Statistical Characterization of Maximum Temperature of Kerala, India

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ABSTRACT

Temperature is an essential climate variable that significantly contributes to the characterization of Earth's climate. The rise of temperature intensity is a major contribution that has resulted from natural as well as anthropogenic activities over the past few decades. India habitats an extraordinary variety of climatic regions making generalizations challenging. The study focuses on the statistical characteristics of daily maximum temperature of 8 stations namely, Kozhikode, Kannur, Alappuzha, Kochi (NAS), Punalur, Kottayam, Trivandrum city and Trivandrum Airport belonging to the state of Kerala, India. In order to explore the spatial and temporal behaviour of maximum temperature in Kerala, the variability of daily maximum temperature data from 1981 to 2020 (40 years) is analysed by looking at trend, stationarity, homogeneity, noise, and randomness. It was found that all the stations have an increasing stochastic trend with no noise and are heterogeneous and non-random in nature. The best fit probability distribution that suits the daily maximum temperature data for all the 8 stations were identified. The study aims to provide a knowledge base on the trend, pattern and variability of daily maximum temperatures of Kerala, India for better management of health, agriculture, irrigation, energy and ecology. Additionally, it will assist the state's policy makers and catastrophe management in reducing upcoming extreme temperature events.

Keywords: Temperature; Statistical characteristics; Probability distribution

1 Introduction

The average weather in a region over a longer length of time, from months to many billions of years, is typically referred to as the climate [1]. Despite the notion that climate change is a global problem, future changes are not expected to be uniform worldwide; rather, regional impacts may differ greatly. The statistical properties of climate variables, which serve as the fundamental inputs for applications of environmental modelling and simulations of climate, require a significant investment of time and effort to comprehend. The two primary variables used to describe the climate are precipitation and temperature, both of which can have significant impacts on ecosystems and human existence. Numerous hydrological processes including rainfall, are impacted by temperature and its variations, and these processes in turn have an impact on temperature. Temperature changes can interfere with natural processes, especially if they occur more frequently, for longer periods of time, and with more intensity than what humans can tolerate. The survival rate of plants and animals is also governed by annual and seasonal temperature trends.

Numerous scholars have examined trends in temperature and precipitation at individual stations as well as national and regional scales [2]–[9]. As far as the Indian context is concerned, the average annual temperature rose by 0.4°C/100 years throughout the 20th century, according to Hingane et al., [10]. The annual mean, maximum, and minimum temperatures have dramatically increased by 0.2°C per decade during the past three decades, according to Kothawale & Rupa Kumar's [11] analysis of surface temperature trends over India from 1901 to 2003. Various researches on trend analysis of temperature and other climate variables [12]–[17] on different spatial scales has already been conducted. "The Annual Climate of India

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report, which the Indian Meteorological Department has been producing every January since 2016, may not contain information that is applicable or actionable at the regional or state levels. State-level or even district-level climate reports are required in order to properly plan, undertake sector-based assessments, and carry out future climate research." said Dr. D Sivananda Pai, Senior Meteorologist and Director of the Institute for Climate Change Studies (ICCS) under the Kerala State Council for Science, Technology, and Environment. This was reported in an article published in Indian Express written by Anjali Marar dated on 22nd April 2022. The only study that has specifically addressed Kerala's streamflow variability is Drissia et al's [18] investigation of 43 river gauge stations from 25 west-flowing rivers in Kerala, India, that included a comprehensive statistical analysis of daily as well as flood discharge.

However, study on the statistical characteristics of maximum temperatures of Kerala, India has not been reported yet and this study intends to provide a platform to evaluate the spatio-temporal dynamics of daily maximum temperature (DMT) of Kerala. For more than 40 years, the daily maximum temperature dataset for the 8 stations in Kerala, India, that are currently in operation was obtained from the Indian Meteorological Department (IMD), Pune (1981-2020). The DMT series was subjected to descriptive statistics and inferential statistics, including trend, stationarity, noise, randomness, and change point detection. From the DMT data, the maximum temperature for each month and year was taken, and its variation was also examined. In order to draw a conclusion, the probability distribution that best fits the DMT data from all the stations was found. Section 2 discusses briefly on the study area, data collection and the methodology followed. The results and discussions are covered in Section 3 and Section 4 outlines the major conclusions drawn from this study.

2 Materials and Methods

2.1 Area of Study and Data Collection

Kerala, a coastal state in the south-west of India, can be found between 8° 17' 30" and 12° 47' 40" in the north and between 74° 27' 47" and 77° 37' 12 in the east. The state's distinctive geographical features result in a diversity of climates. Kerala typically experiences temperatures between 28°C and 32°C and has an annual average rainfall of roughly 3000 mm. The DMT dataset for the period 1981 – 2020 (40 years) were collected from Indian Meteorological Department (IMD) Pune for the 8 working stations namely, Kozhikode, Kannur, Alappuzha, Kochi (NAS), Punalur, Kottayam, Trivandrum city and Trivandrum Airport. Figure 1 depicts the locations of the temperature stations.

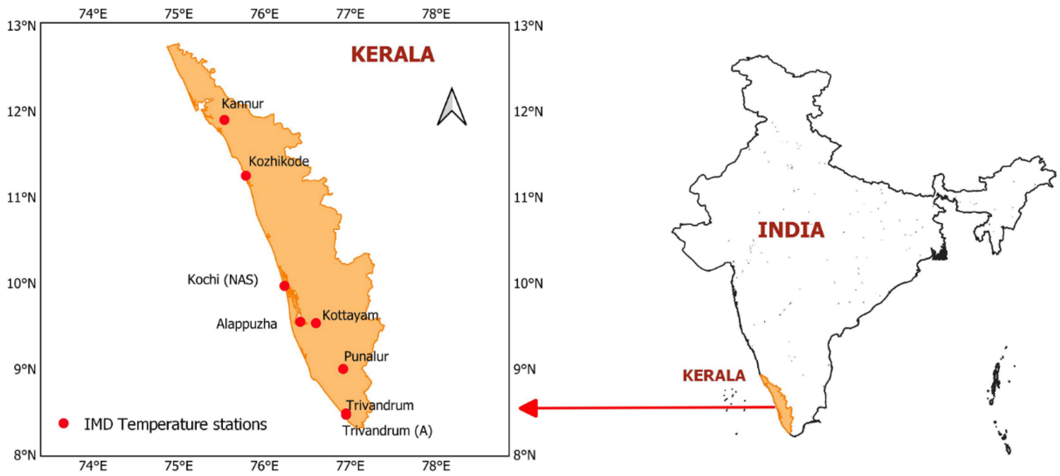

Figure 1: *Location of IMD Temperature stations in Kerala, India*

2.2 Methodology

The temporal variation of DMT time series is examined using an array of statistical tests. For a comprehensive knowledge of the dataset, descriptive statistics, including maximum, minimum, average, standard deviation (S.D), coefficient of variation (C.V), skewness & kurtosis, are performed. For the DMT series, inferential statistical analysis is also addressed, including trends, stationarity, change points, noise, and randomness. Each test was run using multiple methods to confirm the statistical properties of the DMT dataset at a significance level of 5%. Any test with a p-value < 0.05 accepts the alternative hypothesis and rejects the null hypothesis. Figure 2 gives an overall outline of the various statistical tests that were carried out on the DMT series.

The evolution of DMT series over an extended period of 40 years is defined with the help of trend analysis. Trend in the times series is estimated Mann-Kendall (MK) test [19], [20] and Sen's slope test [21] with the help of R package “trends”. In MK test, if p-value < 0.05 tells that there is monotonic trend else it means no trend. Sen's slope value and the MK test's sign (z-statistics) suggest that the trend is either diminishing or growing. Sen's slope estimator's magnitude provides a sense of change per unit of time.

While the stationarity test reveals the temporal variation of mean and variance, trend analysis reveals the overall trend in a time series. Augmented Dickey-Fuller (ADF) [22], Kwiatkowski-Phillips-Schmidt-Shin (KPSS) [23] and Phillips-Perron (PP) test [24] were used for testing the stationarity using R package “tseries”. While KPSS only examines stationarity around a deterministic trend, ADF and PP test examines unit root and stationarity existing in the time series. The presence of white noise in the time series was determined using Box-Pierce [25] and Ljung-Box [26] tests. If p-value > 0.05, then the series is considered to have white noise making the dataset to be independent and identically distributed. If else, the dataset is highly correlated and does not have noise. Randomness of each station were tested using Runs test [27] with the help of R package “randtests”.

Change point analysis also known as homogeneity tests gives the break point in the timeseries from where shifts occur. Through the use of the R package "trends," the homogeneity of the time series was examined using the Pettit's test [28], Standard normal homogeneity (SNH) test [29], Buishand range (BR) test [30], and Lanzante's test [31]. While BR and Pettitt tests are sensitive to finding changes in the middle of a series, SNH tests are known to discover change points closer to the beginning and conclusion of the series.

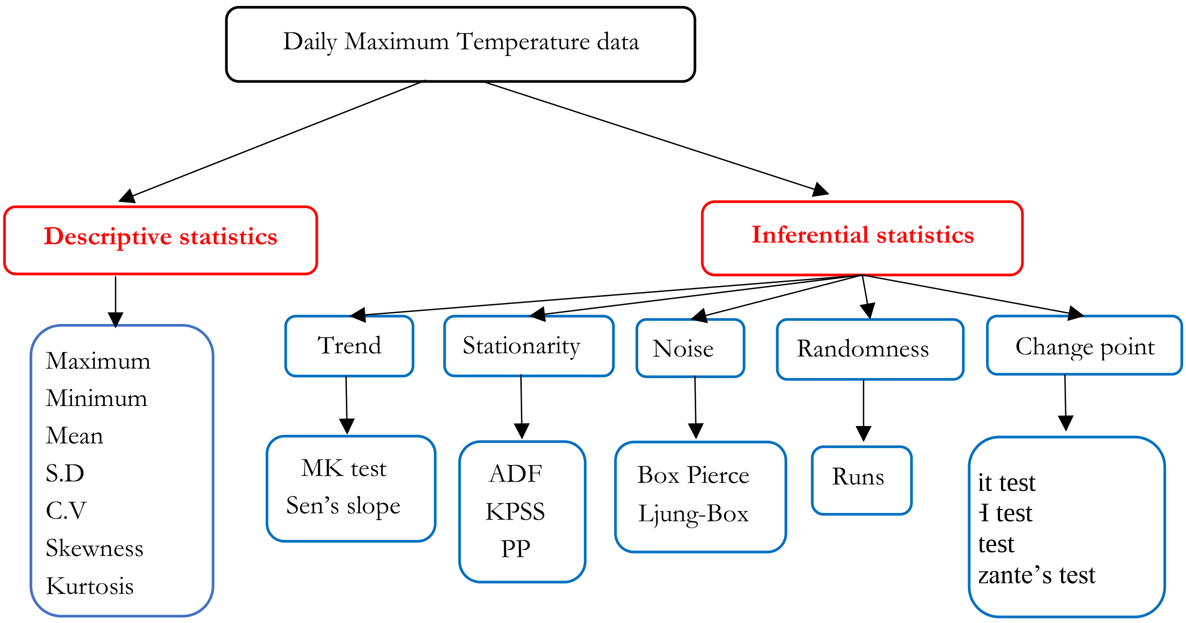

Figure 2: *Flowchart outlining the methods for statistically analysing daily series*

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3 Results and Discussion

Table 1 provides the descriptive statistics for the DMT. The highest and lowest temperature was observed at Punalur when compared to other stations. The DMT dataset is spread out with a S.D of about 1.51°C to 2.55°C. The C.V is very less (< 10%) which means that the level of dispersion around the mean is low making the dataset to be more precise. All the stations are moderately skewed (negative). In this study, all the stations have a positive kurtosis except for Kannur and Alappuzha, but in general it can be stated that all the stations follow a near normal distribution.

Table 1: *Descriptive statistics of DMT (1981-2020)*

Stations	Maximum	Minimum	Mean	S.D	C.V(%)	Skewness	Kurtosis
Kozhikode	39.2	24.4	31.94	2.27	7.1	-0.43	0.21
Kannur	39.2	23.2	32.23	2.45	7.6	-0.43	-0.07
Alappuzha	38.0	24.0	31.79	2.19	6.9	-0.35	-0.05
Kochi (NAS)	38.6	24.1	31.42	1.68	5.3	-0.70	0.88
Punalur	40.6	23.2	33.14	2.55	7.7	-0.22	0.13
Kottayam	38.6	23.7	32.19	2.24	7.0	-0.55	0.32
Trivandrum	38.2	23.9	31.88	1.85	5.8	-0.55	0.72
Trivandrum (A)	36.3	24.7	31.29	1.51	4.8	-0.40	0.59

The monthly and annual maximum temperature was extracted from DMT series and its variation was also analysed. Figure 3 clearly reveals the monthly variation of maximum temperature in Kerala over the period of 40 years. The maximum temperature rises from the month of January and peaks to its maximum by March and April, the hottest months of Kerala, then leading to the onset of monsoon by June with July and August being the coolest and wettest months. Winter season begins in the month of November and remains till January. This is the pattern observed for all the 8 stations helping us to generalize the month-wise season classification of Kerala.

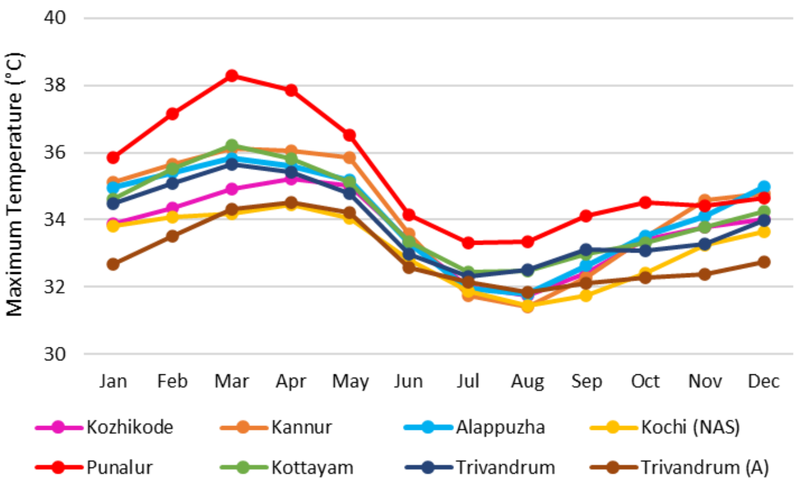

Figure 3: *Monthly variation of maximum temperature of Kerala, India (1981 – 2020)*

The annual maximum temperature trend followed by the 8 stations are shown in Figure 4 for better visualization. All the stations showcase an increasing trend and it is apparently evident that Kozhikode, Kannur, Kottayam and Trivandrum city have a significant presence of trend when compared to the others.

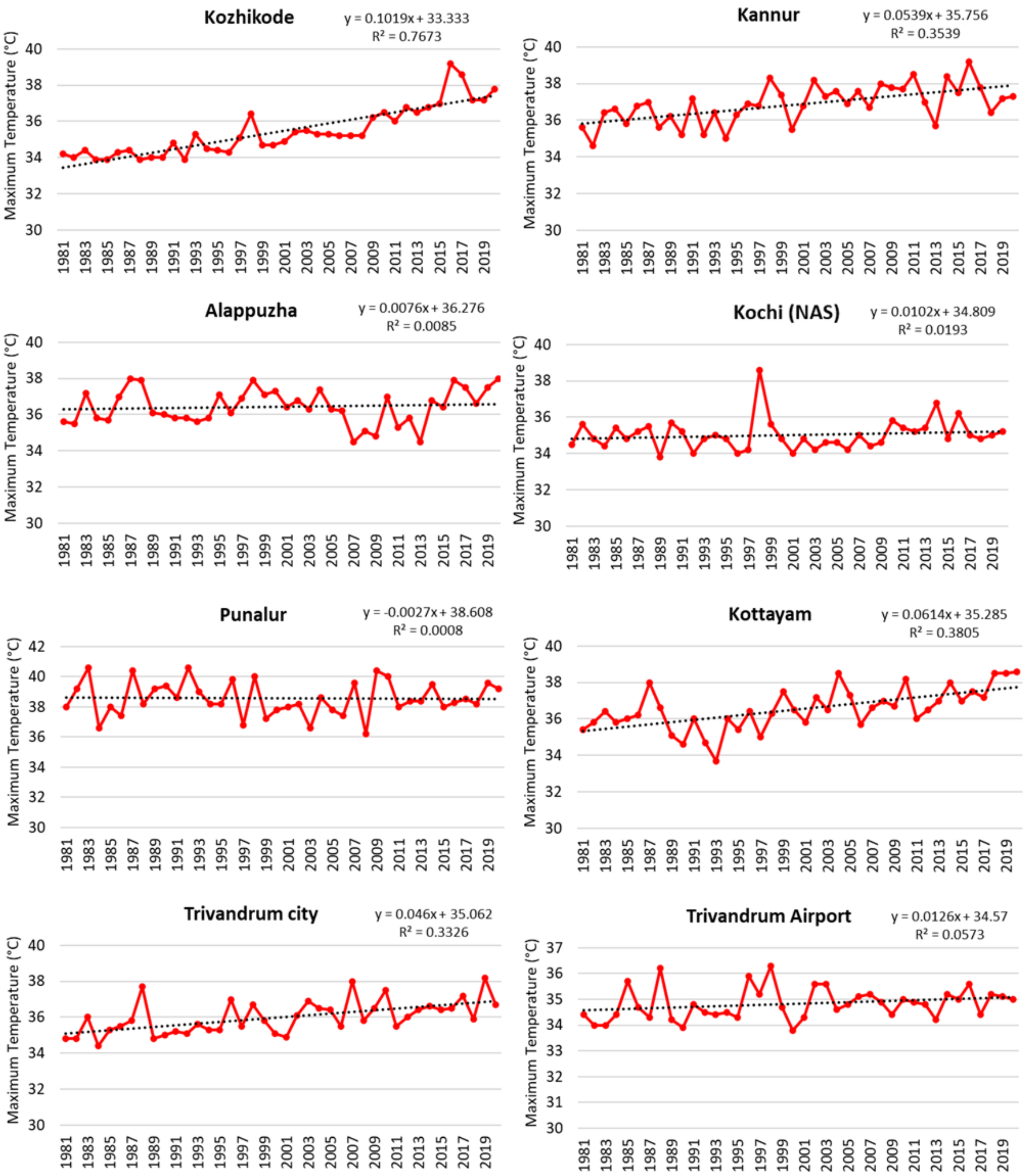

Figure 4: *Variation of annual maximum temperature of Kerala, India (1981 – 2020)*

All of the stations' DMT data were examined for trends, stationarity, change points, noise, and randomness; the results of this analysis are explained in more depth below.

3.1 Trend analysis

The trend in the DMT series was estimated using MK & Sen's slope test. The statistics of trend analysis is represented in Figure 5 (a). As per the p-value obtained from MK test, it was concluded that all the stations had a non-stationary trend. Additionally, Sen's slope test estimates of change magnitude are so negligible that they are almost nil.

3.2 Stationarity, randomness and noise

The stationarity test was carried out for DMT series using ADF, KPSS and PP tests as shown in Figure 5 (b). All stations are stationary in nature, according to the ADF and PP tests. KPSS test states that all the stations are non-stationary. The ADF test and KPSS test tend to give contradictory results since the interpretation of p-value is just the opposite to each other. Given that the KPSS test reveals non-stationarity and the ADF test reveals stationarity, it is possible to say that the DMT series across all stations is difference stationary. Difference stationary means that there is presence of stochastic trend.

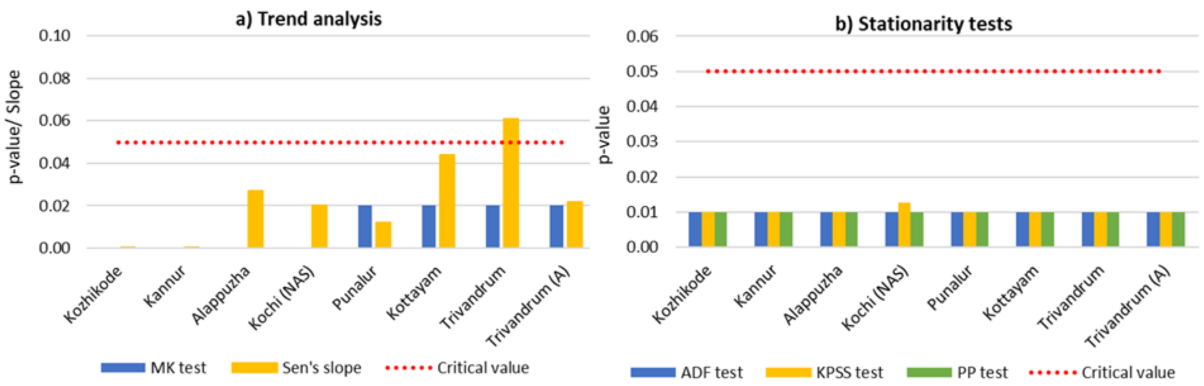

Figure 5: *Results of a) Trend analysis; b) Stationarity tests for DMT series*

The DMT series of all 8 stations were identified to be non-random in nature with the help of Runs test ensuring their correlation. The Box-Pierce and Ljung-Box tests were used to determine whether white noise was present. All of the stations' p-values were less than 0.05, indicating that the DMT series is noise-free and that they are connected.

3.3 Change point analysis

The homogeneity of the DMT series was assessed using the Petitt's, SNH, BR and Lanzante's test. If the stations are found to have change points, then the dataset is considered to be heterogeneous. All of the tests led to the conclusion that the 8 stations are not homogeneous in nature. Even though all the tests confirmed overall presence of heterogeneity, the break points identified were not the same by all tests in certain stations as depicted in Table 2.

Table 2: *Change point analysis of DMT series*

Stations	Pettit test	BR test	SNH test	Lanzante test
Kozhikode	2008	2008	2008	2014
Kannur	1995	1995	1995	1995
Alappuzha	2013	2013	2013	2013
Kochi (NAS)	2009	2009	2009	2009
Punalur	2008	1996	1996	2008
Kottayam	1998	1998	1998	1998
Trivandrum	2001	2001	2001	2001
Trivandrum (A)	1995	1995	1995	1995

Statistical characterization of any dataset is incomplete without determining the right distribution that fits the data. The identification of the right probability distribution that fits the data helps us to model our world, enabling us to possibly predict the probability of occurrence of an extreme event. Hence to summarize this study, the appropriate probability distribution function that suits the DMT dataset of all the 8 stations is identified from a list of 7 candidate distributions namely Normal, Lognormal, Logistic, Loglogistic, Gamma, Weibull and Generalized Extreme value (GEV) distributions as shown in Figure 6. Majority of the stations namely, Kozhikode, Kannur, Kochi (NAS), Kottayam and Trivandrum city obtained Weibull distribution as the best fit. While Alappuzha had GEV, Punalur had Normal and Trivandrum Airport had Logistic as the best fit distributions.

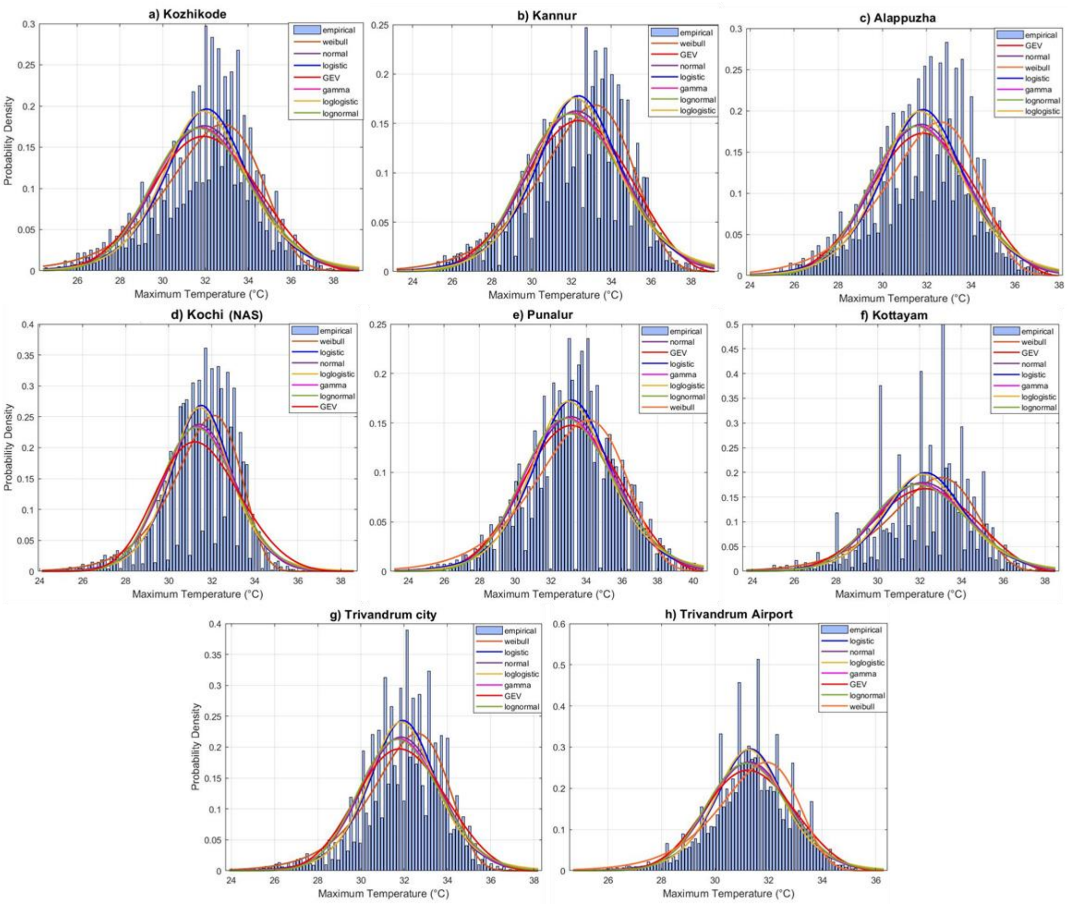

Figure 6: *Best fit distribution for DMT series*

4 Conclusions

The statistical characteristics of DMT data of currently working 8 IMD stations of Kerala, India was examined for a period of 40 years (1981-2020). The highest temperature was observed at Punalur station when compared to the others. The DMT dataset is spread out with a S.D of about 1.51°C to 2.55°C and has a low C.V making the dataset precise. All the stations are moderately skewed (negative) and follow a near normal distribution as per the values obtained for kurtosis. It was discovered that the DMT dataset is non-homogeneous and non-random in nature, and exhibits a stochastic growing trend with no noise. The Weibull distribution was found to provide the best fit for the data for Kozhikode, Kannur, Kochi (NAS), Kottayam, and Trivandrum city. Alappuzha, Punalur and Trivandrum Airport identified GEV, Normal and Logistic distributions as the best fit distributions respectively. It is highly important to statistical evaluate and understand the available dataset in order to blend it with probability to predict how the real (non-available) data will behave in the years to follow. Such studies will definitely support meteorologists, hydrologists, policy decision makers and disaster managers in the management and mitigation of future extreme temperature disaster events.

5 Declarations

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5.3 Competing Interests

The authors affirm that they have no known financial or interpersonal conflicts that would have appeared to have an impact on the research presented in this study.

5.4 Publisher's Note

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