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Determination and Analysis of Weather over Administrative Regions of India: 1951 to 2021

Anubhab Pattanayak
K.S. Kavi Kumar

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MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
Chennai 600 025
India

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Anubhab Pattanayak
(Corresponding author)
IIT-Kharagpur, Kharagpur, India
anubhab@hss.iitkgp.ac.in

and

K.S. Kavi Kumar
Madras School of Economics, Chennai, India
kavi@mse.ac.in

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MADRAS SCHOOL OF ECONOMICS
Gandhi Mandapam Road
Chennai600 025
India

Phone: 2230 0304/2230 0307/2235 2157
Fax: 2235 4847/2235 2155
Email : info@mse.ac.in
Website: www.mse.ac.in

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Abstract

Non-availability of official, single-source, reliable and easy to access weather data at administrative regions such as states and districts poses significant challenges for Indian social science research community interested in climate impact research and policy. This paper provides a brief summary of evolution of access to weather data in the public domain over the past three decades in India. Gridded datasets being the standard for making available the official weather information, the paper discusses the concepts and procedures involved in using such data products to arrive at weather information at various administrative scales. A transparent approach to spatially interpolate the gridded weather data (supplied by IMD) on temperature and rainfall to determine state and district level estimates of weather over the period 1951 to 2021 is presented. The paper further analyzes the long-term trends and changes in the distribution of annual and intra-annual temperature and rainfall at the All India level and at one sub-national state (Tamil Nadu) level across multiple time-scales (i.e., 1951-1980, 1981-2010, and 2011-2021) using traditional methods such as Mann-Kendall tests and Sen's Slope estimates. The paper further reports the climate trends across Tamil Nadu districts over the period 1951 to 2021 using the visually appealing Innovative Polygon Trend Analysis.

Key words: *Weather Data; Climate Trends; Mann-Kendall; IPTA*
JEL Codes: *C14; C23; Q54*

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Anubhab Pattanayak
K.S. Kavi Kumar

INTRODUCTION

The weather and climate[1] data constitute one of the key inputs in the analyses of climate risk assessment and the assessment of economic impacts due to climate change (Dell *et al.*, 2014). It is a common practice for the meteorological agencies to report the weather (and climate) data either at meteorological stations, or in standardized grid format. However, since the climate risk assessments are usually carried out at administrative region level (such as states and districts in India), non-availability of weather/climate data at such disaggregation mandates the researchers to map the weather/climate data from station/grid level to the administrative regions. This often poses a significant challenge, especially to social science researchers.[2] The official source of available weather data are supplied (on real-time basis) in standardized grids that are more amenable for climate research and keeping in view the requirements of the natural science researchers. While making available the weather information in gridded format it is perhaps assumed that the end-users in other disciplines, including those with social science background, are already well-acquainted with the various terminologies involved in the examination and processing of such data to meet their research requirements. This is true in general for the social science researchers in developing countries. Although, the information on how the gridded data products are arrived at is made publicly available, it is possible that several social scientists (in India, and elsewhere) may not necessarily always possess the required technical knowledge, including use of spatial techniques and computational skills, to understand and process these data.

[1] As it is usually the case, climate here refers to average (say, over 30 year) weather.

[2] Auffhammer *et al*. (2013) discuss a few challenges in using gridded data products for statistical modelling to assess the economic impacts of weather/climate.

While investing time and resources by social scientists in the examination of such data may appear desirable from the skill acquisition standpoint, such investments may prove unproductive, inefficient and ultimately costly in view of the following reasons. First, unavailability of such official source of information at the scales relevant for social science research encourages a `reinventing-the-wheel' behavior across multiple researchers. Second, many of these studies do not necessarily detail the method(s) or procedure followed in arriving at the fine scale data at the desirable administrative scales. Thus, the scope for comparison and validation of the weather information used across scientific studies remains limited. Third, a single-sourced weather/climate data over administrative regions helps to address at least one factor contributing to uncertainty – which may be significantly costly for policy making in the context of climate impact research (Auffhammer *et al*. 2013). Fourth, it can also be argued that non-availability of such official/single source of data creates significant inequities and divide within the social science researcher community, many of whom may stumble upon meteorological data that remain less decipherable given their background and training.[3]

Keeping in view the above reasons and for the benefit of the of social science research community in India, this paper details the various concepts and procedures involved in using gridded data to arrive at consistent, at fine-scaled geography (state and district-level) and temporal (annual, monthly, and daily) weather data that can be readily

[3] Many climate risk assessment studies in the social science discipline are produced through inter-disciplinary collaboration with natural science researchers. Here, the natural science researchers responsible for the determination of weather data at the administrative scales from the gridded datasets may save the significant time investment that would be otherwise needed from the social science researchers. The `reinventing-the-wheel' and the `uncertainty' arguments nevertheless remain valid.

used for further empirical and statistical analysis.[4] The data reported in this paper pertains to temperature (maximum and minimum) and rainfall over the period 1951 to 2021. Using the weather/climate data prepared for the administrative regions of India, the paper further explores trends and patterns in temperature and rainfall over the period 1951-2021 and multiple sub-periods, at all-India level and at sub-national level (Tamil Nadu) using a variety of techniques.

The rest of the paper is structured as follows: The next section provides a brief overview on reporting of weather/climate data in India. The third section describes the approach followed in determination of weather/climate data over administrative regions of India for the period 1951-2021. The next section discusses the trends and patterns observed in weather/climate at all-India level and in Tamil Nadu over the study period. The last section provides a brief summary of findings and concludes.

WEATHER/CLIMATE DATA IN INDIA: BRIEF OVERVIEW

India Meteorological Department (IMD) is responsible for collecting weather data in India. The data is usually collected from *in situ* measurement of various weather parameters at meteorological stations spread across the country. While the meteorological stations collect data on several parameters (e.g., maximum and minimum temperature, rainfall, humidity etc.), data on rainfall is also collected through a larger network of rain gauge stations. Among other places, IMD used to publish the monthly and seasonal rainfall data across meteorological sub-divisions in *Mausam* journal. Further, IMD periodically publishes climate

[4] In the manual for using Geographic Information System (GIS) for applied economic research, Dell (2009) briefly presents the approach to determine weather data using ArcGIS and Python programing. Lekshmi *et al*. (2022) present a manual for the analysis of modern meteorological gridded dataset using Python programing.

data through its publication, *Climatological Tables of Observatories in India*. These tables provide meteorological station level *normal* climate data – i.e., average weather over 30 year period. While the first publication in 1904 provided data for 171 stations spread across India, the ninth edition published in 2022 provided climate data corresponding to the period 1991-2020 for 405 meteorological observatories. While the climate data at meteorological station level was available in the public domain, yearly weather data was more difficult to obtain, even for research purpose.

Researchers relying on station-level weather data face the challenge of addition and/or removal of the weather stations, creating inconsistency in the availability of weather data records. Further, since weather stations are not uniformly spread across geography, availability of a weather station in the location of interest is not ensured. To overcome these challenges posed by station-level weather data, came along the development of gridded weather data sets (Auffhammer *et al*. 2013).[5] As noted by Pai *et al*. (2014), the first gridded daily rainfall data for Indian region was prepared by Hartmann and Michelsen (1989), by grouping station data into $1^{\circ} \times 1^{\circ}$ latitude/longitude grid boxes using the daily rainfall data of 1901-1970 sourced from IMD. They computed simple average of all available station observations falling within a grid box for each day. Further, as observed by Pai *et al*. (2014), this gridded data was used by several other studies such as Krishnamurthy and Shukla (2000); Krishnamurthy and Shukla (2007; 2008) – to examine the intra-seasonal and inter-annual variability of rainfall over India; and Goswami *et al.* (2006) – to examine the increasing trend of extreme rain events in India.

[5] Significant uncertainty can also arise in the development/production of the gridded data products due to differences in gridding procedure or technique, quality control and reconstruction (see Serrano-Notivoli and Tejedor, 2021).

Table 1 below describes the gridded data on temperature and rainfall currently made available in the public domain by IMD.

Table 1: Details of the Gridded Data on Temperature and Rainfall in India

Variable	Period	Grid (lat/lon)	Temporal Frequency	Developed by
T_{max}	1951-2024	$1^{\circ} \times 1^{\circ}$	Daily	Srivastava *et al.* (2009)
T_{min}	1951-2024	$1^{\circ} \times 1^{\circ}$	Daily	Srivastava *et al.* (2009)
Rainfall	1901-2024	$1^{\circ} \times 1^{\circ}$	Daily	Rajeevan *et al.* (2008)
	1901-2024	$0.25^{\circ} \times 0.25^{\circ}$	Daily	Pai *et al.* (2014)

Gridded Data Structure:

The daily gridded data supplied by the IMD are usually made available either in binary format (*.grd*) files or in Network Common dataset (NetCDF) (*.nc*) format.[6] The structure of the *.nc* file is as follows:

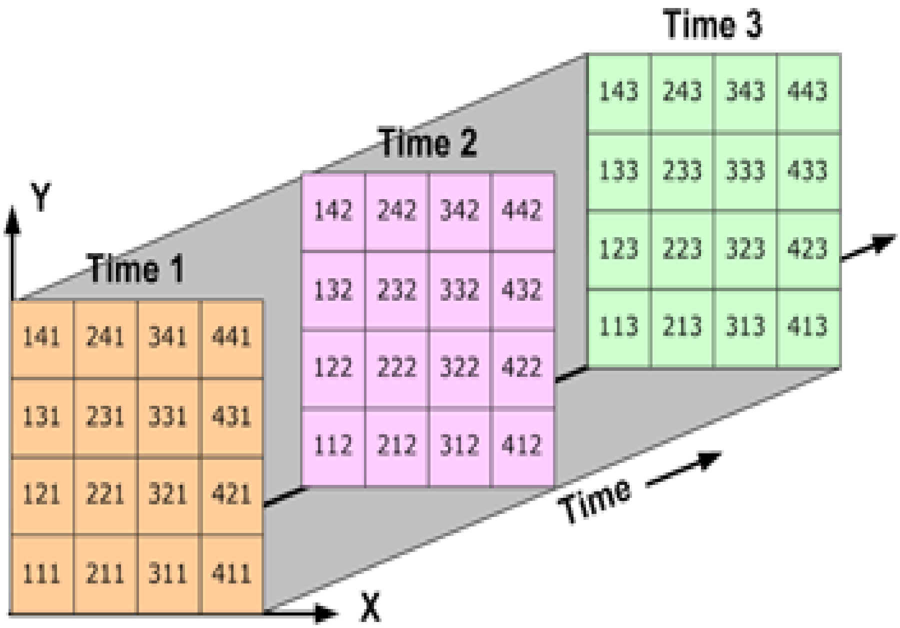
- A single grid = $1^{\circ} \times 1^{\circ}$ lat/lon ($\cong$ 111 km $\times$ 111 km at the equator) – square "grid box" or simply "grid box".
- A slice: Collection of *N* grid boxes with each grid box of a specific dimension (e.g., $1^{\circ} \times 1^{\circ}$ lat/lon for temperature or $0.25^{\circ} \times 0.25^{\circ}$ lat/lon for rainfall)
- A daily slice: Collection of grid boxes of a specific dimension for a single day (say, 01 January 1951)

[6] IMD gridded data on maximum and minimum temperature and rainfall in NetCDF (.nc) format and binary (.grd) format is available at: https://imdpune.gov.in/lrfindex.php

- For a single day slice of **IMD gridded (1º × 1º lat/lon) temperature** covering the entire country there are 31 × 31 = 961 grid boxes, each with 1º × 1º lat/lon dimension.
- For a single day slice of **IMD gridded (0.25º × 0.25º lat/lon) rainfall** covering the entire country there are 135 × 129 = 17,415 grid boxes, each with 0.25º × 0.25º lat/lon dimension.

- A brick: Collection (stack) of daily slices (1, 2,…, 365 days) – see Figure 1 below.

Figure 1: Illustration of a *Brick* in Gridded Data



Note: Each grid box is identified with numeral *xyt*, where *x* = longitude, *y* = latitude, and *t* = time. For a single slice (*t* is fixed), moving right (along *x*-dimension or longitude) to a different grid box, the first numeral ('*x*') representing the longitude changes. Similarly, for a single slice (*t* is fixed), moving up (along *y*-dimension or latitude) to a different grid box, the second numeral ('*y*') representing the latitude changes. The third numeral '*t*' changes when moving from once slice to another, for given *x* and *y* values.
Source: ArcGIS link

DETERMINATION OF WEATHER/CLIMATE OVER ADMINISTRATIVE REGIONS OF INDIA: 1951-2021

As mentioned above, the weather/climate data is often available at meteorological station level, whereas the rest of the data (used in say, impact assessment studies) is available at administrative region (such as state, or district) level. To map the weather/climate data with district level data, impact assessment studies in the past used a variety of approximations. For instance, the Ricardian studies that aimed at estimating climate change impact on agriculture (see Mendelsohn *et. al.*, 1994; Kumar and Parikh, 2001; Sanghi and Mendelsohn, 2008) carried a spatial statistical analysis, that examined the determinants of the weather/climate of each region. Kumar and Parikh (2001), for instance, in Indian context assume that all the meteorological stations within 600 miles radius from the geographic center of the district provide some useful information about that district’s climate. The choice of 600 mile radius is arbitrary; and the intention was to draw as many stations as possible into the circle, so that the estimates do not depend too heavily on any one station. A climate surface in the vicinity of the district is then estimated by running a weighted regression across all meteorological stations within 600 miles. The stations which are nearer to the district center presumably contain more information, than the stations that are far away. Hence the inverse of the square root of a station’s distance from the district center is used as the weight. A second order polynomial relationship is estimated through weighted regression between monthly temperature and precipitation, and latitude, longitude, altitude and shoreline distance, separately for each district. As reported in Kumar and Parikh (2001), this elaborate procedure involved estimating as many as 13008 statistical relationships for arriving at monthly *climate* (temperature and precipitation) of 271 districts considered in the analysis, and 71544 statistical relationships to assess district level monthly *weather* (temperature and precipitation) over the period 1970 to 1980.

With the availability of gridded weather/climate data described in the previous section and wide spread use of GIS techniques, it become a common practice to use spatial interpolation approach to estimate temperature and rainfall of each geographical region from gridded data. This approach is used in the present study to estimate daily temperature (maximum and minimum) and rainfall for 640 districts (as per 2011 Census) in India over the period 1951 to 2021 using the gridded data specified in Table 1 above.[7] The steps involved in the estimation of district level weather are described below:

a. NetCDF (.nc) file for a single year is downloaded from the IMD website.
b. Read the NetCDF file (e.g., 1951.nc) for the year into R software;
    a. There are 365 day (time) slices stacked in this file (366 for the leap years);
    b. For temperature: With 961 grid boxes for a single day slice, a single year NetCDF file (say, for 1951) contains 365 slices and will have a total of 961 $\times$ 365 = 3, 50, 765 grid boxes;
    c. For rainfall: With 17,415 grid boxes for a single day slice, a single year (say, for 1951) file contains 365 slices and will have a total of 17,415 $\times$ 365 = 6, 356, 475 grid boxes;
c. Select the slice for a single day;

[7] While IMD provides the data up to 2024, the present study relies on data up to 2021 to ensure consistency of past records since more recent year records are liable to be updated.

d. Read the district boundaries (shapes) from the district polygon file (called *shapefile*) available in ESRI shapefile (.shp) format in the public domain (districts.shp)[8]; shapefile contains polygon features for 640 districts as of 2011 Census year for India;

e. Overlay or superimpose the shapefile on the day slice (consisting of 961, or 17415 grid boxes) and calculate the daily *area-weighted* average weather for the district. The fraction of the district area accounted for by each grid box covering the district is used to calculate the grid box weights;

   For example, if K_d = 4 grid boxes cover 1 district and the k^{th} grid box accounts for w_k fraction of the district area, then the district average temperature (T_d) is the area-weighted average of the temperature of the K_d = 4 grid boxes covering the district and is given by Eq (1):

$$T_d = \sum_{k=1}^{K_d} w_k T_k \tag{1}$$

   where $w_k = \frac{A_k}{\sum_{k=1}^{K_d} A_k}$; and A_k is the total area (in km^2) of the district covered by grid box *k*.

f. Repeat the above two steps for the other 364 slices in the stack to obtain the daily average temperature and rainfall values for the year 1951; the final processed data *for each year* will have total number of (N = # of *districts* x # of *days* = 640 $\times$ 365 =) 2,33,600 temperature and rainfall observations (and 2,34,240 observation for each leap year);

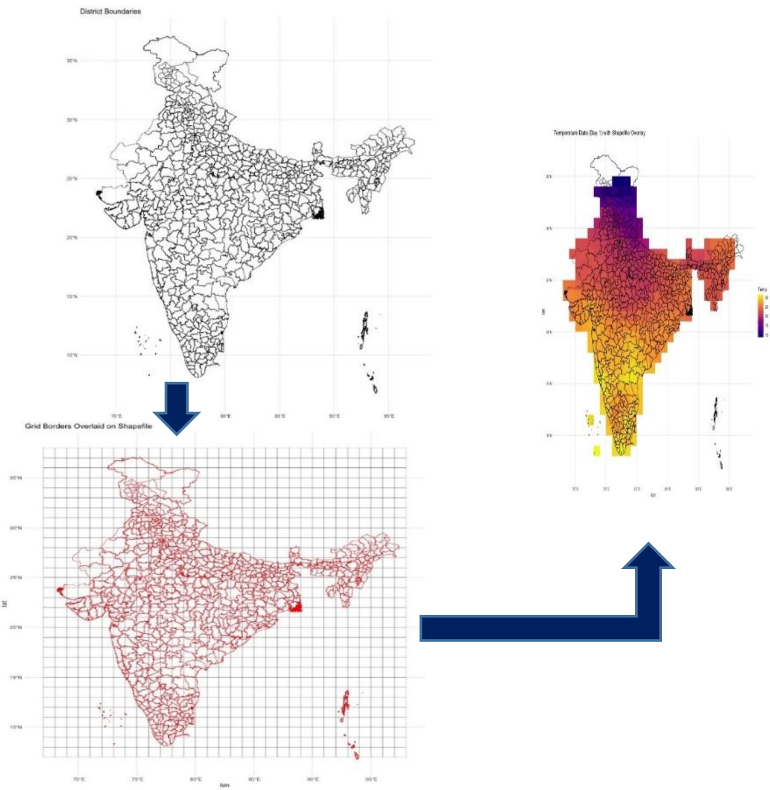
[8] Accessed from https://surveyofindia.gov.in

g. Repeat Step *f* for each year from 1951 – 2021 (for 71 years); the final dataset consisting of 71 years has a total of 16,596,400 ($\cong$ 1.66 crore) district$\times$day observations;

h. To obtain the monthly, seasonal and the annual average temperature for a district for 1951, calculate the *average* over month/season/year of the daily temperature values for that district. To obtain the monthly, seasonal and annual total rainfall for a district, *add* the daily rainfall for that district over the month/season/year; and for obtaining the state and all India monthly/yearly temperature and rainfall values, calculate the *average* of all district monthly/yearly average temperature and rainfall within each state.

Figure 2 below pictorially illustrates the above process for assessing district level maximum temperature for day 1 of 1951 using gridded temperature data for the same day.

Figure 2: Determination of District Level Weather – Illustration for Maximum Temperature



Note: Top left panel shows the district shapefile of India; the bottom left panel shows gridded maximum temperature for day 1 of 1951 overlaid on district shapefile; and right panel shows the estimated grid-level maximum temperature for day 1 of 1951 – where higher temperature is captured by the yellow and orange shades.
Source: Author's own preparation

TRENDS IN WEATHER/CLIMATE: INDIA AND TAMIL NADU

Based on recorded temperature and rainfall data over several years, some studies in the past have analyzed the trends in weather/climate across India. Goswami *et al.* (2006) analyzed the increasing trend in extreme rainfall events in India, whereas Srivastava *et al*. (2022) analyzed the trend in heat waves across India based on meteorological station level data over the period 1980 to 2010. Singh *et al.* (2024) analyzed the trend in maximum and minimum temperature in agro-climatic zones of India using meteorological station level data over the period 1951-2022. CSTEP (2022) is one of the few studies that analyzed the trend in temperature and rainfall over administrative regions of India. Based on data over the period 1990-2019, this study showed that 70 (54) percent of the districts in India have experienced an increase in maximum (minimum) temperature. The same study also showed that monsoon rainfall has also increased across India over the study period.

Using the district-wise temperature and rainfall determined for the period 1951-2021, the present study estimates trends in maximum and minimum temperature, and rainfall at all-India level as well as at one sub-national level – viz., Tamil Nadu, the southern-most coastal state of India. Apart from considering the entire seventy year time period, the study also analyzes the trends over three sub-periods, viz., 1951-1980, 1981-2010, and 2011-2021. In case of Tamil Nadu, the trends in temperature are analyzed across districts as well as agro-climatic zones. For the purpose of trend analysis, the study uses various methods described below.

Trend Analysis – Methods

a. *Mann-Kendall Test & Sen's Slope:*

   Behaviour of annual, seasonal and monthly time series of temperature/rainfall is studied by subjecting the series to non-parametric Mann-Kendall test and increasing or decreasing slope of trends in the time series is determined using Sen's method (Sen, 1968). The Mann-Kendall test consists of comparing each value of the time-series with the remaining others, always in sequential order. The number of times that the remaining terms are greater than that under analysis is counted.

The Mann-Kendall statistic is given by:

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} \mathrm{sign}(x_i - x_j)$$

where *n* is the length of the time series, x_i and x_j are two generic sequential data values.

The function $\mathrm{sign}(x_i - x_j)$ assumes the following values:

$$\mathrm{sign}(x_i - x_j) = \begin{cases} +1, \text{ if } (x_i - x_j) > 0 \\ \ \ 0, \text{ if } (x_i - x_j) = 0 \\ -1, \text{ if } (x_i - x_j) < 0 \end{cases}$$

Under the hypothesis of independent and randomly distributed variables when $n \geq 8$, the statistic S is approximately normally distributed with zero mean and the variance $\mathrm{Var}(S)$ as follows:

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

The standardized test statistic Z is given by:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S-1}{\sqrt{\mathrm{Var}(S)}} & \text{if } S < 0 \end{cases}$$

The presence of a statistically significant trend is evaluated using the Z value. A positive Z indicates an increasing trend in the time-series, while a negative Z indicates a decreasing trend. In this study, if $Z > +1.96$ or $Z < -1.96$, the null hypothesis (H_0) is rejected at the 95% significance level.

The estimate for the magnitude of the slope of trend b is calculated using non-parametric Sen's method, which is the median of slopes of all data value pairs.

$$b = \text{ median } \left[\frac{(X_j - X_i)}{(j - i)}\right], \text{ for all } i < j$$

where b is the slope between data points X_j and X_i measured at times j and i respectively.

b. *Shift in Distribution:*

Trends are also assessed by analyzing the shifts in distributional characteristics using quantile plots, the empirical CDF and PDF across the three sub-periods mentioned above.

c. *Innovative Polygon Trend Analysis:*

Introduced by Şen *et al.* (2019), innovative polygon trend analysis (IPTA) provides visually identifying trend in the time series. The present study examines monthly maximum and minimum temperature series to plot polygons. The data series is first divided into two equal halves and the average temperatures are calculated for each month in each of the two sub-series. With first and second half temperatures on the x- and y-axes, respectively, the polygon is generated by joining all monthly values. By observing whether the plotted polygon is above or below the 45^{o} line, the increasing or decreasing trend in the original series is ascertained.

Table 2 below provides a summary of the analyses undertaken at all-India level and for Tamil Nadu.

Table 2: Summary of Trend Analyses Undertaken

Sl. No.	Geographic Coverage	Periods	Variables	Frequency (of meteorological variables)	Analysis
1	All India	1951-2021 1951-1980 (Pd1) 1981-2010 (Pd2) 2011-2021 (Pd3)	Tmax Tmin Rainfall	Annual Jan-Feb March-May June-Sep Oct-Dec	Time Series plots; MK trend test
2	Tamil Nadu	1951-1980 (Pd1) 1981-2010 (Pd2) 2011-2021 (Pd3)	Tmax Tmin Rainfall	Annual	Quantile plots; Empirical CDF & PDF
3	Districts/ACZ of Tamil Nadu	1952-2021	Tmax Tmin	Annual	IPTA

Climate Trends – All India

Figures 3a, 3b, and 3c show the time-series plots of maximum temperature, minimum temperature and rainfall, respectively based on all-India data. In each figure the highlighted (red) portion of the plots in each column correspond to the entire period (1951-2021), or the three sub-periods (i.e., 1951-1980, 1981-2010, 2011-2021). The plots across the rows depict the annual and seasonal (i.e., January-February, March-May, June-September, and October-December) values. Wherever the trend is statistically significant, the plot area has been highlighted by a thick (red) border. The following broad inferences are drawn based on M-K test and Sen's slope estimate:

a. Annual average Maximum temperature (T_{max}) showed a positive and statistically significant trend with an estimated slope of 0.07 ºC/10yrs, which approximately equals to 0.5 ºC for the entire 1951-2021 period. Most of this increment is due to the faster pace of temperature rise during the 1981-2010 sub-period during which the estimated slope is 0.16 ºC/10yrs. The increase in maximum temperature over the sub-annual months of June-September and October-December are responsible for the rise in the annual average.

b. Annual average Minimum temperature (T_{min}) also shows significant increase over the period 1951-2021 with an estimated slope of 0.06 ºC/10yrs, which approximately equals to 0.4 ºC for the entire period. While the first sub-period shows a decreasing trend in nighttime temperature, the next period (1981-2010) showed significant positive trend with slope = 0.24 ºC/10yrs (i.e., ~ 0.7 ºC increase over the 30-year period). Statistically significant and increasing nighttime temperature especially during the summer months (June-September) (slope = 0.38 ºC/10yrs ~ 1.2 ºC) and the winter months (October-December) (slope = 0.35 ºC/10yrs ~ 1.1 ºC) have contributed to the rising annual average trend during this period.

c. Rainfall has exhibited an increasing trend only in the most recent period, 2011-2021, which in turn is attributed to a positive trend in October-December rainfall.

Climate Trends – Tamil Nadu

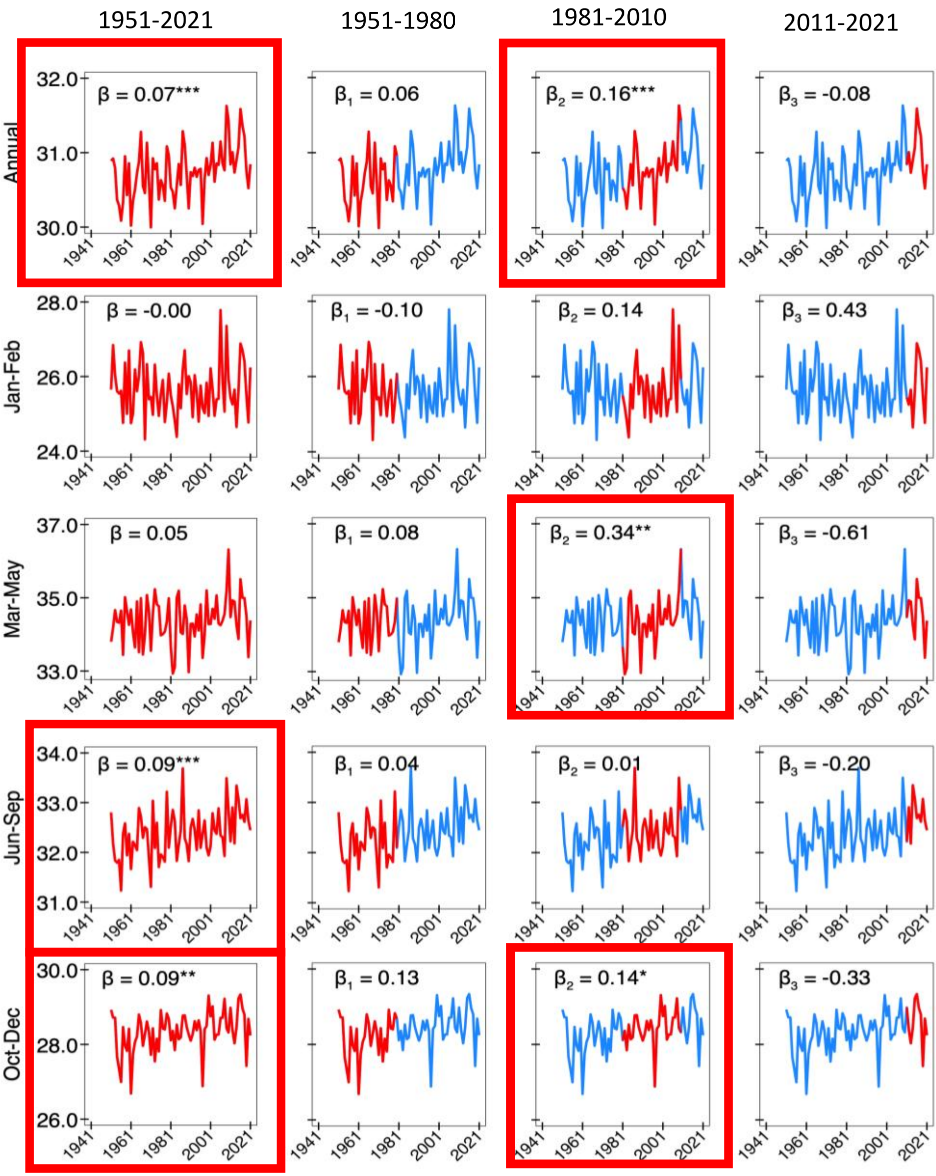
In addition to the all-India analysis, an attempt has also been made to understand the climate trends observed at sub-national level, such as state and district. For expositional purpose, the state and districts of

Tamil Nadu are considered here.[9] Figure 4 shows the quantile plots and empirical CDF & PDF for maximum, minimum temperature, and rainfall across the three sub-periods (i.e., 1951-1980, 1981-2010, and 2011-2021). These plots reveal the following in case of Tamil Nadu:

- T_{max} records significant changes between the first two sub-periods particularly at the upper end of the distribution. Between period 2 and period 3, the increase is not as substantial and changes are relatively uniform.
- For T_{min}, the distribution is relatively uniform between the first two sub-periods. However, between the second and the third sub-period an increase in nighttime warming in the hotter districts is observed.
- For rainfall, a clear increase in average rainfall as well as extreme rainfall is observed when last two sub-periods are compared.

[9] The state of Tamil Nadu – a water-stressed region – has already experienced changing rainfall patterns and higher incidence of rainfall extremes – droughts and floods. The state is projected to experience reduction in rainfall and higher temperature over the 21st Century (see Bal *et al.*, 2016). https://www.annauniv.edu/cccdm/ccprojection.pdf

Figure 3a: Time-series Plots Showing Trends in Maximum Temperature – Over Time and Seasons



Source: Author's own preparation

Figure 3b: Time-series Plots Showing Trends in Minimum Temperature – Over Time and Seasons

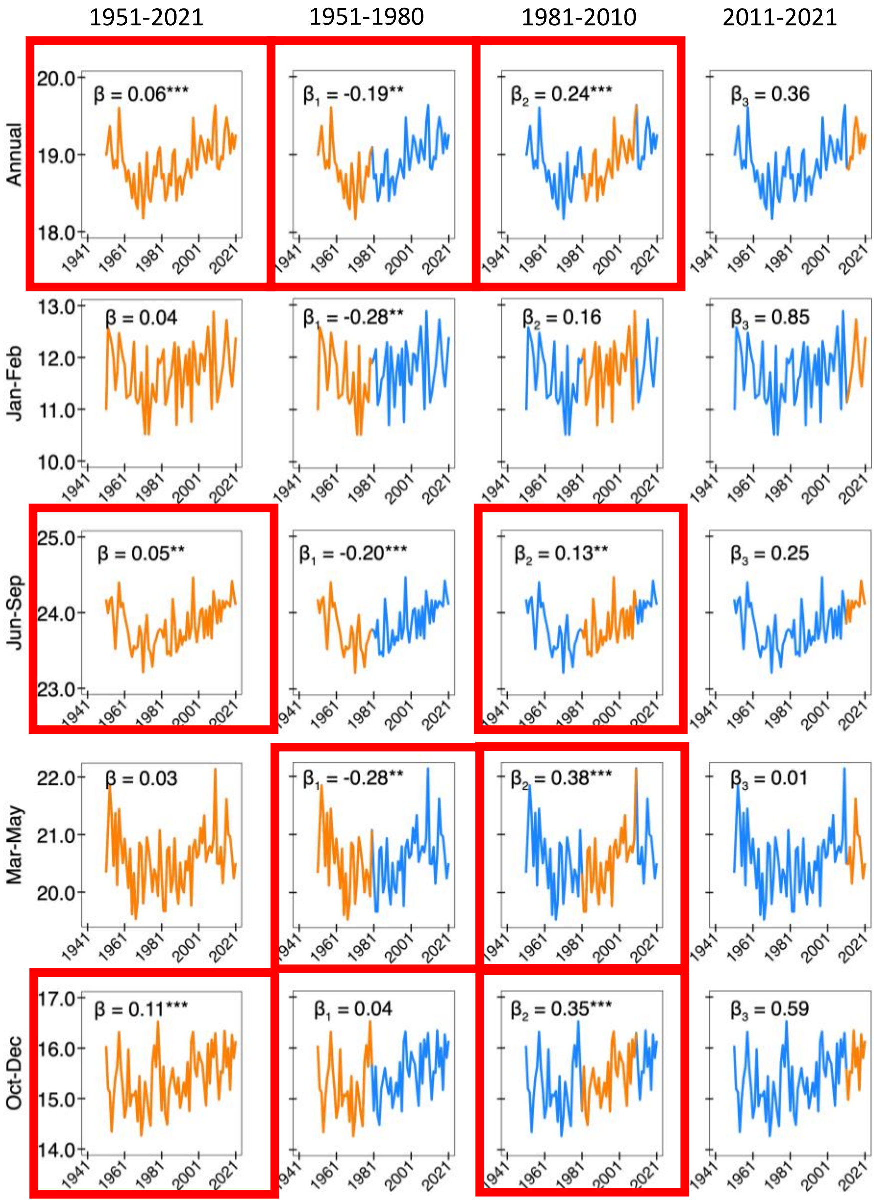
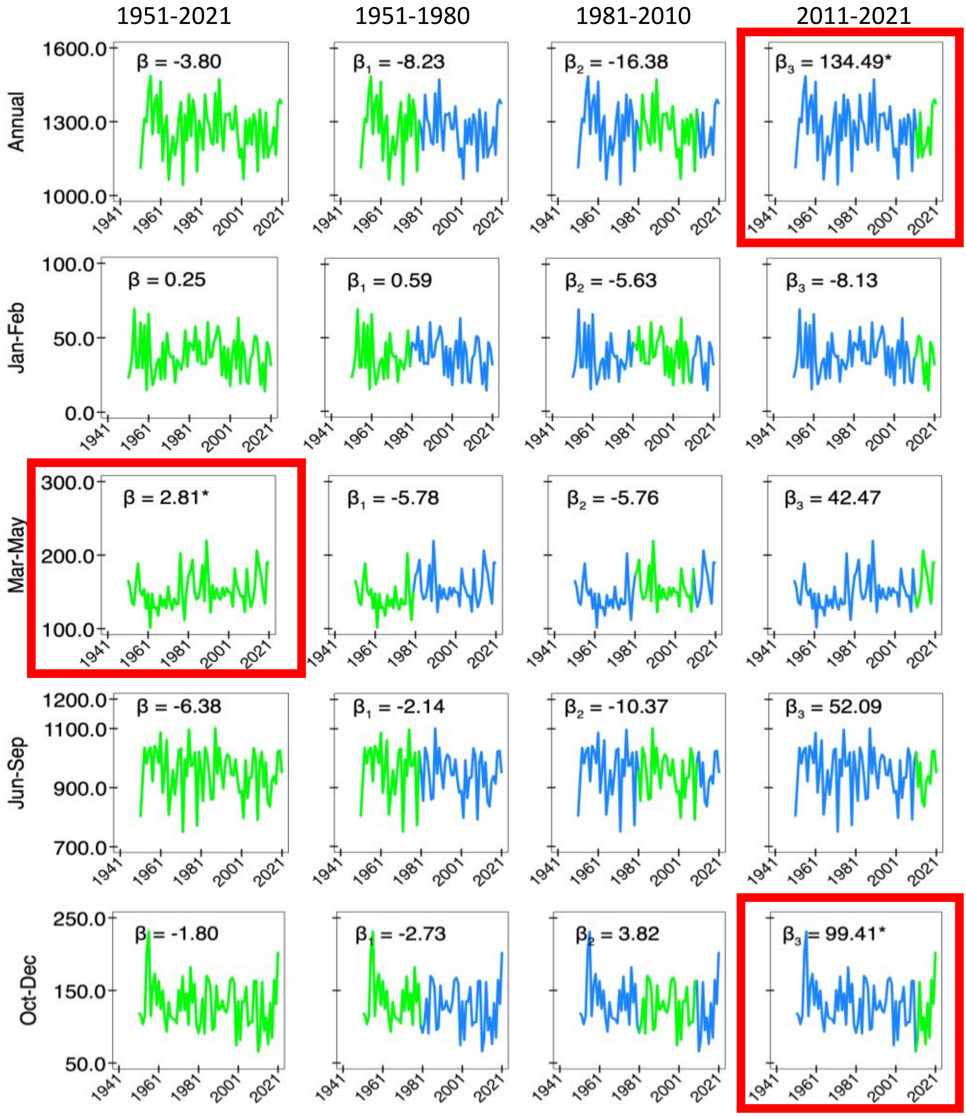
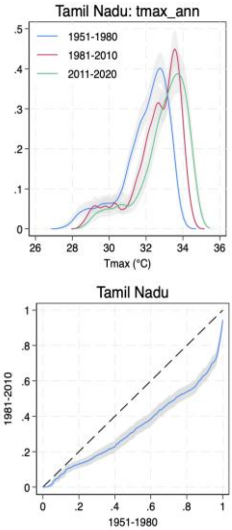


Figure 3c: Time-series Plots Showing Trends in Rainfall – Over Time and Seasons

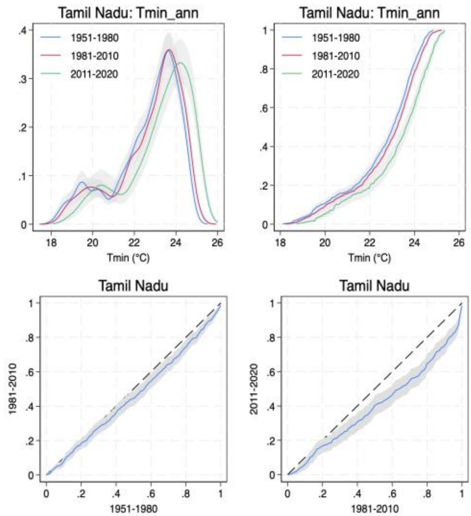


Source: Author's own preparation

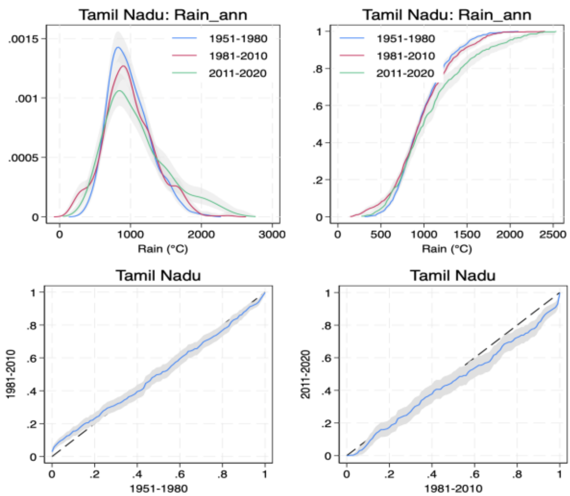
Figure 4: Distributional Characteristics of (a) Maximum Temperature; (b) Minimum Temperature; (c) Rainfall in Tamil Nadu – 1951-1980; 1981-2010; and 2011-2021



a: Max Temp



b: Min Temp

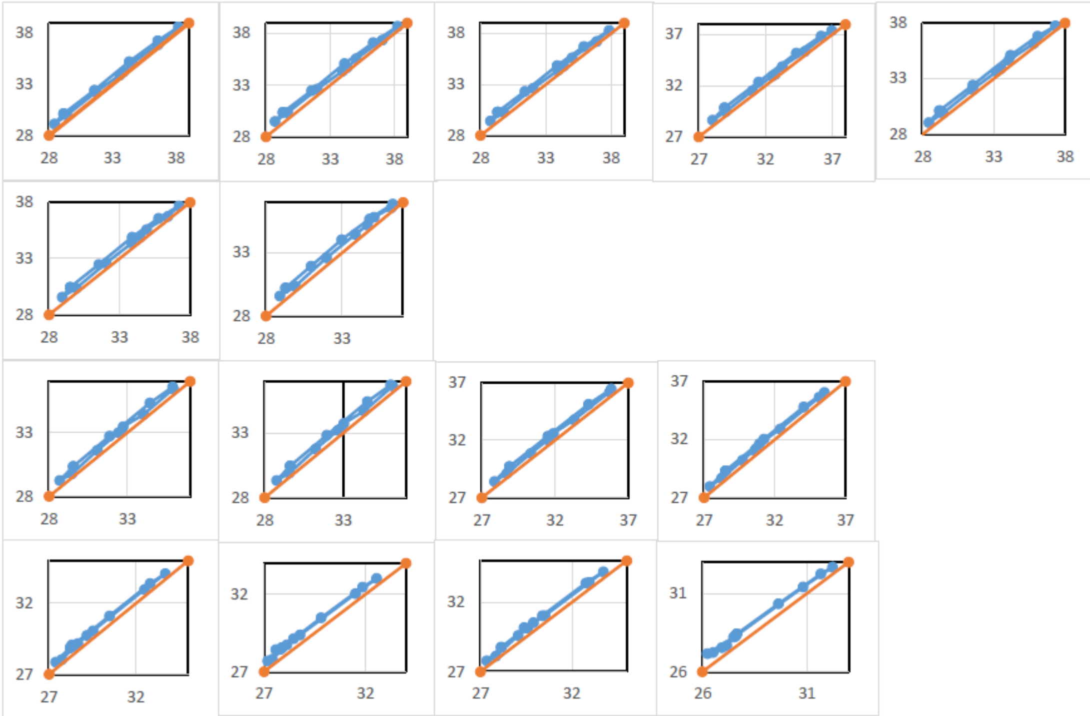


c: Rainfall

Source: Author's own preparation

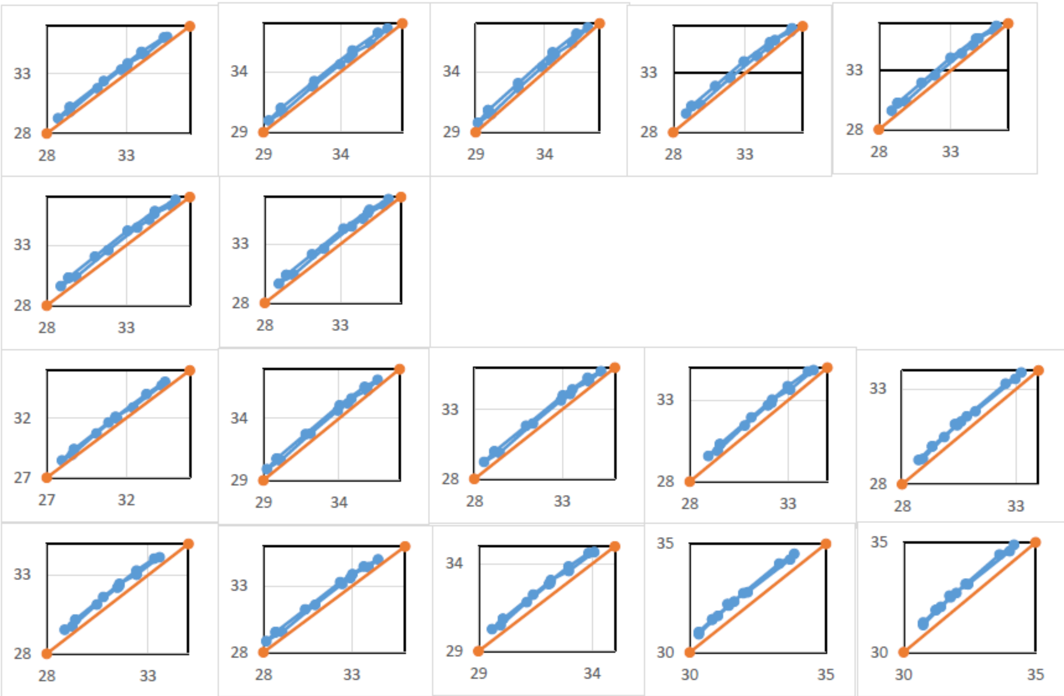
The changing climatic conditions across districts and agro-climatic zones of Tamil Nadu are analyzed through IPTA. However, the discussion here is restricted to maximum and minimum temperature as the rainfall showed considerable variation. As mentioned above, for plotting the IPTA, the data over the period 1952-2021 is considered, comparing the monthly averages over the period 1952-1986 with those over the period 1987-2021. Figure 5a and 5b show the district-wise IPTA plots for maximum and minimum temperature. The districts are grouped into their respective agro-climatic zones. As it could be seen from the IPTA plots, there is significant increase in both maximum and minimum temperature across all districts spread across different ACZs. All the increases are also statistically significant. Further, maximum temperature recorded relatively greater increase compared to the minimum temperature in almost all the districts of Tamil Nadu.

Figure 5a: IPTA – Maximum Temperature, Tamil Nadu Districts: 1952-2021



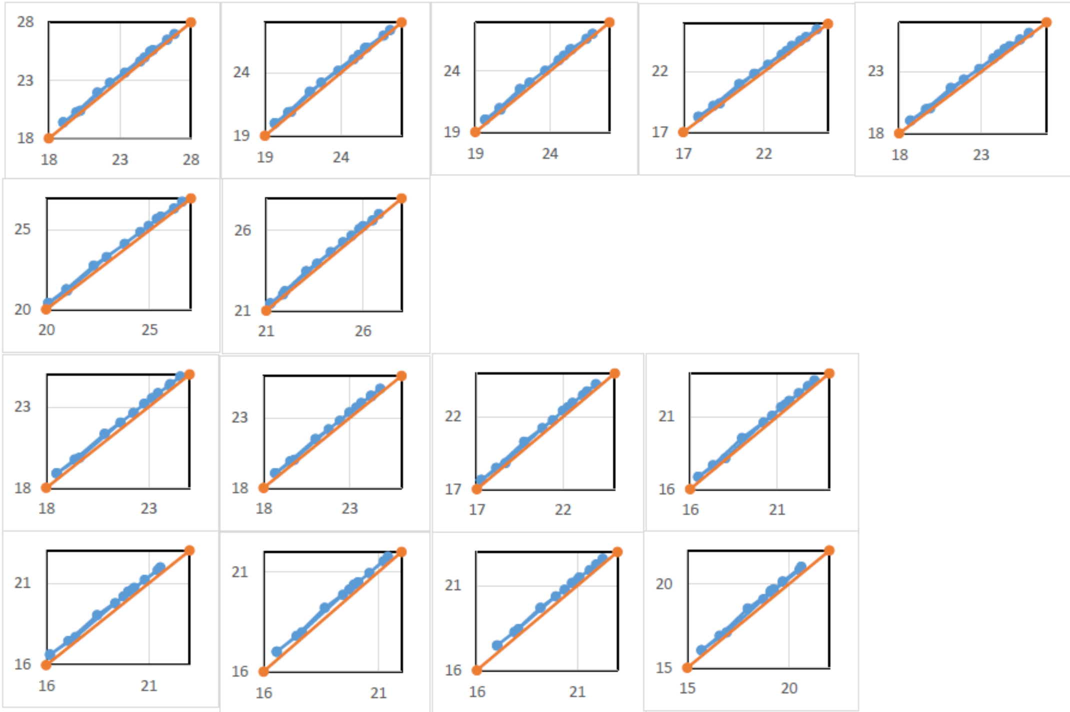
Note: North Eastern zone (Thiruvallur; Chennai; Kancheepuram; Vellore; Tiruvannamalai; Villupuram; Cuddalore) – top two rows; North Western zone (Krishnagiri; Dharmapuri; Salem; Namakkal) – third row; West zone (Erode; Coimbatore; Tirupur) & The Nilgiris – last row

Figure 5a: (continued)



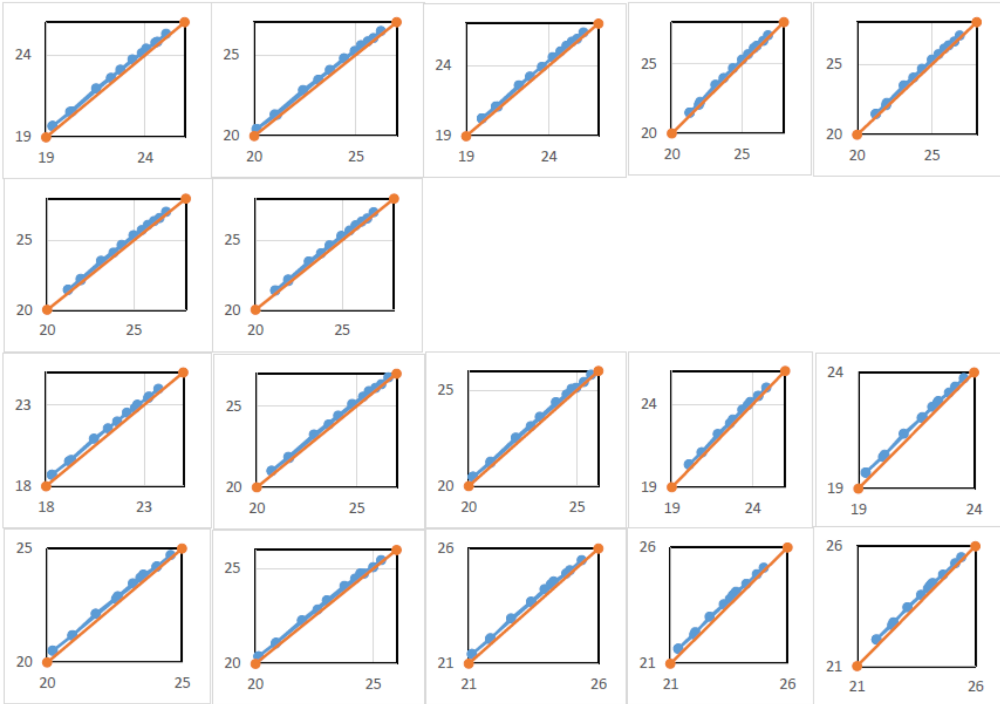
Note: Cauvery Delta zone (Karur; Tiruchirapalli; Perambalur; Ariyalur; Thanjavur; Thiruvarur; Nagapattinam) – top two rows; Southern zone (Dindigul; Pudukkottai; Sivaganga; Madurai; Theni; Virudunagar; Ramanathapuram; Thoothukkudi; Tirunelveli) & Kanniyakumar – bottom two rows

Figure 5b: IPTA –Minimum Temperature, Tamil Nadu Districts: 1952-2021



Note: North Eastern zone (Thiruvallur; Chennai; Kancheepuram; Vellore; Tiruvannamalai; Villupuram; Cuddalore) – top two rows; North Western zone (Krishnagiri; Dharmapuri; Salem; Namakkal) – third row; West zone (Erode; Coimbatore; Tirupur) & The Nilgiris – last row

Figure 5b: (continued)



Note: Cauvery Delta zone (Karur; Tiruchirapalli; Perambalur; Ariyalur; Thanjavur; Thiruvarur; Nagapattinam) – top two rows; Southern zone (Dindigul; Pudukkottai; Sivaganga; Madurai; Theni; Virudunagar; Ramanathapuram; Thoothukkudi; Tirunelveli) & Kanniyakumar – bottom two rows

CONCLUSIONS AND DISCUSSION

Social science researchers, carrying out climate risk assessments, face significant challenges due to unavailability of an official, single-source, fine-scaled weather data at the administrative geographies (e.g., Indian districts). Increasingly, weather data is made available in gridded form, which directly caters to the need of researchers from natural science discipline. Social science researchers, on the contrary, require such weather data at the administrative boundaries for their research objectives. Therefore, social science researchers need to engage in the determination of weather at the administrative scales based on the available gridded weather data products. Invariably, this requires each social scientist to: (a) invest significant time acquiring the GIS skills required for processing the gridded weather data, (b) 're-invent-the-wheel', limiting the scope for standardization, comparability, and reproducibility of the administrative scale weather data and/or the research output generated thereon. Failing to limit the uncertainty that could arise in the process of determination of administrative-scale weather could prove significantly counterproductive and costly for climate policy makers.

Given this backdrop, this paper provided a summary of the evolution of the publicly accessible official source of weather/climate data. Noting that official weather information is available publicly in gridded form, the paper also discussed the concepts and procedures involved in using these gridded weather data products to consistently arrive at weather for various administrative scales. The study further embarks on trend and distributional analysis of weather and climate for all India as well as focusing on the state of Tamil Nadu. The study also has the dual objective of – ease of access to such data – by making available the monthly weather information determined at the Indian state-level and annual weather data at the district scales for the benefit of Indian social science research community. Finally, by undertaking a comparison of the magnitude of the climate trends from the present study with that made available by the government agencies, the paper emphasizes that the differences can be minimized if government agencies such as the IMD assume responsibility as the single source supplier of weather data in India for the researchers from both natural and social science communities.

Data Availability Statement

The state-level monthly weather data and the district-level annual data will be made available to researchers on reasonable request.

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