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SPATIAL HETEROGENEITY IN LONG-TERM DIURNAL TEMPERATURE RANGE TRENDS ACROSS KARNATAKA, INDIA (1958–2024)

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ABSTRACT

Diurnal temperature range (DTR), the difference between daily maximum and minimum temperature, is an important indicator of asymmetric warming. This study analyses long-term spatial variability in DTR across Karnataka, India, using district-level temperature series derived from the TerraClimate dataset for 1958–2024. Annual DTR trends were evaluated using the non-parametric Mann–Kendall test and Sen's slope estimator. Results indicate pronounced spatial heterogeneity across districts. Increasing DTR trends occur primarily in southern Karnataka, whereas decreasing trends dominate northern semi-arid regions. Several coastal districts exhibit weak or non-significant trends. These findings demonstrate that aggregated temperature indicators mask substantial regional variability in diurnal thermal behaviour.

KEYWORDS: Climate variability; diurnal temperature range; Karnataka; mann–kendall test; spatial analysis.

INTRODUCTION

Diurnal temperature range (DTR), the difference between daily maximum (Tmax) and minimum (Tmin) temperatures, captures changes in the relative behaviour of daytime and nighttime temperatures that are not evident from mean temperature alone. DTR is influenced by cloud cover, atmospheric moisture, surface radiation, soil moisture and land-surface characteristics, making its long-term variation useful for examining regional differences in warming.

Changes in DTR have been observed across many regions, often reflecting unequal rates of change in Tmax and Tmin. Karl *et al.* (1993) reported faster increases in minimum than maximum temperatures across many locations, resulting in a decline in DTR. Subsequent studies have related DTR variability to precipitation, cloud cover and associated changes in surface radiation (Zhou *et al.,* 2009). In India, Roy and Balling (2005) reported an inverse association between DTR and cloud cover, indicating the importance of cloudiness in modifying daytime and nighttime temperature differences.

Long-term temperature records for India also show marked spatial variation in the behaviour of Tmax and Tmin (Kumar *et al.,* 1994; Kothawale and Rupa Kumar, 2005; Mall *et al.,* 2021). Dhorde *et al*. (2017) identified spatial differences in temperature trends across Maharashtra and Karnataka, while Mohapatra (2002) reported changes in DTR over Bengaluru in association with urbanisation and local environmental change. At the district scale, Simpson *et al.* (2024) documented spatial variation in temperature and rainfall trends across Karnataka. Their analysis, however, did not specifically examine DTR. District-level evidence on long-term DTR trends across Karnataka therefore remains limited.

This gap is important because Karnataka contains markedly different climatic regions, ranging from the humid coast and Western Ghats to the semi-arid interior. State-level averages may therefore conceal differences in the relative rates of daytime and nighttime warming. Gridded climate data make it possible to examine these differences consistently across districts and over long periods, including areas where station coverage may be uneven.

The present study examines long-term DTR trends across Karnataka using district-level Tmax and Tmin series derived from TerraClimate for 1958–2024. The Mann–Kendall test and Sen's slope estimator are used to assess the direction, statistical significance and magnitude of trends. The analysis focuses on whether the relatively stable statewide DTR pattern masks contrasting trends

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among districts and on the spatial distribution of these changes across Karnataka.

MATERIAL AND METHODS

Study Area

Karnataka is located in southern India between approximately 11°–18° N latitude and 74°–78° E longitude. The state encompasses diverse climatic and physiographic regions, including the humid coastal belt along the Arabian Sea, the elevated Western Ghats mountain range, and the semi-arid interior plateau. These regions differ substantially in rainfall, temperature regimes, elevation, and land-surface characteristics. Annual rainfall exceeds 3,000 mm in parts of the Western Ghats but falls below 600 mm in northern interior districts. Temperature conditions also vary considerably across these zones due to differences in altitude, continentality, and proximity to maritime influences. This pronounced environmental heterogeneity makes Karnataka an appropriate region for examining spatial patterns and long-term variability in diurnal temperature range.

Climate Data

Monthly maximum temperature (Tmax) and minimum temperature (Tmin) data were obtained from the TerraClimate dataset, a high-resolution global climate dataset providing monthly climate and water balance variables at approximately 1/24° spatial resolution (~4 km). TerraClimate integrates high-resolution climatology with global reanalysis data and station observations to generate spatially consistent climate fields (Abatzoglou *et al.,* 2018). The dataset covers the period from 1958 onward and is widely used for long-term climate analyses.

District-level temperature series were derived by overlaying Karnataka district boundary polygons on the TerraClimate grid. Monthly Tmax and Tmin values were calculated as spatial averages of all grid cells intersecting each district boundary. Diurnal temperature range (DTR) was then computed as the difference between Tmax and Tmin for each district and month. The monthly district-level series spanning 1958–2024 were subsequently aggregated to annual averages to construct long-term time series for trend analysis.

Trend Detection: Mann–Kendall Test

Long-term trends in annual DTR were evaluated using the non-parametric Mann–Kendall (MK) test. The MK test is widely used in climatological studies because it does not require the data to follow a specific distribution and is robust to outliers. The method assesses whether a monotonic upward or downward trend exists in a time series.

For a time series $x_1,x_2,\ldots,x_n$, the MK test statistic Sis calculated as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i)$$

where the sign function is defined as:

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

Under the null hypothesis of no trend, the variance of Sis given by:

$$Var(S) = \frac{n(n-1)(2n+5)}{18}$$

The standardized test statistic Zis then computed as:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}, & S > 0 \\ 0, & S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}}, & S < 0 \end{cases}$$

A positive value of Zindicates an increasing trend, whereas a negative value indicates a decreasing trend. Statistical significance was assessed at the 5 per cent significance level ($p<0.05$).

Estimation of Trend Magnitude: Sen's Slope

The magnitude of the monotonic trend in DTR was estimated using Sen's slope estimator. This method calculates the median slope of all possible pairs of observations in the time series and provides a robust estimate of the rate of change over time.

For all pairs of observations (x_i,x_j) where $j>i$, the slope is calculated as:

$$Q_i = \frac{x_j - x_i}{j - i}$$

Table 1. District-wise Mann–Kendall (MK) test statistics and Sen's slope estimates for diurnal temperature range (DTR) across Karnataka for the period 1958–2024. Positive (negative) Z values and Sen's slopes indicate increasing (decreasing) DTR trends. Statistically significant trends are identified at the 5% significance level.

District	Z	S	Var(S)	p_value	Trend	Sen_slope	Intercept
Bagalkote	-3.5177	-651	34143	0.0004	decreasing	-0.0057	11.3170
Ballari	-0.5358	-100	34144	0.5921	no trend	0.0000	11.0121
Bengaluru	3.6477	675	34141	0.0003	increasing	0.0058	11.1542
Belagavi	-3.5987	-666	34146.67	0.0003	decreasing	-0.0065	11.5871
Bengaluru Rural	3.8911	720	34144	0.0001	increasing	0.0058	11.1441
Bidar	-3.8803	-718	34144	0.0001	decreasing	-0.0078	11.6921
Chamarajanagara	3.1495	583	34147.67	0.0016	increasing	0.0056	10.2054
Chikkaballapura	3.7559	695	34143	0.0002	increasing	0.0059	11.0051
Chikkamagaluru	2.1268	394	34144	0.0334	increasing	0.0034	9.9914
Chitradurga	2.1051	390	34146.67	0.0353	increasing	0.0026	10.9394
Dakshina Kannada	2.4569	455	34145.67	0.0140	increasing	0.0041	7.9399
Davanagere	0.8605	160	34144	0.3895	no trend	0.0001	11.0914
Dharwad	-2.5922	-480	34146.67	0.0095	decreasing	-0.0038	11.1348
Gadag	-2.2837	-423	34145.67	0.0224	decreasing	-0.0032	11.3598
Hassan	3.2253	597	34147.67	0.0013	increasing	0.0051	10.0233
Haveri	-0.9092	-169	34145.67	0.3633	no trend	-0.0003	10.8915
Kalaburagi	-3.8153	-706	34144	0.0001	decreasing	-0.0074	12.1091
Kodagu	3.2254	597	34145.67	0.0013	increasing	0.0051	8.3120
Kolar	3.3283	616	34144	0.0009	increasing	0.0057	10.7992
Koppal	-2.1160	-392	34144.67	0.0343	decreasing	-0.0026	11.2027
Mandya	3.4310	635	34145.67	0.0006	increasing	0.0057	10.6334
Mysuru	3.4798	644	34144.67	0.0005	increasing	0.0056	9.6164
Raichur	-2.0131	-373	34147.67	0.0441	decreasing	-0.0030	11.2624
Ramanagara	3.4041	630	34142	0.0007	increasing	0.0057	11.0397
Shivamogga	1.0228	190	34146.67	0.3064	no trend	0.0002	10.0901
Tumakuru	3.4580	640	34146.67	0.0005	increasing	0.0055	11.0396
Udupi	1.3150	244	34146.67	0.1885	no trend	0.0018	8.2091
Uttara Kannada	-1.8021	-334	34146.67	0.0715	no trend	-0.0025	9.4733
Vijayapura	-3.8368	-710	34146.67	0.0001	decreasing	-0.0066	12.0402
Yadgir	-2.3921	-443	34143	0.0168	decreasing	-0.0049	11.6097

The Sen's slope estimate is the median of all calculated slopes: Q="median"(Q_i)

Positive values of Qindicate increasing trends, while negative values indicate decreasing trends. The slope values represent the annual rate of change in diurnal temperature range for each district.

Data Processing and Analysis

All data processing and statistical analyses were conducted using Python within the Spyder integrated development environment. Spatial aggregation of TerraClimate data to district boundaries was performed using geospatial libraries, and statistical analyses were implemented using standard scientific computing packages. Trend statistics and slope estimates were computed for each district-level DTR time series covering the period 1958–2024.

RESULTS AND DISCUSSION

Temporal Evolution of Statewide Diurnal Temperature Range

The annual mean diurnal temperature range (DTR) averaged across Karnataka exhibits moderate inter-annual variability over the period 1958–2024 (Fig. 6). Statewide mean DTR values generally fluctuate between approximately 10 and 11.3 °C, indicating relatively stable long-term thermal variability at the aggregated scale. Although both maximum temperature (Tmax) and minimum temperature (Tmin) show gradual increases over time (Fig. 1), their broadly concurrent behaviour results in limited long-term change in the state-averaged DTR series.

Temporal fluctuations are nevertheless evident across different decades. Higher DTR values occur during parts of the 1960s, followed by relatively lower averages during the 1970s. Subsequent decades show gradual recovery and stabilization, with moderate year-to-year variability persisting through the most recent period. These results suggest that while long-term warming has occurred across Karnataka, the relative balance between daytime and nighttime temperatures has remained broadly stable when averaged across the entire state. However, aggregated averages may conceal important spatial differences in temperature behaviour across districts.

Spatial Distribution of District-Level DTR

Substantial spatial variability in DTR is observed across Karnataka districts (Fig. 7). Coastal districts such as Dakshina Kannada, Udupi, and Uttara Kannada exhibit relatively low median DTR values, typically around 8 °C, with comparatively narrow distributions. These patterns are consistent with the moderating influence of maritime air masses, higher humidity, and persistent cloud cover, which tend to reduce daytime heating and limit diurnal thermal contrasts.

In contrast, interior semi-arid districts including Kalaburagi, Vijayapura, Bagalkote, Gadag, and Ballari display higher median DTR values, often exceeding 11–12 °C. These districts also exhibit wider interquartile ranges, reflecting greater inter-annual variability in diurnal thermal conditions. The larger DTR values observed in these regions are consistent with lower humidity, reduced cloud cover, and stronger daytime heating typical of continental semi-arid climates.

Districts located within transitional or topographically complex regions, including Belagavi, Shivamogga, and Chikkamagaluru, show broader distributions and occasional outliers in DTR values. These patterns suggest greater sensitivity to inter-annual climatic variability in areas influenced by both coastal and interior climatic regimes.

Relationship between daytime and nighttime Temperatures

The spatial distribution of long-term mean Tmax and Tmin across districts is shown in Fig. 4. The relationship between annual mean Tmax and Tmin across Karnataka demonstrates a strong positive association (Fig. 5), indicating that warming trends generally involve concurrent increases in both daytime and nighttime temperatures. However, the dispersion of Tmin values varies across the Tmax range. Lower Tmax values, typically associated with higher-elevation or coastal districts, correspond to relatively narrow Tmin ranges. In contrast, intermediate Tmax values display a wider spread in Tmin, reflecting greater variability in nighttime temperatures across districts.

At higher Tmax levels, Tmin tends to increase more rapidly, suggesting stronger nighttime warming in warmer interior districts. Such behaviour may be associated with regional differences in atmospheric moisture, land-surface conditions, or radiative processes

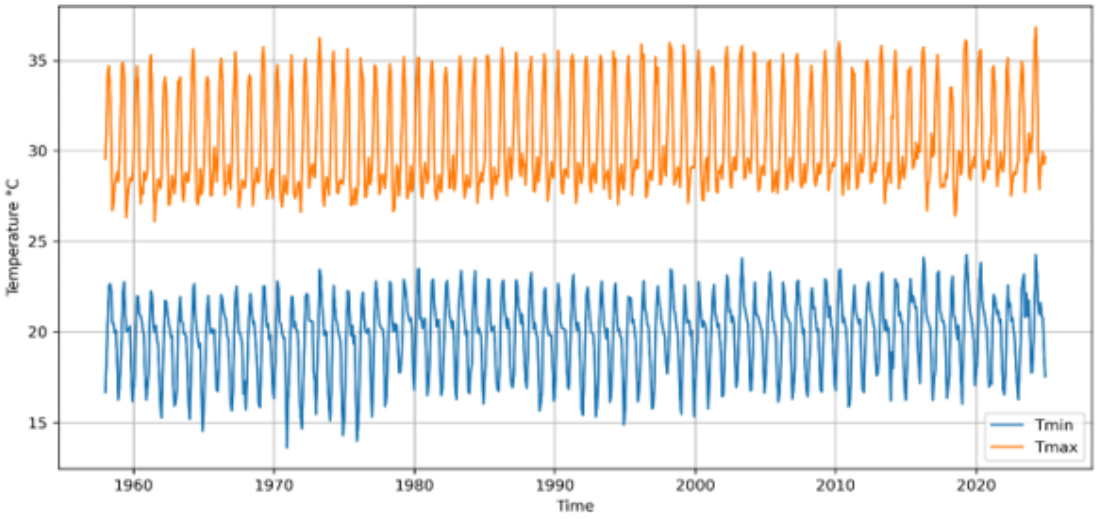


Fig. 1. Temporal evolution of annual mean maximum temperature (Tmax) and minimum temperature (Tmin) averaged across Karnataka for the period 1958–2024, illustrating concurrent warming behaviour

that influence nighttime heat retention. These variations in the relative behaviour of Tmax and Tmin contribute to spatial differences in DTR trends across the state.

Decadal Changes in Tmax and Tmin

Decadal averages of Tmax indicate a consistent increase across most districts from the earlier period (1960–1980) to the more recent period (2000–2024) (Fig. 2). Northern and north-eastern districts maintain the highest daytime temperatures throughout the study period, while districts in the Western Ghats and southern regions remain comparatively cooler due to elevation and maritime influences. Nevertheless, the overall pattern suggests widespread warming across Karnataka in recent decades.

Minimum temperature trends show a broadly similar pattern of long-term increase (Fig. 3). Coastal and Western Ghats districts consistently exhibit higher Tmin values relative to interior regions, reflecting the moderating effects of humidity and cloud cover. However, interior districts display notable increases in Tmin over time, indicating progressive nighttime warming across much of the state.

Spatial Patterns of DTR Trends

Results from the Mann–Kendall trend analysis and Sen's slope estimation reveal pronounced spatial heterogeneity in long-term DTR trends across Karnataka (Table 1; Fig. 8). Of the 30 districts analysed, 14 exhibit statistically significant increasing trends, 10 display statistically significant decreasing trends, and 6 show no statistically significant monotonic trend.

Increasing DTR trends are primarily concentrated in southern and south-eastern districts, including Bengaluru, Bengaluru Rural, Chikkaballapura, Mandya, Mysuru, Tumakuru, Kolar, Hassan, Kodagu, Ramanagara, Dakshina Kannada, and Chamarajanagara. Sen's slope estimates for these districts range from approximately 0.0026 to 0.0059 °C yr^{-1}, indicating persistent long-term increases in diurnal temperature range.

In contrast, decreasing DTR trends dominate northern and north-eastern semi-arid districts such as Bidar, Kalaburagi, Vijayapura, Bagalkote, Belagavi, and Yadgir. These districts exhibit Sen's slope values ranging from approximately −0.0026 to −0.0078 °C yr^{-1}, indicating gradual compression of diurnal temperature range over time.

Districts without statistically significant trends show near-zero Sen's slope estimates, suggesting relatively stable long-term DTR conditions or offsetting inter-annual fluctuations. Baseline DTR levels also vary substantially across districts, with lower intercept values observed in coastal and Western Ghats regions and higher values in interior semi-arid districts.

Interpretation of Spatial Trends

The contrasting spatial patterns observed in this study highlight the importance of regional climatic and environmental factors in shaping diurnal thermal

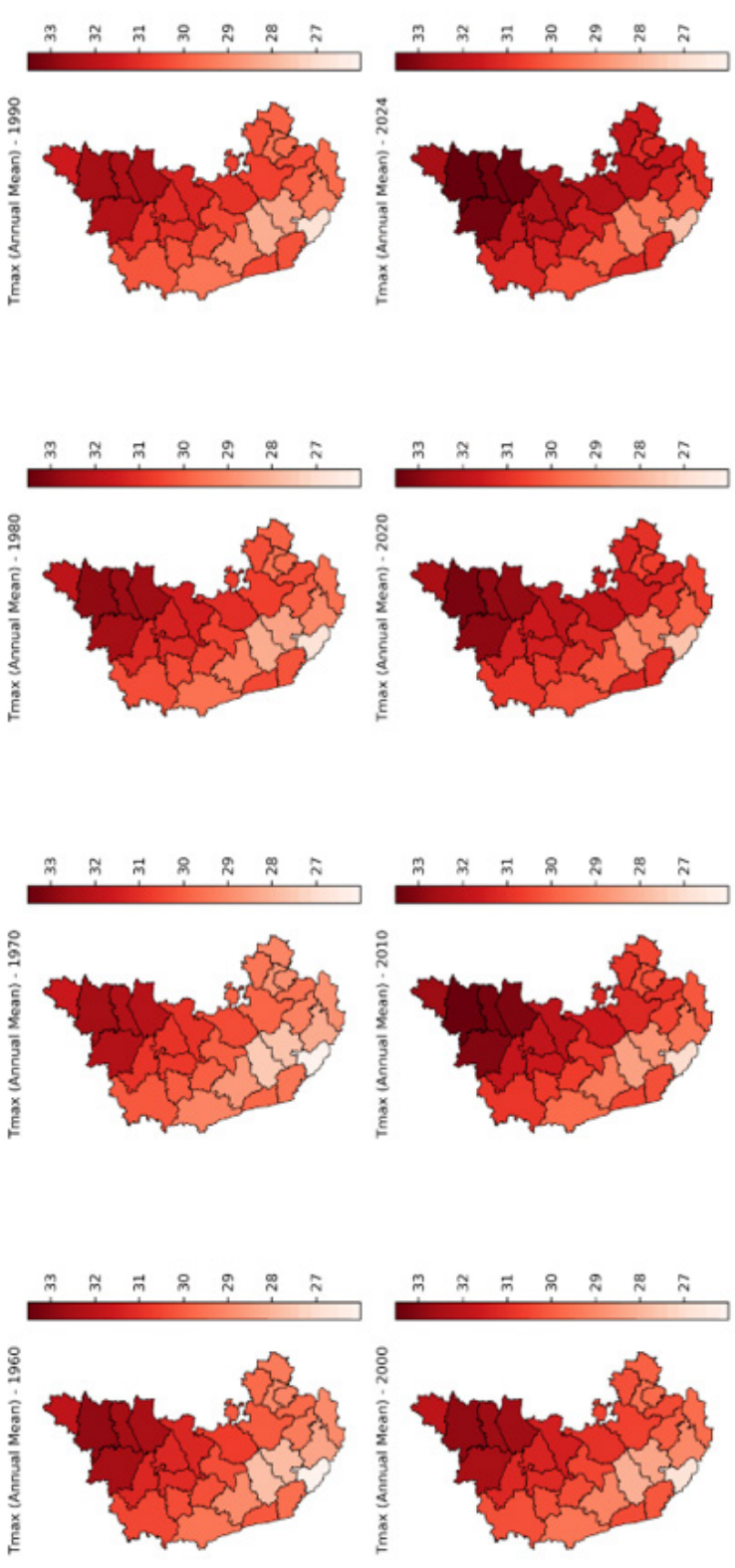


Fig. 2. Decadal averages of annual mean maximum temperature (Tmax) across Karnataka districts for selected periods between 1960–1980, 1980–2000, and 2000–2024, illustrating spatial patterns and temporal evolution of daytime temperature

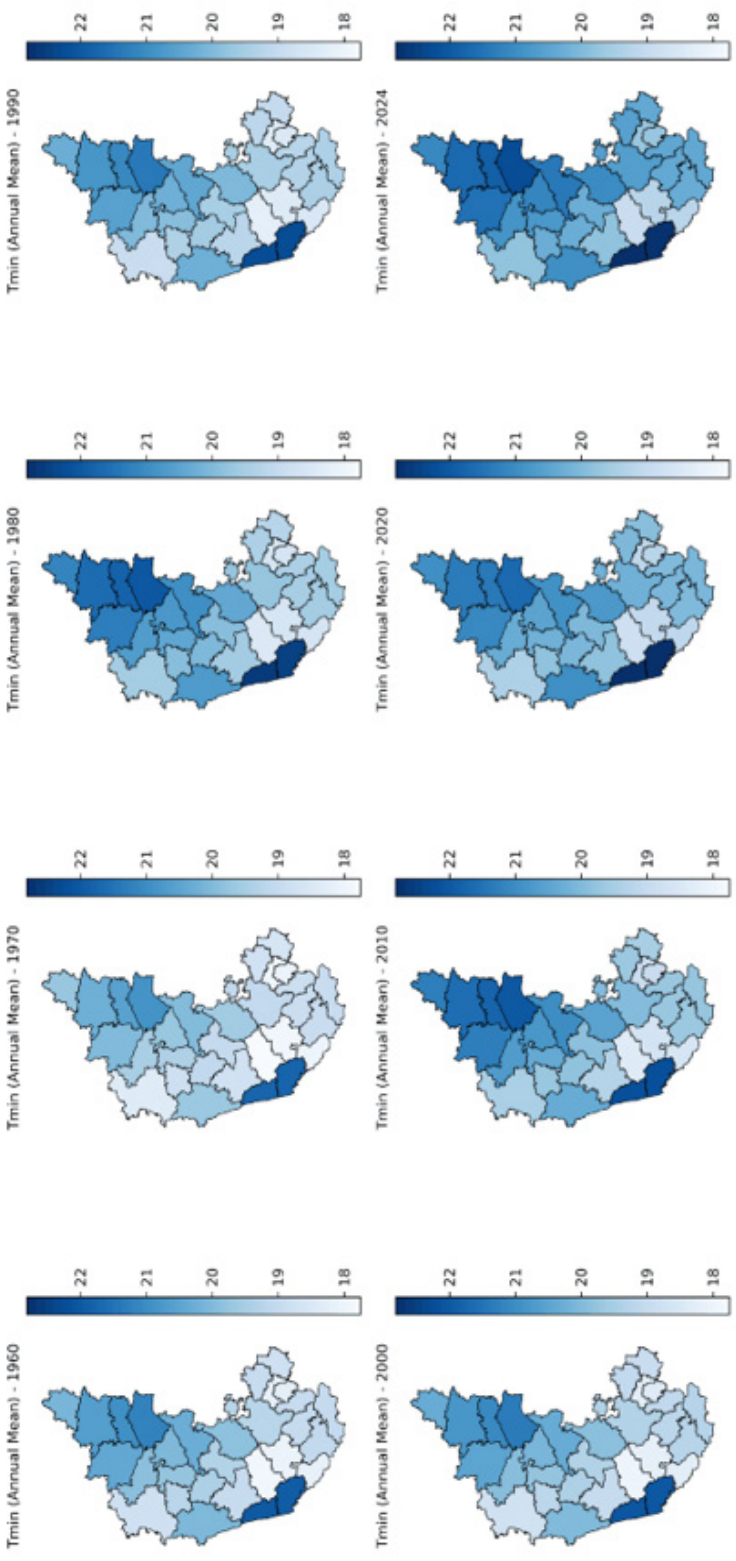


Fig. 3. Decadal averages of annual mean minimum temperature (Tmin) across Karnataka districts for selected periods between 1960–1980, 1980–2000, and 2000–2024, highlighting spatial variation and long-term nighttime warming patterns

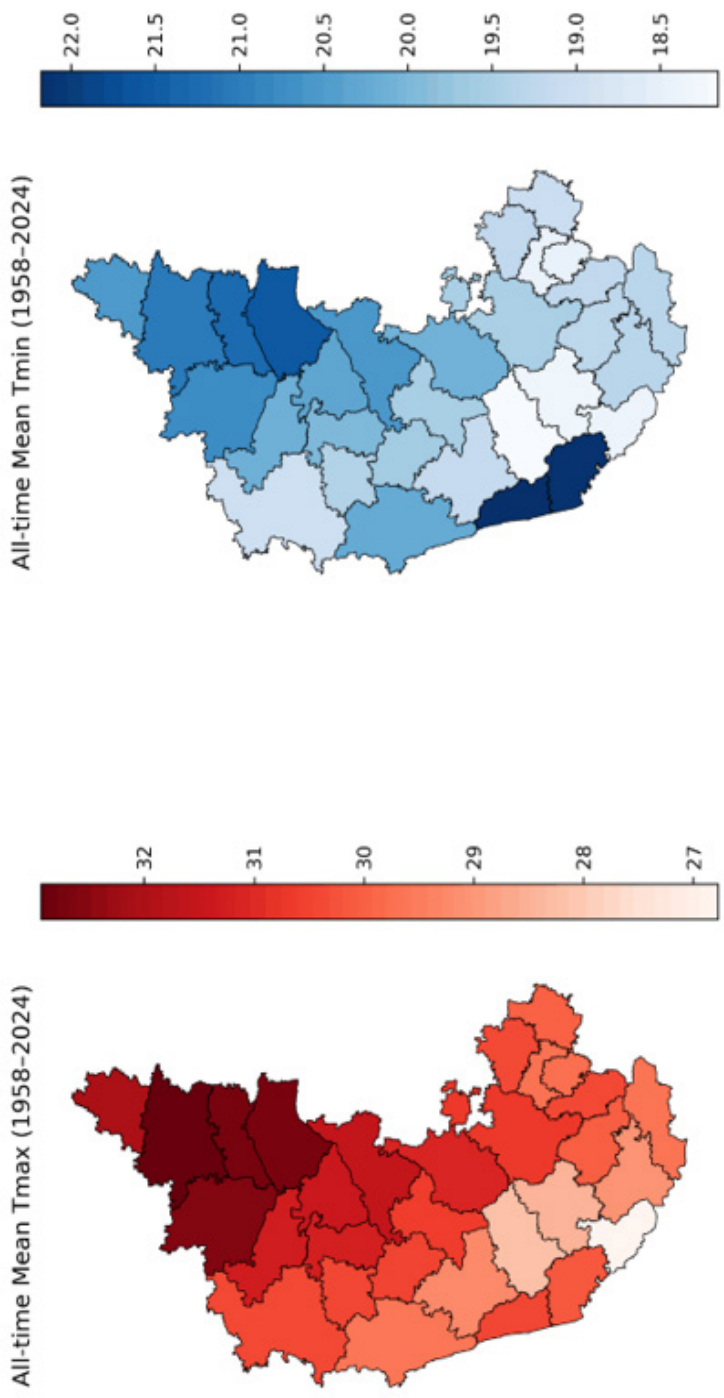


Fig. 4. Spatial distribution of long-term mean annual maximum temperature (Tmax) and minimum temperature (Tmin) across Karnataka districts for the period 1958–2024, illustrating baseline thermal contrasts across the state

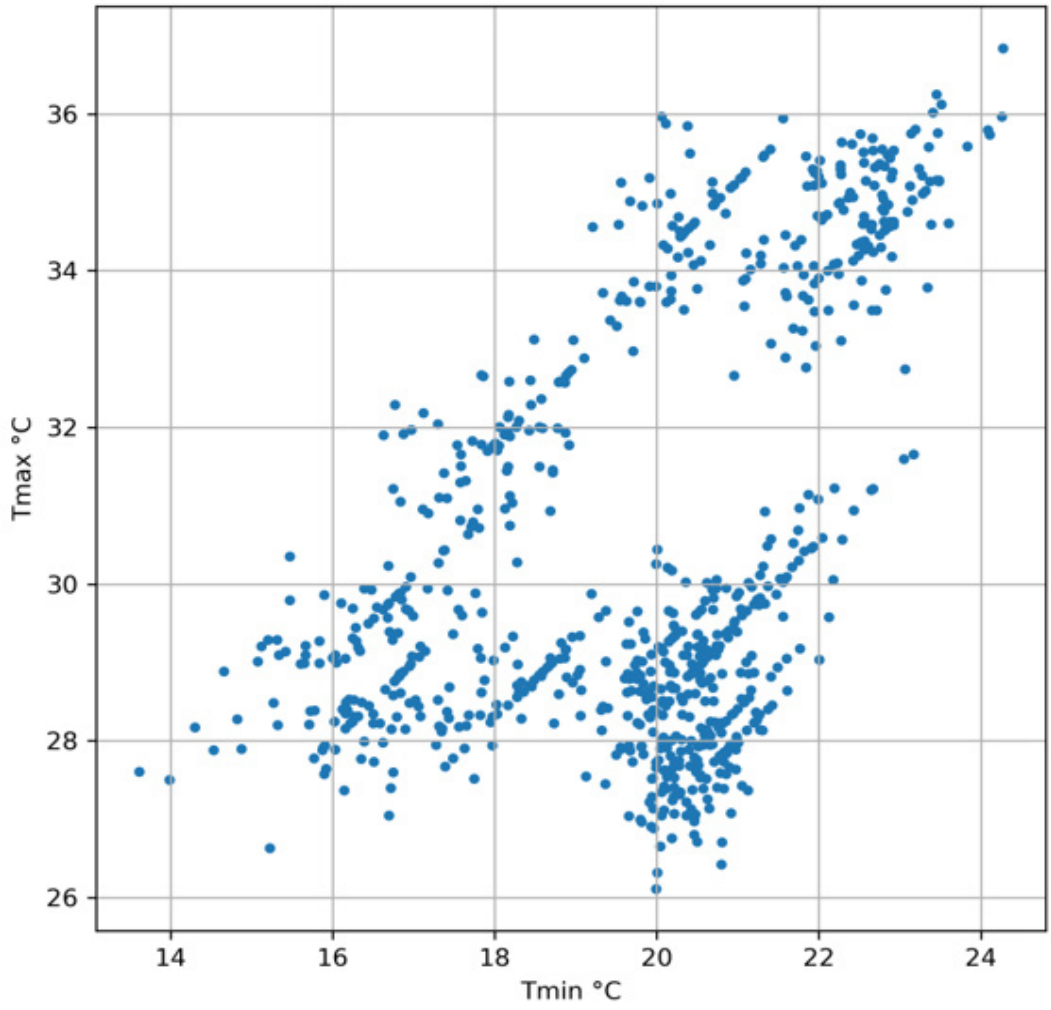


Fig. 5. Relationship between annual mean maximum temperature (Tmax) and minimum temperature (Tmin) across Karnataka for 1958–2024. Colour-coded points illustrate different temperature ranges and associated thermal conditions

behaviour. Increasing DTR trends in southern districts suggest that daytime warming has exceeded nighttime warming in these regions. Such patterns may be associated with reduced cloud cover, land-surface changes, or enhanced solar radiation that increases daytime heating.

Conversely, decreasing DTR trends in northern semi-arid districts indicate relatively stronger nighttime warming compared with daytime temperatures. This behaviour may reflect increased atmospheric moisture, irrigation expansion, or other land-surface processes that limit nocturnal cooling. Similar mechanisms have been proposed in earlier studies examining regional variations in diurnal temperature trends.

Coastal and Western Ghats districts generally display weaker or non-monotonic trends. The relatively stable DTR behaviour in these regions likely reflects the moderating influence of maritime climate, higher humidity, persistent cloud cover, and complex topography.

The spatial contrast in DTR trends across Karnataka may reflect differences in regional climate regimes and land–atmosphere interactions. Northern districts of the state lie within semi-arid interior zones that experience stronger continental influences and greater sensitivity to changes in surface moisture conditions. Expansion of irrigation, increasing atmospheric humidity, and enhanced cloud cover can reduce nocturnal cooling and elevate minimum temperatures, thereby contributing to declining DTR. In contrast, southern districts influenced

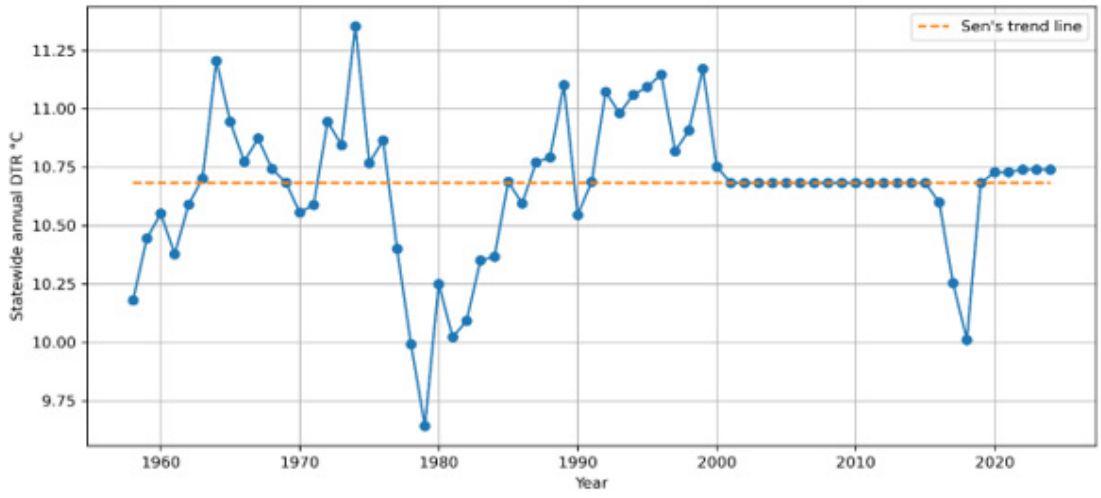


Fig. 6. Time series of annual mean diurnal temperature range (DTR) averaged over Karnataka for the period 1958–2024. The series highlights inter-annual variability and overall temporal evolution of DTR at the state scale

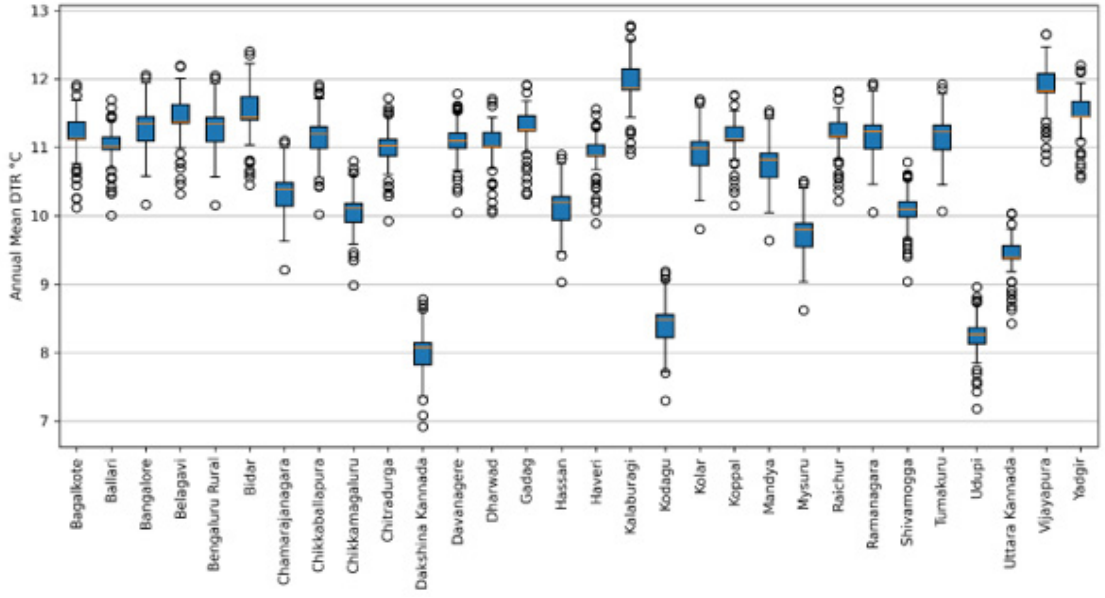


Fig. 7. Boxplot showing the distribution of annual diurnal temperature range (DTR) across Karnataka districts for the period 1958–2024. The plot highlights inter-district differences in median values, dispersion, and outliers

by higher elevation and relatively lower moisture variability may experience stronger daytime heating relative to nighttime warming, resulting in increasing DTR. Coastal and Western Ghats districts remain strongly influenced by maritime air masses, persistent cloud cover, and orographic effects associated with the southwest monsoon, which moderate both daytime heating and nighttime cooling. These regional climatic controls likely contribute to the heterogeneous spatial patterns of DTR trends observed across the state.

Overall, these findings demonstrate that statewide averages obscure significant spatial contrasts in the evolution of diurnal thermal regimes. District-level analysis reveals divergent warming pathways within the state, emphasizing the importance of spatially resolved temperature indicators for understanding regional climate variability.

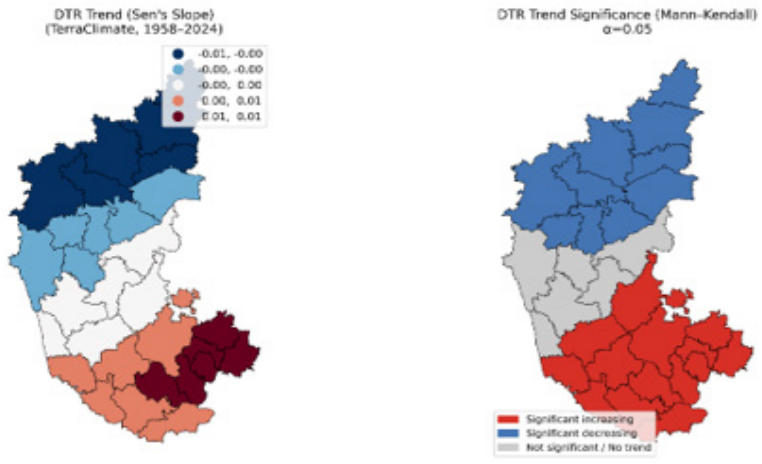


Fig. 8. Spatial distribution of district-level diurnal temperature range (DTR) trends across Karnataka based on Mann–Kendall (MK) test results and Sen's slope estimates for 1958–2024. Positive (negative) values indicate increasing (decreasing) DTR trends, while non-significant districts are indicated separately

This study examined long-term spatial patterns in diurnal temperature range (DTR) across Karnataka using district-level temperature series derived from the TerraClimate dataset for the period 1958–2024. Trend analysis using the Mann–Kendall test and Sen's slope estimator reveals pronounced spatial heterogeneity in DTR behaviour across the state. While statewide averages indicate relatively stable long-term DTR conditions, district-level analysis shows contrasting regional trends.

Increasing DTR trends are primarily observed in southern and south-eastern districts, suggesting that daytime warming has exceeded nighttime warming in these regions. In contrast, decreasing DTR trends dominate northern semi-arid districts, reflecting relatively stronger increases in minimum temperatures and a gradual compression of the diurnal temperature range. Coastal and Western Ghats districts generally exhibit weak or statistically insignificant trends, likely due to the moderating influence of maritime conditions and higher humidity.

These findings demonstrate that aggregated temperature indicators can obscure important regional differences in thermal behaviour. Spatially resolved assessments of diurnal temperature range provide valuable insight into regional climate variability and may help inform environmental monitoring and climate adaptation strategies in climatically heterogeneous regions.

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