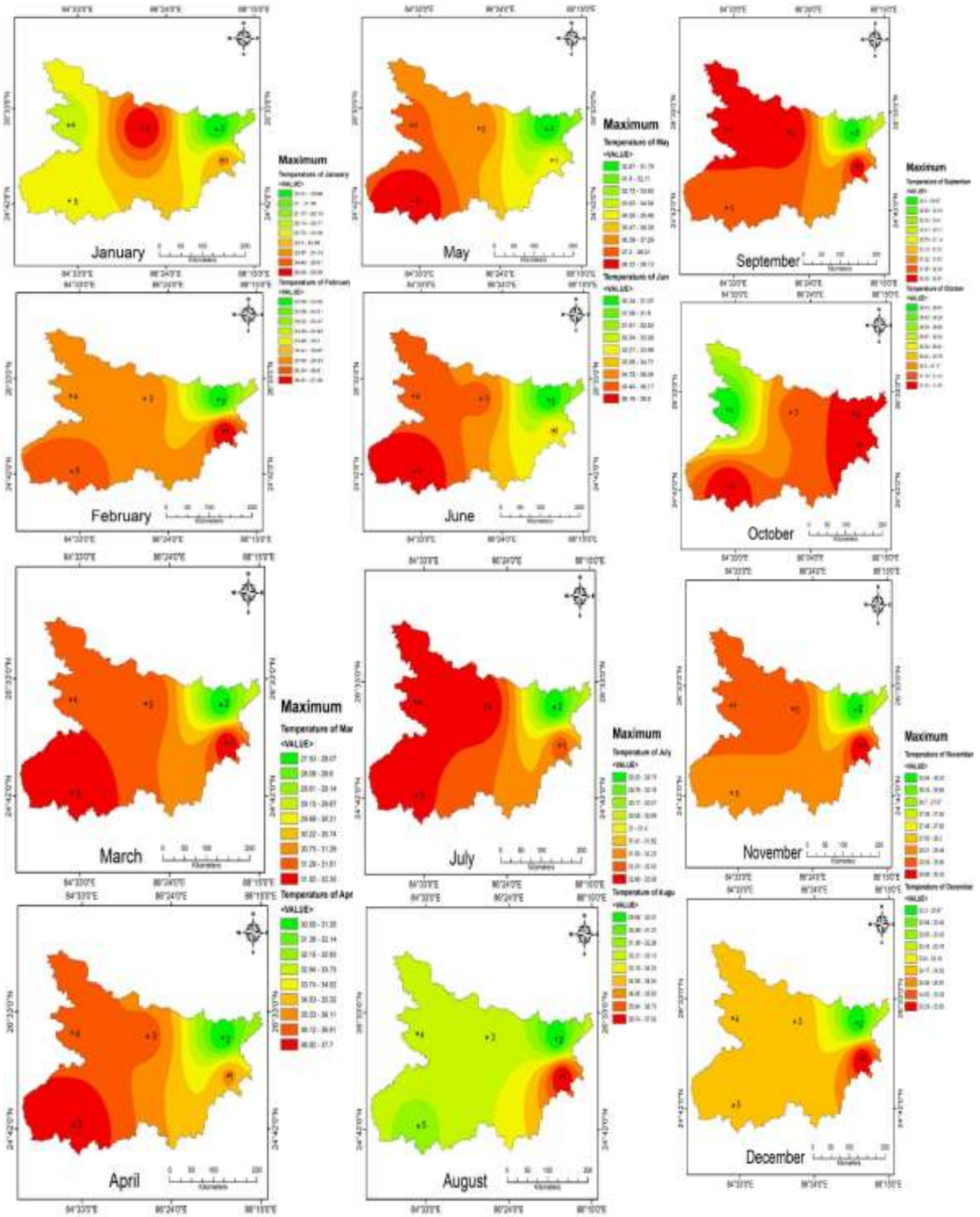


Figure 6: Variation of average minimum temp of five districts of Bihar (1-Katihar, 2-Araria, 3-Darbhanga, 4-Siwan and 5-Aurangabad)

Maximum Temperature Trends:

The maximum temperature maps show a pronounced warming trend from February through June, with the highest values observed during May and June. Aurangabad and Siwan, located in the southwestern part of Bihar, experience the most extreme temperatures, often surpassing 40°C, shown in deep red tones.

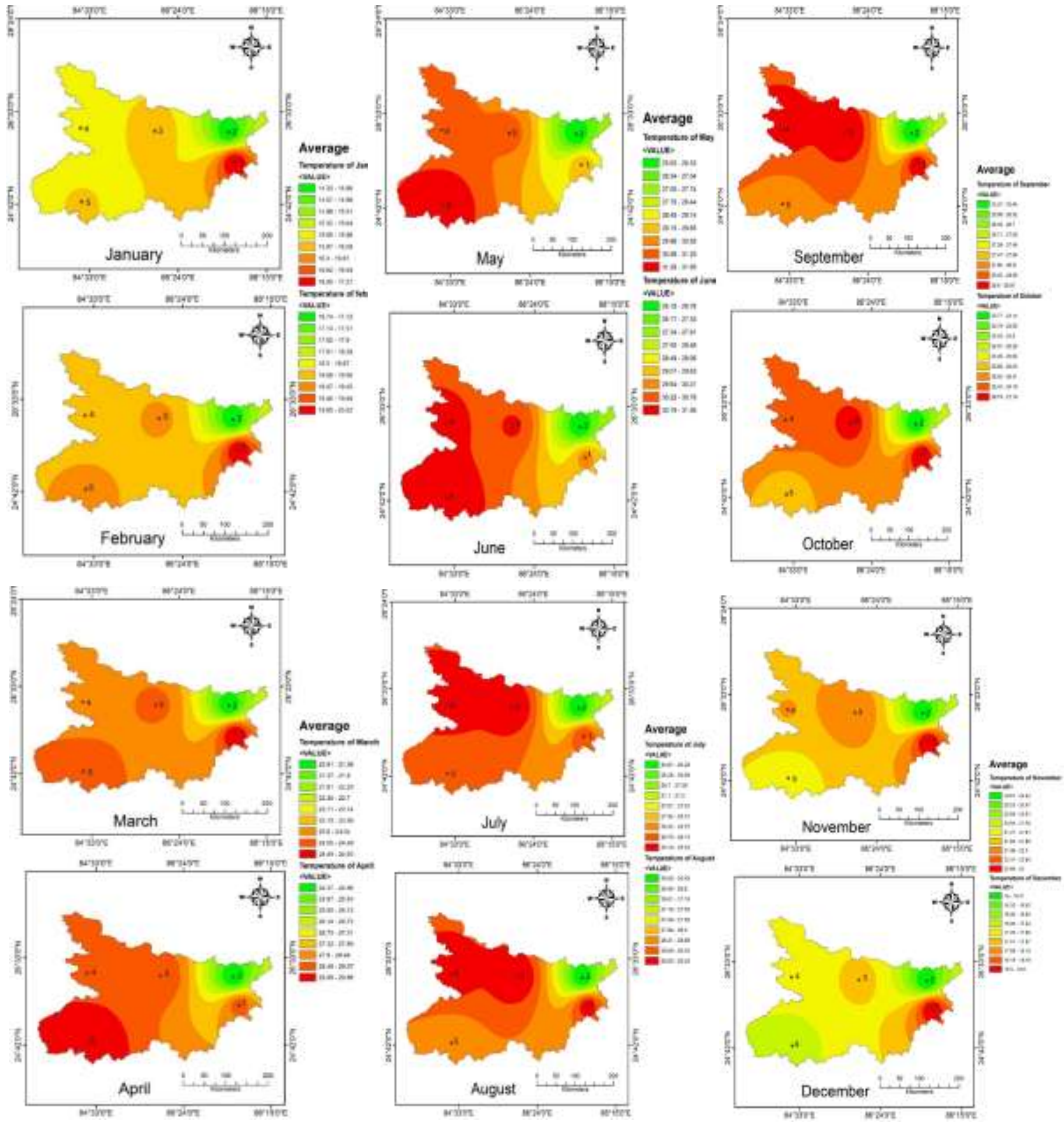


Variation of average maximum temp of five districts of Bihar (1-Katihar, 2-Araria, 3-Darbhanga, 4-Siwan and 5-Aurangabad)

These regions remain consistently warmer throughout the year. Monsoon months (July–September) bring a cooling effect, visible in the transition to lighter shades of orange and yellow, likely due to increased rainfall and cloud cover. Post-monsoon months (October–November) show a gradual decline in maximum temperatures.

Average Temperature Patterns:

The average temperature maps synthesize the minimum and maximum trends, offering a balanced view of the monthly climate. During winter, northern districts maintain cooler average temperatures, while southern regions remain comparatively warmer.



Variation of average temp of five districts of Bihar (1-Katihar, 2-Araria, 3-Darbhanga, 4-Siwan and 5-Aurangabad)

The summer months (March–June) exhibit a steady increase in mean temperatures, peaking in May. July through September show moderated temperatures due to monsoonal influence, with relatively uniform distribution across all five districts. By December, temperatures drop again, restoring the seasonal cycle.

Conclusion

This study presents a thorough examination of temperature trends in Bihar over a 70-year period (1951–2021), utilizing robust statistical methods such as the Mann-Kendall test and Sen's Slope Estimator to assess data sourced from the India Meteorological Department (IMD). The analysis indicates a notable trend of increasing minimum temperatures across the five districts studied: Aurangabad, Siwan, Araria, Darbhanga, and Katihar, with a maximum slope observed in warm days. Specifically, the results reveal a range of Mann-Kendall values from -0.258 to 0.442, signalling varying degrees of temperature trends among districts.

These findings underscore critical implications for agriculture and public health in a predominantly agrarian state like Bihar, where temperature increases can adversely affect crop yields and food security. The rise in warm days combined with significant increases in minimum temperatures could lead to higher instances of heat stress-related health issues, compounding public health challenges in urban areas.

Moreover, the diverse temperature trends across districts necessitate tailored adaptation strategies that reflect local climatic conditions. Policymakers must prioritize the integration of climate resilience into urban planning and agricultural practices to address the challenges posed by these trends effectively.

In conclusion, this analysis of temperature variations not only enhances our understanding of Bihar's climatic dynamics but also provides essential insights for developing effective intervention strategies to mitigate the impacts of climate change. Continued monitoring and research are paramount to inform future policies, ensuring sustainable development and resilience in the face of evolving climatic conditions.

Author declarations

Conflicts of interest: Authors state no known conflict of interest.
Author's contribution: Authors contributed equally.
Ethics declarations : The authors did not receive financial support from any organization for the submitted work. The authors declare they have no financial interests.

References

1. Adamowski, K., & Bougadis, J. (2003). Detection of trends in annual extreme rainfall. Hydrological Processes, 17(18), 3547-3560.
2. Brunetti, M., Colacino, M., Maugeri, M., & Nanni, T. (2001). Trends in the daily intensity of precipitation in Italy from 1951 to 1996. International Journal of Climatology, 21(3), 299-316.
3. Chaouche, K., Neppel, L., Dieulin, C., Pujol, N., Ladouche, B., Martin, E., ... & Caballero, Y. (2010). Analyses of precipitation, temperature and evapotranspiration in a French Mediterranean region in the context of climate change. Comptes Rendus. Géoscience, 342(3), 234-243.
4. Gebert, W. A., & Krug, W. R. (1996). STREAMFLOW TRENDS IN WISCONSIN'S DRIFTLESS AREA 1. JAWRA Journal of the American Water Resources Association, 32(4), 733-744.
5. Ghosh, P., Roy, A., & Bhaduri, S. (2022). Urban heat islands and health risks: Implications for climate resilience in India. Environmental Research Letters, 17(3), 1-12.
6. Hamed, K. H., & Rao, A. R. (1998). A modified Mann-Kendall trend test for autocorrelated data. Journal of hydrology, 204(1-4), 182-196.
7. Intergovernmental Panel on Climate Change (IPCC). (2021). Climate Change 2021: The Physical Science Basis. Cambridge University Press.
8. Kampata, J. M., Parida, B. P., & Moalafhi, D. B. (2008). Trend analysis of rainfall in the headstreams of the Zambezi River Basin in Zambia. Physics and Chemistry of the Earth, Parts A/B/C, 33(8-13), 621-625.
9. Kendall, M. G. (1938). A new measure of rank correlation. Biometrika, 30(1-2), 81-93.
10. Kumar, K., Singh, V., & Roshni, T. (2022). Variations of precipitation and runoff in the Bagmati river basin, Bihar, India. Water Practice & Technology, 17(12), 2554-2569.
11. Kumar, R., Singh, S., & Mishra, V. (2021). Assessing climate variability and its impact on agriculture in Bihar, India. Journal of Climate Studies, 9(2), 45-62.
12. Marengo, J.A. (2004) Interdecadal variability and trends of rainfall across the Amazon basin. Theoretical and Applied Climatology 78, 79-96.
13. Mirza, M. Q., Warrick, R. A., Ericksen, N. J., & Kenny, G. J. (1998). Trends and persistence in precipitation in the Ganges, Brahmaputra and Meghna river basins. Hydrological Sciences Journal, 43(6), 845-858.
14. Mishra, P., & Tiwari, R. (2020). Temperature variations and their impacts on food security in India: A case study of Bihar. Agricultural Economics Review, 11(1), 77-94.
15. Pant, G. B., Rupa Kumar, K., & Borgaonkar, H. P. (1999). Climate and its long-term variability over the western Himalaya during the past two centuries. The Himalayan Environment, 171-184.
16. Pratap Singh, P. S., Vijay Kumar, V. K., Thomas, T., & Manohar Arora, M. A. (2008). Basin-wide assessment of temperature trends in northwest and central India.
17. Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. Journal of the American statistical association, 63(324), 1379-1389.
18. Sharma, N., Gupta, A., & Verma, R. (2019). Temperature trends and climate change implications in South Asia. Climate Research Journal, 6(1), 88-102.
19. Shrestha, A. B., Wake, C. P., Mayewski, P. A., & Dibb, J. E. (1999). Maximum temperature trends in the Himalaya and its vicinity: an analysis based on temperature records from Nepal for the period 1971–94. Journal of climate, 12(9), 2775-2786.
20. Singh, R., & Pandey, M. (2020). Climate change adaptation strategies in Bihar: An assessment of temperature trends and mitigation measures. Environmental Policy and Research, 5(3), 112-126.
21. Singh, R., & Pandey, M. (2020). Climate change adaptation strategies in Bihar: An assessment of temperature trends and mitigation measures. Environmental Policy and Research, 5(3), 112-126.
22. Solomon, S. D. (2007). Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change 2007.