

SPATIAL VARIATION OF AIR TEMPERATURE AND TREND DETECTION USING NON-PARAMETRIC ANALYSIS FOR TAMIL NADU

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ABSTRACT

Assessment of spatiotemporal dynamics of meteorological variables is essential in the context of climate change. Maximum and minimum temperature data on a monthly scale of 30 years (1991-2020) were used to determine the possible changes in air temperature. The Mann-Kendall (MK) trend test is a nonparametric, rank-based approach identifying significant monotonic trends in meteorological and hydrological data. The spatial variation of maximum temperature revealed that out of 38 districts studied, more than 35°C was observed in 12 districts during March, 23 districts during April, 27 districts during May, 20 districts during June, nine districts during July and three districts during August respectively. Higher minimum temperature of more than 27 °C was observed during April (3 districts), May (16 districts), June (12 districts), July and August (3 districts each) and September (2 districts) respectively. The rate of increase in temperature will eventually affect the crop production and agricultural activities. Notably, during December, minimum temperature exhibited an increasing trend @ 0.12°C/year at Krishnagiri followed by 0.11°C /year each in Dharmapuri, Dindigul, Namakkal and Salem districts of Tamil Nadu. The crops raised during rabi season in these districts may face terminal heat stress in achieving high productivity of the crops.

KEYWORDS: Mann-Kendall test, Maximum and Minimum temperature, Tamil Nadu, Trend

1. INTRODUCTION

The Intergovernmental Panel on Climate Change reported that the global temperature is likely to rise by about 1.5°C between 2030 and 2052. Climate change has increased the frequency and intensity of extreme precipitation and temperature events across the world. Rising greenhouse gas concentrations have altered both the amplitude and seasonal pattern of temperature and rainfall (Yurekli, 2015). Understanding climate variability is vital for identifying and implementing adaptation options in climate sensitive sectors such as forestry agriculture and water resources (Ganeshkumar et al., 2022). The most obvious effects of climate change are altering precipitation patterns and an increase in global temperature. These changes have serious implications for the social economic and environmental systems that sustain human life. Over the past few decades the climate has undergone major changes that threaten long term sustainability (IPCC, 2022). Variations in daily maximum and minimum temperatures can significantly influence mean surface temperatures (Karl et al., 2004). The daily temperature range is therefore considered an important indicator of climate change and has been widely studied using station level observations.

Researchers have adopted different statistical techniques to assess climate variability. Both parametric and non parametric methods have been used (Swain et al., 2022). Parametric tests such as linear regression, F test and T test are efficient when the data follow a normal distribution. However climate data often contain missing values non normal distributions and outliers. These limitations make non parametric methods more suitable for long climate time series (Yang et al., 2022). Methods such as the Mann–Kendall trend test the modified Mann–Kendall test Sen slope estimator and Kruskal–Wallis test require minimal assumptions and are robust against outliers. Among these the Mann–Kendall test and Sen slope estimator are widely used for detecting trends in climatic variables (Vu Duy et al., 2022). Accurate forecasting of meteorological variables depends on analysing historical patterns understanding variability and identifying shifts within the data (Gul and Ren, 2022). While many studies have examined the fluctuations of rainfall and temperature there remain large gaps in understanding how climate variability affects local communities and ecosystems (Dad et al., 2021). Analysing trends and forecasting meteorological variables at multiple spatial and temporal scales provides valuable insight into interactions between terrestrial ecosystems and climate systems.

At regional and local levels policymakers are increasingly focusing on strategies that reduce climate risks and promote climate resilience. Micro level trend analysis of climatic variables is crucial for planning context specific adaptation measures. Scientific evaluation of observed changes in regional climate variables forms the foundation for effective adaptation and mitigation actions. Several studies have examined the spatial and temporal variability

of temperature across the world including in India. The rate of temperature increase in India varies across regions. Findings from the India Meteorological Department show that the country's annual mean temperature rose by about 0.56°C between 1901 and 2009 with noticeable regional differences in warming intensity (Attri and Tyagi, 2010). Studies also show that while large scale patterns are consistent with global trends regional scale analyses often reveal deviations based on local conditions and specific time periods. India has recently increased its focus on the risks that climate change poses to society and development. The government has directed all states to prepare State Action Plans on Climate Change (SAPCC) that reflect national objectives while accounting for local vulnerabilities. Implementing these plans requires clear understanding of climate change characteristics at spatial and temporal scales within each state. However in some regions information on long term trends and variability of climate parameters remains limited. In Tamil Nadu studies on long term regional climate trends are scarce. There is a need to analyse climate change at the cadastral level to support climate resilience efforts through the State Action Plan. This study therefore aims to examine monthly temperature variability across Tamil Nadu to present a comprehensive picture of temperature changes within the state.

2. Study area and methodology

2.1. Study area

Tamil Nadu is a southernmost State of the Indian peninsula spreading over 130,058 km². The geo-coordinates lie between 8° 5" to 13° 35" N and 76° 15" to 80° 20" E. The climate of Tamil Nadu is referred to as semiarid, tropical monsoon. Due to its topographical features and geographical area, the climate of Tamil Nadu is outstandingly different from the general climate of the country. The long coastal stretch in the east, hill orography of the western rim and plain inlands play a significant role and influence the climate of the state (TNSAPCC, 2015). Except for the monsoon season, the state's climate is tropical with little seasonal change in summer and winter temperatures and blistering heat all year round. Due to the area's proximity to the ocean, the temperature and humidity are consistently high. The sweltering summer season lasts from April to June and sees highs of 43°C. With an average winter temperature of 18°C, November to February is the coldest month of the year (Jeganathan et al., 2019).

2.2. METHODOLOGY

The monthly maximum and minimum temperature data of the recent thirty years (1991-2020) were used to determine the possible changes in temperature. India Meteorological Department (IMD) is considered to be the reliable source of meteorological data, which provides a complete climate dataset with quality control. The spatial variability in maximum, minimum, mean and diurnal temperature for Tamil Nadu was worked out for 30 years. The following assumptions were taken for the study.

1. To demarcate the districts receiving more than 35°C as maximum temperature which poses discomfort in daily activities
2. To delineate the districts receiving more than 27°C as minimum temperature which indirectly indicates warm nights

The Mann-Kendall (MK) trend test is a nonparametric, rank-based method for detecting significant monotonic trends in meteorological and hydrological data. It has the benefit of not having any prerequisites, such as that the time series data be normally distributed, that a linear line exists, that any data values be absent, etc. The MK test was first used to check whether the trend analysis shows a uniform linear growth or fall inclination. Then, the linear trend was evaluated using the nonparametric Sen's slope estimate, which provides a statistical (°C/month) representation of the increase or decrease in temperature under consideration.

Historically, linear regression was the most commonly used method for trend identification, but it is parametric and needs data to be normally distributed. Due to the MK test's ease of use, ability to accept missing data and non-normal data distributions, and capacity to reduce the effects of outliers and eliminate significant data flaws, it has been widely employed in trend analysis. Additionally, the MK test can be used for different time periods, including monthly, seasonal, and yearly.

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

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

In which x_j and x_i are the temperature observations recorded at times j and i (with $j > i$), respectively, and n is the length of the time series data. Under the null hypothesis (H_0) condition, the distribution of S is symmetrical and normal in the limit as n becomes large, with zero mean and variance:

$$\text{Var}(S) = \left[n(n-1)(2n+5) - \sum_{i=1}^m t_i(t_i-1)(2t_i+5) \right] / 18$$

where t_i indicates the number of ties with extend i .

Finally, the statistic (Z_{mk}) for the given variance (S) is calculated by the following equation.

$$Z_{mk} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & \text{for } S < 0 \end{cases}$$

The positive (or negative) of Z_{mk} from the equation indicates the increasing (or decreasing) direction of the trend in the time series. In this study, data were employed for trend analysis at a 95% significance level and the null hypothesis for no trend in temperature was rejected if Z_{mk} was greater than 1.96.

3. RESULT AND DISCUSSION

3.1. Spatial variation of Maximum and Minimum temperature

During the hot weather period from March to May, more than 35°C was recorded in 12 districts in March, 23 districts in April and 27 districts in May. During the South West Monsoon from June to September, more than 35°C was observed in 20 districts in June, nine districts in July three districts in August and only one district in September (Fig. 1). High temperature and strong UV radiation created severe heat discomfort during summer. As the monsoon advanced temperatures gradually dropped. Higher minimum temperature of more than 27°C was observed during April (3 districts), May (16 districts), June (12 districts), July and August (3 districts each) and September (2 districts) respectively (Fig. 1). These values indicated warm nights with high cloud cover. Warm night conditions increase respiration in crops and can reduce productivity. Increased maintenance respiration reduces non structural carbohydrate reserves and raises the metabolic processes such as protein turnover and ion regulation leading to yield loss in many staple crops (Sharma et al. 2022).

Among the seven agro climatic zones of Tamil Nadu, the districts of Sivaganga Ramanathapuram and Virudhunagar in the Southern Zone recorded maximum temperature above 35°C and minimum temperature above 27°C throughout the South West Monsoon. In the North Eastern Zone and the Cauvery Delta Zone these conditions were seen only in June. Even a small rise in temperature during flowering can cause complete loss of grain in some crops (Lobell et al. 2011). Short periods of heat stress during reproductive stages can reduce floral buds cause flower abortion and lead to sterility (Sage et al. 2015).

In maize air temperature above 35°C reduces ear expansion and affects cob development due to limited photosynthate supply and impaired hemicellulose and cellulose synthesis. Groundnut shows a reduction in peg and pod number under such heat stress (Yang et al. 2017). In gingelly, temperatures above 32°C reduce grain yield and grain weight. In horticultural crops, photosynthesis decreases in mango when temperature crosses 35°C (Liu et al. 2023). In chillies ideal temperatures for fruit development are 15 to 17°C at night and 24 to 30°C in the day while the crop suffers fruit and flower abortion when temperature rises beyond 38°C (Thuy and Kenji 2015). Reduced fruit set is also observed in tomato when maximum temperature exceeds 35°C (Vijayakumar et al. 2021).

3.2. Spatial variation of Diurnal Temperature Range

Diurnal Temperature Range varied from 2.8°C to 10.0°C (January), 3.4°C to 11.3 °C (February), 3.7°C to 12.1°C (March), 3.6°C to 10.6°C (April), 4°C to 10.3°C (May), 3.3°C to 9.4°C (June), 3.5°C to 9.1°C (July), 3.9°C to 9.2°C (August), 4.2°C to 9.5°C (September), 3.6°C to 7.9°C (October), 2.6°C to 6.8°C (November) and 2.4°C to 8.1°C (December) respectively across the State (Fig. 2). The increase in minimum temperature narrowed down the diurnal temperature range in Tamil Nadu. Climate change-related variations in daytime and night time temperatures reduce the diurnal temperature amplitude, which can affect plant circadian rhythms.

3.3. Mann-Kendall Trend in maximum and minimum temperature during Southwest Monsoon

Both significant ($p < 0.05$) and ($Z_{mk} > 1.96$) and non-significant ($p > 0.05$) and ($Z_{mk} < 1.96$) increasing trend in temperature was observed in south west monsoon (June to September). Across the State, Kancheepuram district exhibited a significant ($p < 0.05$) and ($Z_{mk} > 1.96$) increasing trend in maximum temperature each @ 0.03°C /year during June and August respectively and 0.02°C during September except July (Table 1). Interestingly, 23 districts exhibited a significantly increasing trend in maximum temperature during July followed by June (9 districts) and August (8 districts) and September (2 districts). Approximately 82% of the total stations have shown a significant positive trend in mean annual temperature and mean maximum temperature at the 95% confidence level (Rangarajan et al., 2017).

Considering the minimum temperature, a significant increasing trend ($p < 0.05$) and ($Z_{mk} > 1.96$) was noticed during June (34 districts), July (31 districts), August (33 districts) and September (36 districts). Furthermore, 30 districts reported a series of significantly increasing trends from June to September in minimum temperature (Table 1).

3.3. Mann-Kendall Trend in maximum and minimum temperature during Northeast Monsoon

During the North east monsoon, 29 districts exhibited a significantly increasing maximum temperature trend ($p < 0.05$) and ($Z_{mk} > 1.96$) during October followed by 26 districts each during November and December months respectively (Table 2).

Considering the minimum temperature, all districts exhibited a significantly increasing trend across the State. During October, a significantly increasing trend @ 0.06 °C /year was observed in Dindigul, Madurai, Theni, Vellore and Virudhunagar districts. During November, a significantly increasing trend @ 0.06°C /year was observed in Coimbatore, Dindigul, Madurai, Salem, Tenkasi, The Nilgiris, Theni and Tirupur districts. During December, an alarming increase @ 0.12°C /year was observed at Krishnagiri followed by 0.11°C /year was

observed in Dharmapuri, Dindigul, Namakkal and Salem districts (Table 2). Rise in minimum temperature is occurring at a faster rate (@ 0.32°C 10 yr⁻¹) than maximum temperature (@ 0.28°C 10 yr⁻¹) over large wheat growing areas of India (Rao et al., 2015). The crops raised during rabi season may face terminal heat stress in achieving high productivity of the crops.

CONCLUSION

The monthly maximum and minimum temperature data of the recent thirty years (1991-2020) were used to determine the possible changes in temperature. During the different seasons (June to September) of maximum and minimum temperature, both non-significant and significant increasing trend was observed in south west monsoon. Considering the minimum temperature, all districts exhibited a significantly increasing trend irrespective of all districts in the State. Subsequent research endeavours could encompass examining temperature extremes on a more precise regional scale, ascertaining temperature thresholds particular to a cultivar, and adapting to temperature extremes in future climates while maintaining improved yield characteristics in crops.

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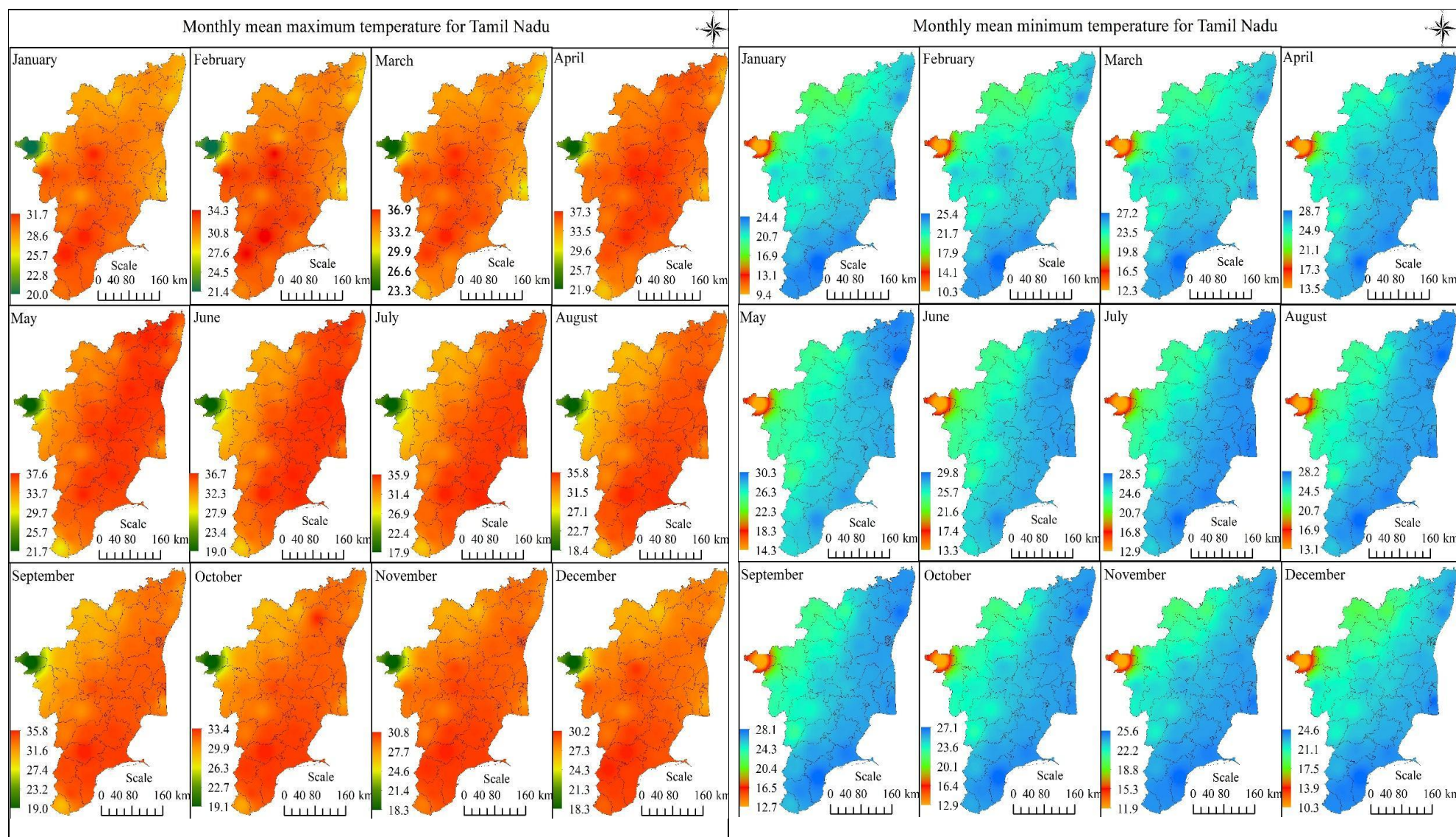


Fig. 1 Spatial variation of maximum and minimum temperature in Tamil Nadu

Diurnal temperature for Tamil Nadu

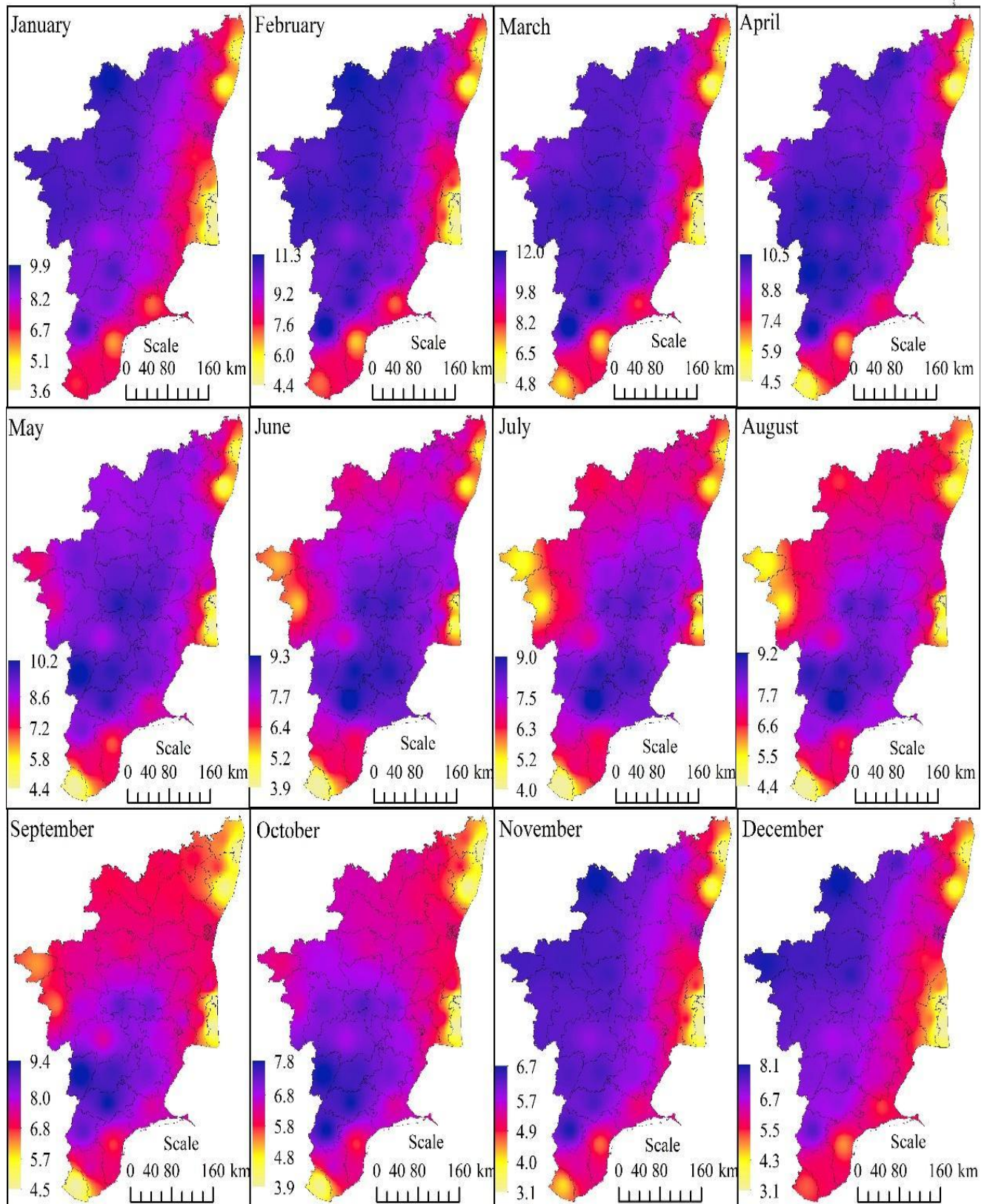


Fig 2. Spatial variation of diurnal variation in temperature in Tamil Nadu

Maximum temperature									Minimum temperature							
Districts	Jun	S	Jul	S	Aug	S	Sep	S	Jun	S	Jul	S	Aug	S	Sep	S
Ariyalur	-	0.03	-	0.03	-	-0.01	-	0	I	0.03	I	0.03	I	0.02	I	0.03
Chengalpattu	-	0.02	-	0	-	0	-	-0.01	-	0.02	-	0.01	-	0.01	I	0.02
Chennai	-	0.02	-	0.01	-	0	-	-0.01	-	0.02	-	0.01	-	0.01	I	0.02
Coimbatore	-	0.03	I	0.07	-	0.03	-	-0.01	I	0.02	I	0.05	I	0.04	I	0.03
Cuddalore	-	0.02	-	0.02	-	-0.01	-	0	I	0.03	I	0.03	I	0.02	I	0.03
Dharmapuri	-	0.02	I	0.04	-	0.03	-	0.01	I	0.04	I	0.04	I	0.04	I	0.03
Dindigul	-	0.04	I	0.04	I	0.02	-	0.02	I	0.05	I	0.05	I	0.05	I	0.05
Erode	-	0.02	I	0.03	-	0.02	-	-0.01	I	0.02	I	0.04	I	0.04	I	0.03
Kallakurichi	-	0.04	I	0.04	-	0.03	-	0.03	I	0.04	I	0.04	I	0.04	I	0.04
Kancheepuram	I*	0.03	-	0.02	I	0.03	I	0.02	-	0.03	-	0.03	-	0.02	-	0.01
Kanyakumari	I	0.04	I	0.05	I	0.04	-	0	I	0.03	I	0.04	I	0.04	I	0.03
Karur	-	0.03	I	0.04	-	0.01	-	0	I	0.03	I	0.04	I	0.03	I	0.03
Krishnagiri	-	0.03	I	0.03	I	0.03	-	0.02	I	0.03	I	0.03	I	0.04	I	0.04
Madurai	-	0.05	I	0.04	-	-0.01	-	-0.01	I	0.05	I	0.05	I	0.04	I	0.03
Mayiladuthurai	-	0.02	-	0.02	-	-0.01	-	0	I	0.04	I	0.03	I	0.02	I	0.03
Nagapattinam	-	0.01	-	0	-	0	-	-0.01	I	0.02	I	0.02	-	0.01	-	0.01
Namakkal	-	0.03	I	0.04	-	0.01	-	-0.01	I	0.03	I	0.04	I	0.04	I	0.03
Perambalur	-	0.03	-	0.04	-	0	-	0.02	I	0.04	I	0.04	I	0.03	I	0.03
Pudukkottai	-	0.05	I	0.05	-	0.03	-	0	I	0.05	I	0.05	I	0.04	I	0.03
Ramanathapuram	I	0.04	I	0.03	-	0.01	-	0.02	I	0.05	I	0.05	I	0.04	I	0.04
Ranipet	-	0.02	-	0.03	-	0.03	-	0.02	I	0.03	-	0.03	I	0.03	I	0.03
Salem	-	0.03	I	0.05	-	0.03	-	0.01	I	0.04	I	0.05	I	0.04	I	0.03
Sivaganga	-	0.05	I	0.05	-	0.01	-	0.01	I	0.05	I	0.05	I	0.04	I	0.03
Tenkasi	I	0.06	I	0.07	-	0.03	-	-0.01	I	0.04	I	0.05	I	0.04	I	0.04
Thanjavur	-	0.02	-	0.03	-	-0.01	-	0	I	0.04	I	0.03	I	0.02	I	0.03
The Nilgiris	-	0.02	I	0.04	I	0.03	I	0.03	I	0.03	I	0.04	I	0.04	I	0.05
Theni	-	0.04	I	0.06	-	0.02	-	-0.02	I	0.04	I	0.05	I	0.05	I	0.04
Thiruvallur	-	0.03	-	0.02	-	0.02	-	0.01	-	0.02	-	0.02	I	0.03	I	0.02
Thiruvarur	-	0.02	-	0.02	-	-0.01	-	-0.01	I	0.04	I	0.03	I	0.02	I	0.02
Thoothukudi	I	0.05	I	0.05	I	0.02	-	0.01	I	0.04	I	0.05	I	0.04	I	0.03
Tiruchirappalli	-	0.03	I	0.04	-	0.01	-	0	I	0.04	I	0.04	I	0.03	I	0.03
Tirunelveli	I	0.05	I	0.06	-	0.02	-	0	I	0.04	I	0.05	I	0.04	I	0.04
Tirupathur	I	0.03	I	0.03	I	0.04	-	0.03	I	0.04	I	0.03	I	0.04	I	0.04
Tiruppur	I	0.04	I	0.06	-	0.01	-	-0.01	I	0.03	I	0.04	I	0.03	I	0.03
Tiruvannamalai	-	0.03	-	0.03	-	0.02	-	0.01	I	0.03	-	0.02	I	0.03	I	0.03
Vellore	-	0.02	-	0.03	I	0.04	-	0.03	I	0.03	I	0.02	I	0.04	I	0.04
Villupuram	-	0.02	-	0.02	-	0.01	-	0.01	I	0.03	-	0.02	-	0.02	I	0.03
Virudhunagar	I	0.04	I	0.06	-	0	-	0	I	0.05	I	0.05	I	0.04	I	0.03

Table 1. Trend in maximum and minimum temperature during South west monsoon
I: Increasing; -: No trend; S-Slope

Table 2. Trend in maximum and minimum temperature during North east monsoon

Districts	Maximum temperature						Minimum temperature					
	Oct	S	Nov	S	Dec	S	Oct	S	Nov	S	Dec	S
Ariyalur	I	0.05	I	0.04	I	0.06	I	0.05	I	0.04	I	0.07
Chengalpattu	I	0.04	I	0.03	I	0.04	I	0.03	I	0.03	I	0.05
Chennai	I	0.04	I	0.04	I	0.04	I	0.04	I	0.03	I	0.05
Coimbatore	I	0.05	I	0.06	-	0.03	I	0.04	I	0.06	I	0.08
Cuddalore	I	0.05	I	0.04	I	0.06	I	0.05	I	0.04	I	0.07
Dharmapuri	I	0.05	I	0.05	I	0.06	I	0.05	I	0.05	I	0.11
Dindigul	I	0.05	I	0.05	I	0.05	I	0.06	I	0.06	I	0.11
Erode	I	0.03	-	0.04	I	0.03	I	0.04	I	0.05	I	0.10
Kallakurichi	I	0.06	I	0.05	I	0.06	I	0.05	I	0.04	I	0.09
Kancheepuram	I	0.05	I	0.04	I	0.08	I	0.05	I	0.05	I	0.06
Kanyakumari	I	0.04	I	0.04	-	0.03	I	0.04	I	0.04	I	0.06
Karur	I	0.05	-	0.04	-	0.05	I	0.05	I	0.05	I	0.09
Krishnagiri	I	0.05	I	0.06	I	0.06	I	0.04	I	0.05	I	0.12
Madurai	-	0.06	-	0.05	-	0.02	I	0.06	I	0.06	I	0.09
Mayiladuthurai	I	0.04	I	0.03	I	0.05	I	0.04	I	0.04	I	0.06
Nagapattinam	-	0.02	I	0.02	I	0.03	I	0.03	I	0.03	I	0.03
Namakkal	I	0.05	I	0.04	I	0.06	I	0.05	I	0.05	I	0.11
Perambalur	I	0.06	I	0.04	I	0.06	I	0.05	I	0.04	I	0.09
Pudukkottai	I	0.04	-	0.04	I	0.04	I	0.05	I	0.05	I	0.07
Ramanathapuram	-	0.03	I	0.04	I	0.04	I	0.05	I	0.04	I	0.06
Ranipet	I	0.06	I	0.04	I	0.06	I	0.05	I	0.04	I	0.09
Salem	I	0.05	I	0.05	I	0.07	I	0.05	I	0.06	I	0.11
Sivaganga	I	0.05	-	0.04	-	0.03	I	0.05	I	0.05	I	0.07
Tenkasi	-	0.04	-	0.04	-	0.03	I	0.05	I	0.06	I	0.09
Thanjavur	I	0.04	-	0.04	I	0.05	I	0.05	I	0.04	I	0.07
The Nilgiris	I	0.05	I	0.05	I	0.05	I	0.04	I	0.06	I	0.08
Theni	-	0.04	I	0.05	-	0.04	I	0.06	I	0.06	I	0.09
Thiruvallur	I	0.06	I	0.05	I	0.06	I	0.05	I	0.04	I	0.07
Thiruvarur	I	0.04	-	0.04	I	0.05	I	0.05	I	0.04	I	0.06
Thoothukudi	-	0.04	I	0.03	-	0.03	I	0.05	I	0.04	I	0.06
Tiruchirappalli	-	0.05	-	0.05	-	0.05	I	0.05	I	0.05	I	0.08
Tirunelveli	-	0.04	-	0.03	-	0.03	I	0.05	I	0.04	I	0.07
Tirupathur	I	0.05	I	0.04	I	0.07	I	0.05	I	0.04	I	0.10
Tiruppur	I	0.04	-	0.06	-	0.03	I	0.05	I	0.06	I	0.09
Tiruvannamalai	I	0.05	I	0.04	I	0.07	I	0.05	I	0.04	I	0.09
Vellore	I	0.06	I	0.04	I	0.07	I	0.06	I	0.05	I	0.10
Villupuram	I	0.05	I	0.04	I	0.06	I	0.05	I	0.04	I	0.08
Virudhunagar	-	0.03	-	0.04	-	0.02	I	0.06	I	0.05	I	0.07

I: Increasing; -: No trend; S-Slope