__Original Research Article__

Climate dynamics over Kerala, India: Insight from a century-long temperature and rainfall dataanalysis

Abstract

Historical climate data analysis is of great significance in climate change adaptation and mitigation planning at global as well as regional levels. This article attempted to study the long-term trends of temperature and rainfallacross the districts in Kerala, India. CRU monthly time series data of rainfall and temperature data spanning from 1901-2022 were used for the analysis. Mann-Kendall test and Sen'sSlop estimator were applied to detect the presence and magnitude of the trend, and Pettitt's homogeneity test was used to find the climate change point in temperature time series data. The analysis found a significant and positive temperature trend across all districts in Kerala, with temperature increases ranging from 0.0086°C/year to 0.0102°C/year. In terms of rainfall trends, June and January experienced a significant decrease, while July and September saw a significant increase over the years. The year 1976 was identified as the point of climate change. It was observed thatthere was an increase in the southwest and Northeast monsoons in the post-period, with higher variability in the latter. Winter rainfall notably decreased during the post-period. The variability in climate parameters identified in this study could impact crop cycles and agricultural productivity, requiring further investigation at a micro-level for effective adaptation and mitigation strategies for the state.

Keywords: Temperature, rainfall, Mann-Kendall test, Sen's slop estimator

1. INTRODUCTION

Climate change is one of the most widely discussed topics across the globein the 21st century, and numerous studies are being conducted across various disciplines (Hong and Seo, 2011; Boykoff, 2020; Rath, 2022). The Intergovernmental Panel on Climate Change (IPCC) defines "climate change" as "a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and the variability of its properties, and that persists for an extended period, typically decades or longer"(IPCC, 2007). According to the United Nations Framework Convention on Climate Change (UNFCC), climate change can be attributed directly or indirectly to human activity that alters the composition of the global atmosphere, which is in addition to natural climate variability observed over comparable periods (UNFCC, 1992).Over the past decades, there have been evident changes in global climate due to the intensified human activities that disrupted the earth's atmospheric composition (IPCC, 2014). On a global scale, the annual mean surface air temperature is projected to increase by up to 3.7°C by the end of this century (IPCC, 2013). It is also projected that the temperature of the earth's surface will increase by 4.4^0C by the end of the next century (Krishnan et al., 2020). Further, The IPCC 2021 forwarded the starkest warning that the world is set to reach the 1.5^0c level in two decades down the line and emphasized that only immediate drastic cuts in carbon emissions would help prevent an environmental disaster (IPCC, 2021). Tesfaye et al. (2017) projected that the extent of heat-stressed areas in South Asia could increase by up to 12% in 2030 and 21% in 2050 relative to the baseline (1950–2000). Another study indicated that drier regions are forecasted to dry more, with severity as compared to humid regions. Sub-Saharan Africa's population poses more vulnerability in this situation (Lickley and Solomon 2018).

In the Indian scenario, the increase in maximum temperature has exceeded that of minimum temperature, leading to an expansion of the diurnal temperature range across all seven contrasting temperature zones (Dash et al., 2007). Consequently, the Indian subcontinent has experienced a warming of 0.56°C over the past century (Attri and Tyagi, 2010). Monsoon seasons contribute 80% of the annual rainfall received over the Indian sub-continent (Parthasarathy et al., 1994); hence, it is crucial for the performance of the overall economy, especially for the agricultural sector of the country (Ankush & Id, 2020: Dimri et al. 2022). Kerala, a state in southern India, receives the second-highest amount of monsoon among all the states. It often records an average annual rainfall above 3000mm, distributed over six months, with the highest rainfall occurring during June and July (India-Wris, 2015; Hunt & Menon, 2020). However, since 1965, there has been a significant declining trend in annual rainfall. Concurrently, maximum, minimum, and average temperatures in the state have been steadily increasing (Krishnakumar et al., 2009; State Planning Board, Government of Kerala, 2017).On the other hand, heavy rainfall events frequently became headlines, highlighting the natural hazards in different regions in Kerala (De et al., 2005). Changes in the rainfall distribution pattern of seasonal rainfall and inter-annual variations were the driving forces for such hazardous rainfall events (Murphy and Timbal 2007).

The aforementioned factors highlight the climate-sensitive nature of Kerala, and therefore, factoring climate information is crucial to delineate climate-proof development plans in Kerala. Climate data, especially rainfall and temperature, could serve as the basis for climate hazard mapping and risk assessment of various regions, sectors, and communities to ensure climate-proof development (CSTEP, 2022). Numerous studies (Hänsel et al. 2009; ~~Varadan et al., 2017;~~Serencam et al. 2019; Nyatuame et al. 2022; Djaman et al. 202; Rahman et al. 2022; Das et al. 2022; Thotli et al. 2022; Rajput et al. 2023; Maluvu et. Al. 2023) has been conducted to analyze temperature and rainfall trends in various regions worldwide. A few studies also analyzed rainfall and temperature trends in Kerala using the non-parametric Mann-Kendall test and parametric regression test. For instance, Jan et al. (2017) studied the centennialrainfall trend and variability in the Kuttanad region, while the rainfall trend in the Pattambi region was studied by Sai and Joseph (2018). Madhu et al. (2021) analysed rainfall trends in different regions of the Wayanad district, and historical temperature and rainfall trends in the Bharathapuzha river basin were investigated by Varughese et al. (2017). Ajithkumar & Riya (2022) examined the long-term trend of maximum temperature across various agro-climatic regions in Kerala. Nevertheless, there is no study specific to Kerala that identifies the climate change point using temperature time series data or explores how the rainfall distribution pattern varies during either period of the change point. With this backdrop, the present study aims to address the following research questions;

a) What is the trend of mean temperature across districts in Kerala?
b) What is the climate change point year based on temperature time series data?
c) What is the monthly, seasonal, and annual rainfall trend over Kerala?
d) How does the rainfall distribution vary between the pre-and post-period of climate change point?

2. METHODOLOGY

2.1. Data and study location

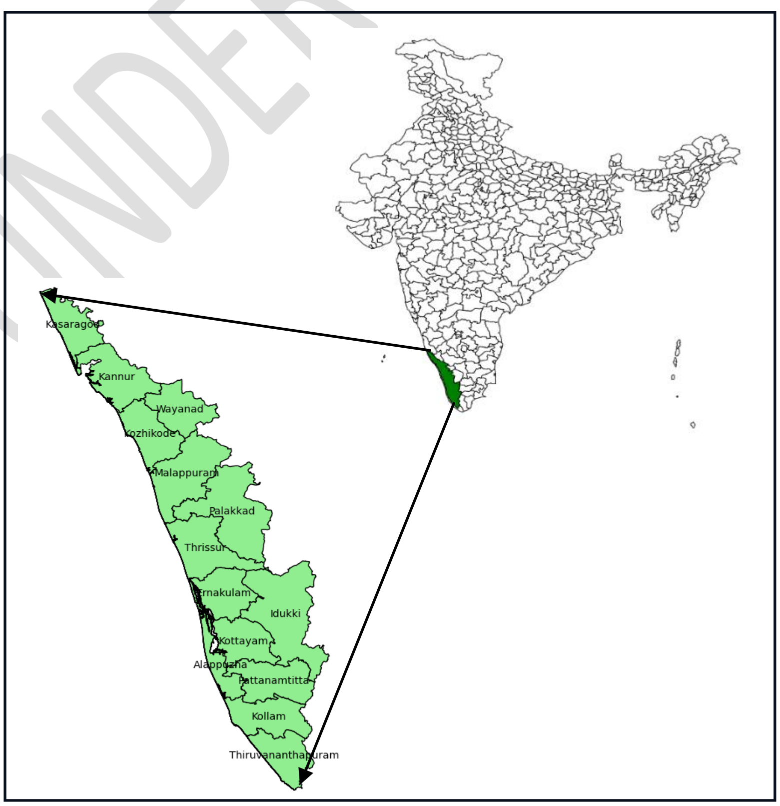


Fig 1. Map of the study area: The state of Kerala

The present study used recent release version 4.07 of the CRU TS (Climatic Research Unit gridded Time Series) dataset, which contains monthly time series data on various climatic variables such as rainfall, temperature, wet days, cloud cover, vapour pressure, frost days and potential evapotranspiration, spanning from 1901 to 2022 (122 years). This is an open sourcedatasetwidely used in climate change research which covers a 0.5° latitude by 0.5° longitude grid over all land domains of the world except Antarctica (Harris et al., 2020). Historical data on rainfall and temperature were then extracted from the CRU TS using R-studio software. The data was first downloaded as nc.gz files, then converted into .nc files, and finally extracted using the “remotes”package available in R-studio.

The southern Indian state, Kerala (Fig. 1), was chosen as the study area because of its climate-sensitive nature (CSTEP, 2022), being highly vulnerable to various extreme climate events like floods, drought, and landslides. Fourteen locations, corresponding to the fourteen districts in Kerala (Table 1), were identified to extract rainfall and temperature data. The CRU data validated with India Meteorological Department (IMD) station observatory data provided the best fit for different locations in Kerala(Jan et al., 2017).Further, as per IMD, the entire state is classified as one meteorological sub-division for climatological purposes, and the whole year is divided into four seasons, viz. South-west monsoon (June to September), Northeast Monsoon (October to December), Winter (January-February), and Summer (March to May).

Table 1. Geographical coordinates of locations chosen for the study

S.N.	Locations	Latitude(^{0}N)	Longitude(^{0}E)
1	Kasargod	12.4997	74.9870
2	Kannur	11.8745	75.3704
3	Wayanad	11.6362	76.0175
4	Kozhikode	11.2588	75.7804
5	Malappuram	11.0510	76.0711
6	Palakkad	10.7867	76.6548
7	Thrissur	10.5276	76.2144
8	Ernakulam	9.9816	76.2999
9	Idukki	9.9189	77.1025
10	Kottayam	9.5916	76.5222
11	Alappuzha	9.4981	76.3388

12	Pathanamthitta	9.2648	76.7870
13	Kollam	8.8932	76.6141
14	Thiruvananthapuram	8.5241	76.9366

2.2. Analytical methods

2.2.1. Mann-Kendall Test

The non-parametric Mann-Kendall test is a widely employed technique to detect monotonic trends in environmental and hydro-meteorological time series of data (Das and Bhattacharya 2018; Rahman et al. 2017, 2016; Das et al. 2020). The null hypothesis, H_0, is that the data come from a population with independent realizations and are identically distributed. The alternative hypothesis, H_A, is that the data follow a monotonic trend. The Mann-Kendall test statistic "S" is calculated using the formula given under (Mann, 1945; Kendall, 1975):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \mathrm{sign}(x_j - x_k) \text{ ------------ } (1)$$

With

$$\mathrm{Sign}(x_j - x_k) = \begin{cases} 1 & \text{if} \quad x_j - x_k > 0 \\ 0 & \text{if} \quad x_j - x_k = 0 \\ -1 & \text{if} \quad x_j - x_k < 0 \end{cases} \text{ ----------------- } (2)$$

The mean of S is E[S] = 0 and the variance of S, Var(S), is calculated as:

$$\mathrm{Var(S)} = \frac{\{n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j - 1)(2t_j + 5)\}}{18} \text{ ----------- } (3)$$

where p is the number of the tied groups in the data set, and tj is the number of data points in the jth tied group.

The statistic S is closely related to Kendall's τ as given by:

$$\tau = \frac{S}{D} \text{ ------------------- } (4)$$

Where,

$$D = \left[\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{j=1}^{p} t_j(t_j - 1)\right]^{1/2} \left[\frac{1}{2}n(n-1)\right]^{1/2} \text{ ---------- } (5)$$

The statistic S is approximately normally distributed provided that the following Z-transformation is employed:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}}; & \text{if} \quad S > 0 \\ \quad 0 \quad ; & \text{if} \quad S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}}; & \text{if} \quad S > 0 \end{cases} \quad ---------------------(6)$$

The positive and negative values of Z statistic represent increasing and decreasing trends in the time series data, respectively. Further, the null hypothesis (H_0) can be either accepted or rejected based on the set probability level, thereby facilitating the interpretation of the presence of significant trends in the data (Pearson and Hartley 1966).

2.2.2. Sen's slop estimator

This test computes both the slope (i.e. linear rate of change) and intercept according to Sen's method (Sen,1968). Sen's slope estimator is used to determine the magnitude of trend in rainfall and temperature time series data that has been identified through the Mann-Kendall test (Jain et al., 2012; Safari, 2012; Varadan et al., 2017; Das et al., 2021). The slope β (Sen's slope estimator) can be calculated from N pairs of data as follows:

$$\beta_i = \frac{x_k - x_j}{k - j}, i = 1,2,3, \cdots \cdots N, k > j \; ------------(7)$$

Where,
x_k and x_j denotes values of data at k and j times, and β_i is the median slope.

2.2.3. Pettitt's homogeneity test

The approach after Pettitt (1979) is widely applied to detect a single change-point or abrupt shift in hydrological series or climate time series data (Smadi and Zghoul, 2006; Zhang et al., 2009). The Pettitt test is an approximation for a sequence of random variables of the non-parametric method (Varadan et al., 2017).It tests the H_0: The T variables follow one or more distributions that have the same location parameter (no change) against the alternative H_A: a change point exists.The non-parametric statistic is defined as follows:

$$K_T = max\left|U_{t,T}\right| -----------(8)$$

Where,

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} \operatorname{sign}(x_i - x_j) ---------- (9)$$

The change-point of the series is located at K_T, provided that the statistic is significant. The significance probability of K_T is approximated for $p \leq 0.05$ with

$$p \simeq 2 \exp\left(\frac{-6K_T^2}{T^3 + T^2}\right) -------------- (10)$$

2.2.4. Box-and-whisker plot

A Box and Whisker Plot (or Box Plot) is a standardized way of visually displaying the data distribution through their quartiles (Kampstra, 2008; Bakar & Rosbi, 2017). Box plot summarizes the data on a five-point basis, viz. minimum or Lower extreme value limit, first quartile (Q_1), median(Q_2), third quartile (Q_3), and maximum or upper extreme value limit(Banacos, 2011). The plot will also display the outliers that go beyond either side of minimum or maximum limits. Since the plot did not make any assumption about the underlying statistical distribution, it is non-parametric. This tool helpsdepict the degree of dispersion in related groups of time series datasets. Therefore, it has been used to compare the quantity and dispersion of monthly and seasonal rainfall between pre- and post-periods of climate change points (Hartell and Skees, 2009; Varadan et al., 2017).

RESULTS AND DISCUSSION

Long-term temperature trend and the year of abrupt shift

The analysis of long-term temperature across the districts (Table 2) indicated that Thrissur had the highest mean temperature (27.28°C) with a CV value of 1.57%. All districts, except Wayanad and Idukki, had a mean temperature of over 25°C during the considered period. The highest CV values were observed in Wayanad and Idukki at 1.88% and 1.87%, respectively. The Man-Kendall test indicated a positive and highly significant (<1%) value of z-statistic in all the districts, which suggests a significant increasing trend in the historical data of mean temperature across the districts. Ajithkumar & Riya, 2022also reported a significant increasing trend in the maximum temperature across all districts of Kerala from 1983 to 2020. The average surface air temperature in Kerala increased by 0.65 °C from 1956 to 2014, and in the Idukki district, the maximum temperature is increasing, and the minimum temperature is declining, resulting in a widening of temperature ranges (Oommen et al., 2022). Mann-Kendall rank statistics provided a statistically significant increasing trend of temporal and seasonal temperature in the Pattambi region, which is located in the Palakkad district of Kerala, from 1950 to 2018(Raj & Azeez, 2022). The southern districts of Kerala, including Kottayam, Alappuzha, Pathanamthitta, Kollam, and Thiruvananthapuram, showed an increase in mean temperature at the rate of 0.01°C/annum. In contrast, the northern districts showed an increase of 0.009°C/annum or less.As revealed by(Sreeraj et al., 2021), pre-monsoon temperature changes in the Kottayam district from 1991 to 2014 indicated a decrease in maximum temperatures and an increase in minimum temperatures, which in turn resulted in the rise in the number of hot days in the region.

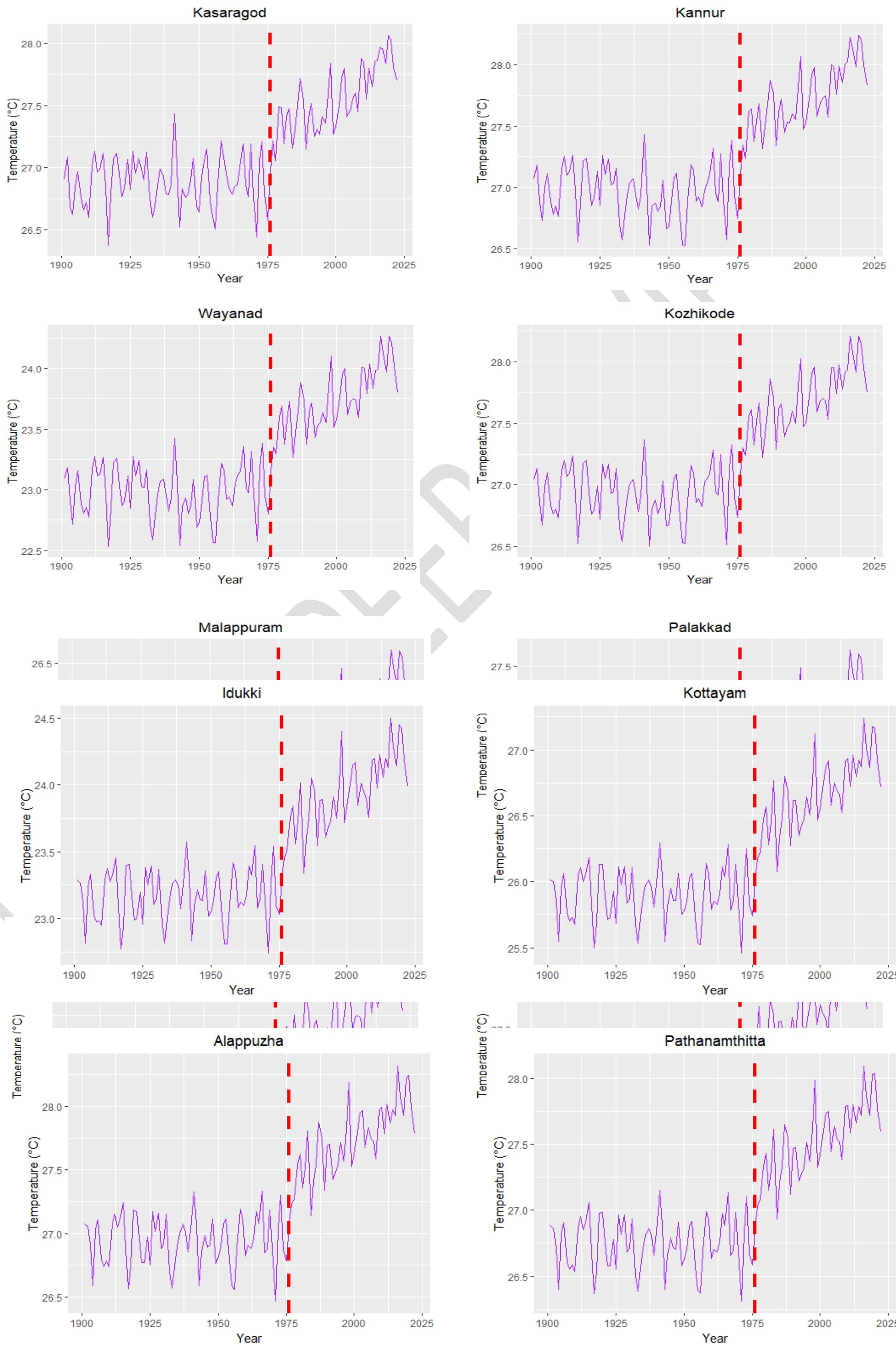
Table 2. Trend analysis of district-wise mean temperature (1901-2022): Mann-Kendall and Sen's slope estimation

District	Mean	CV (%)	MK Tau	Z-statistic	Sen's Slope (°C/annum)
Kasaragod	27.14	1.46	0.5480	8.9426***	0.0086
Kannur	27.26	1.61	0.5323	8.6902***	0.0096
Wayanad	23.27	1.88	0.5462	8.9117***	0.0097
Kozhikode	27.22	1.61	0.5436	8.8675***	0.0098
Malappuram	25.61	1.71	0.5507	8.9826***	0.0098
Palakkad	26.63	1.61	0.5565	9.0820***	0.0096
Thrissur	27.28	1.57	0.5525	9.0156***	0.0096
Ernakulam	27.13	1.65	0.5553	9.0600***	0.0101
Idukki	23.46	1.87	0.5626	9.1773***	0.0099
Kottayam	26.19	1.69	0.5577	9.0998***	0.0100
Alappuzha	27.24	1.65	0.5573	9.0952***	0.0102
Pathanamthitta	27.04	1.65	0.5569	9.0886***	0.0101
Kollam	27.19	1.65	0.5623	9.1771***	0.0102
Thiruvananthapuram	27.20	1.65	0.5573	9.0931***	0.0101

***Significant at 1% level

The next stage of the study involved using Pettitt's test on the district-wise mean temperature data to identify the shift or abrupt change point in the time series data. The K-statistic of the test showed a highly significant value with less than 0.01 probability values in all districts. The test successfully identified the change points in all districts (Fig. 2) and found that 1976 was the climate change point in all districts, except for Malappuram, where it was 1975. Hence, we selected 1976 as the year of climate change in Kerala in our subsequent analyses as well. Similar findings were reported in literature dealingwith multifractal fingerprinting of fine-resolution daily gridded rainfall of Kerala meteorological subdivision (Archana et al., 2021). The study mentioned a global climatic shift that occurred in 1976/77, which they used as a reference point for splitting the time series into two periods. George and Athira (2020) reported a significant change in the climatic pattern in the Bharathapuzha river basin (which covers three districts) in

Kerala after the 1980s. They identified 1980 as a significant change point in the rainfall time series data.



Rainfall trend and distribution over Kerala

The state of Kerala has an average annual rainfall of 2770 mm with a coefficient of variation (CV) of 13.29% (Table 3). The South-west monsoon contributes more (68%) to the annual rainfall, followed by the North-east monsoon (27%), which means that both monsoons together contribute 86% of the annual rainfall over Kerala. Among the months, July receives the highest rainfall (24%), followed by June (20%), while the CV is highest in January (105%).

Month-wise rainfall trend analysis indicated that June had experienced a significant (1% level) decreasing trend over the years, with a magnitude of decrease of 1.18 mm/year. January also showed a decreasing trend of rainfall (0.045 mm/year), which was significant at the 10% level. However, July and September showed a positively significant trend of z-statistic, with a magnitude of increase in rainfall equivalent to 0.88 and 0.62 mm/year, respectively. Among the different seasons, only the winter season showed a significant decreasing trend of rainfall (0.092 mm/year). The rest of the seasons and annual rainfall did not show any significant trend over the years. A study by Vijay et al., 2021, revealed a declining trend of annual and seasonal rainfall for the entire state of Kerala over 118 years ending in 2018.Adarsh & Janga Reddy (2015)indicated that the annual rainfall in the Kerala meteorological sub-division shows a significant decreasing trend, along with a similar decreasing trend in Jun rainfall as well. Further, they found a significantly decreasing trend of post-monsoon rainfall, which includes the months of October and November.

Table 3. Trend analysis of monthly and seasonal rainfall (mm) over Kerala during 1901-2022

Month/Season	**Mean**	**CV (%)**	**% Contribution to annual rainfall**	**MK Tau**	**z-statistic**	**Sen's Slope** (mm/year)
January	12.55	105.18	0.45	-0.1189	-1.9407*	-0.0451
February	17.27	101.19	0.62	-0.0256	-0.4138	-0.012
March	33.25	75.02	1.20	-0.0976	-1.5933	-0.0845
April	112.51	43.60	4.06	0.0637	1.0356	0.1407
May	208.08	49.54	7.51	-0.0597	-0.9737	-0.2368
June	556.25	39.87	20.08	-0.1875	-3.0582***	-1.1889
July	674.41	25.47	24.35	0.1256	2.0492**	0.8884
August	413.36	30.26	14.92	0.057	0.9294	0.3113
September	245.71	45.40	8.87	0.1259	2.0536**	0.6172
October	293.78	33.21	10.61	-0.006	-0.0974	-0.0286
November	160.52	50.03	5.80	-0.0061	-0.0974	-0.0144
December	41.96	83.15	1.52	-0.0263	-0.4293	-0.0279
SW monsoon	1889.73	18.58	68.23	0.031	0.5045	0.4421
NE monsoon	496.25	27.57	17.92	-0.0251	-0.4072	-0.1417
Winter	29.83	75.07	1.08	-0.1168	-1.9031*	-0.0919
Summer	353.84	32.43	12.78	-0.031	-0.5045	-0.1479
Annual	2769.66	13.29	100.00	0.0175	0.2833	0.2550

*Significant at 10% level, **significant at 5% level, ***Significant at 1% level,

The Box plots depicted in Figure 3 show the monthly rainfall distribution over two distinct periods: the first period runs from 1901 to 1976, while the second period is from 1977 to 2022. A comparison between these two periods reveals changes in rainfall patterns over time, with fluctuations in average rainfall and variability observed across different months.

It is worth noting that the average rainfall in January decreased from 14.20 mm to 9.84 mm, while slight increases in average rainfall were observed in July, August, September, October, and November. Interestingly, June and July maintain high average rainfall values in both periods, albeit with a decrease in average rainfall in June during the second period (587 mm to 505 mm). The findings of Madhu et al. (2021) indicated an asymmetric change in rainfall over Wayanad district in Kerala from 1999-2014, with an increase in September rainfall and a decrease in other months, indicating a shift in the distribution pattern. It can also be noted that a greater number of outliers were observed in the June and July months in both periods, indicating extreme rainfall events orfluctuations from the normal trend. The frequency of such outliers is more in number during the first period, particularly in June. These findings align with the observations of Pal & Al-Tabbaa (2011), who reported a significant decrease in monsoon rainfall extremes in Kerala, which could affect the overall tendency of change in seasonal total rainfall.

In the second period, certain months show noticeable increases in CV values compared to the first period, indicating increased variability. For example, January, February, and October showed a high increase in CV values, suggesting greater variability in rainfall during the second period. However, the June and November months showed a decrease in CV (42% to 32% and 50% to 49%), implying lower variability of rainfall in June during the second period.

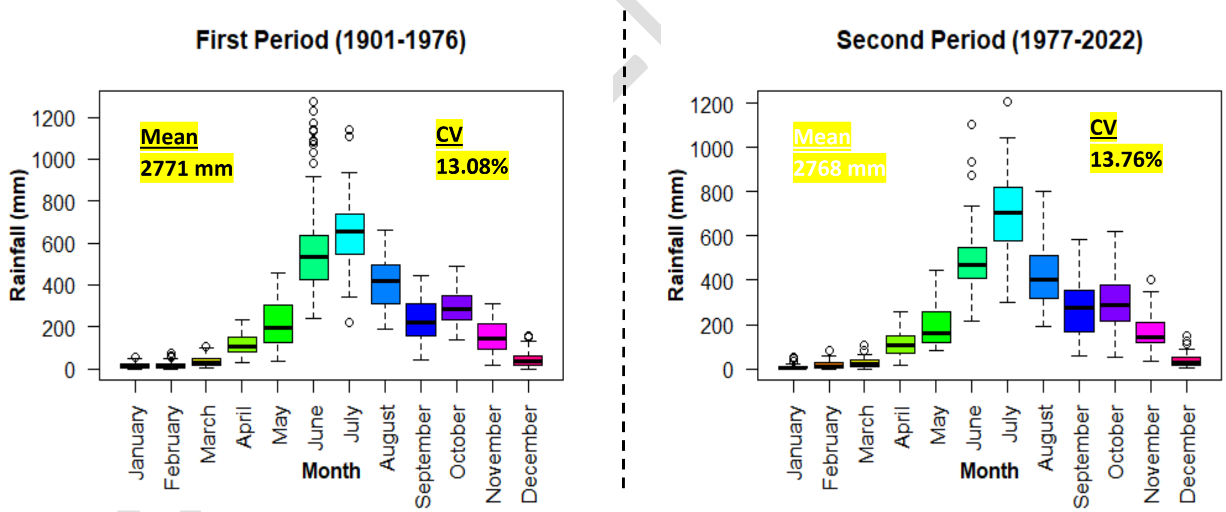


Fig 3. Monthly rainfall over Kerala: Comparison of First (1901-1967) and second periods (1977-2022)

The box plots in Figure 4 provide a comparison between the distribution of seasonal and annual rainfall data for two periods. The average annual rainfall was relatively consistent between the two periods, with only minor variation: 2770.81 mm in the first period and 2767.74 mm in the second period. During the South-west monsoon season, there was a slight increase in mean rainfall from the first period (1882.27 mm) to the second period (1902.06 mm). The decrease in the coefficient of variation (from 19% to 17%) indicates a reduction in variability, which suggests a more consistent dispersion of South-west monsoon rainfall in the second period. Jagadeesh and Anupama (2014) observed an increasing trend of south-west monsoon rainfall during 1976-2008 in the Bharathapuzha river basin areas.

Similarly, the average rainfall during the North-east monsoon increased from the first period (490.46 mm) to the second period (505.83 mm). However, there was a significant increase in the coefficient of variation, indicating higher variability in Northeast monsoon rainfall during the second period. Among these two monsoon seasons that contribute to the lion's share of rainfall over Kerala, the North-east monsoon has depicted higher variability over the years, particularly after the climate change point (1976).Archana et al. (2021) highlighted a change in the pattern of rainfall within the Kerala metrological subdivision after 1977.

The average winter rainfall decreased notably from the first period (31.63 mm) to the second period (26.84 mm). Additionally, there was a substantial increase in the coefficient of variation, suggesting much higher variability in winter rainfall during the second period. The average summer rainfall also decreased from the first period (366.45 mm) to the second period (333.01 mm), albeit with less variability than in winter.

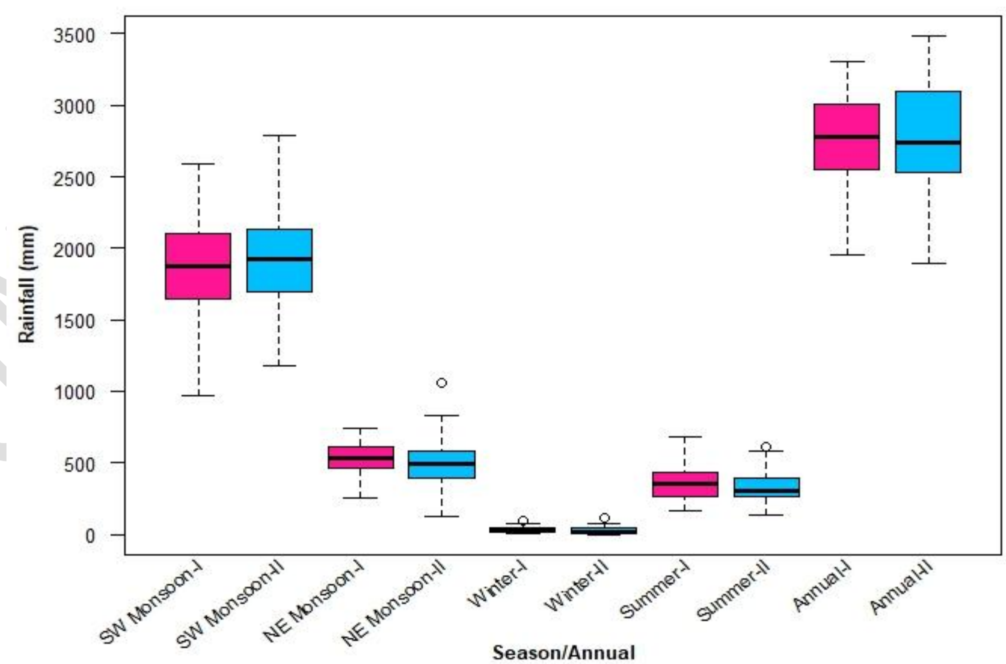


Fig 4. Seasonal and annual rainfall in Kerala: Comparison of first (1901-1967) and second periods (1977-2022)

CONCLUSIONS

Historical climate trend analysis across the districts in Kerala revealed important insights. Every district marked a significant increase in mean temperature over the years, with southern districtsrecording high rates of temperature rise as compared to northern districts. The year 1976 was identified as the point that signifies an abrupt shift in temperature pattern. The rainfall analysis indicated adecreasing trend in January and June and an increasing trend during July and September. Furthermore, winter rainfall showed a significantly decreasing trend over the years. Comparison of rainfall distribution between pre and post-periods of climate change year pointed to a high degree of variability in rainfall in the post-period, particularly for January, February, and April. In contrast, the months of June and Novemberexhibited a decline in rainfall variability. Notably, during the South-west monsoon rainfall, there was a slight increase in average rainfall from the first to the second period with a decline in variability even though North-east monsoon recorded a modest increase in average rainfall in the second period, but with a much higher variability. However, average annual rainfall remained relatively consistent between the two periods, with minor variability. The changes in temperature and rainfall distribution, particularly monsoon rainfall across most of the districts, render the state of Kerala highly vulnerable. This may affect the crop cycle, crop rotation, and, ultimately, the productivity of the overall agricultural system. However, this study does not cover other critical climatic parameters like relative humidity, sunshine, wind patterns, etc. We suggest undertaking in-depth studies on these aspects to explore their individual and combined effects on the state's climate. Yet, our findings are crucial, mainly because they help underscore the dynamic nature of major climatic variablesin Kerala. Further, these findings can be used as indicators for effective adaptation and mitigation planning in the state.

REFERENCES

Adarsh, S., & Janga Reddy, M. (2015). Trend analysis of rainfall in four meteorological subdivisions of southern India using non-parametric methods and discrete wavelet transforms. *International Journal of Climatology*, *35*(6), 1107–1124. https://doi.org/10.1002/joc.4042

Ajithkumar, B., & Riya, K. R. (2022). Temperature Variation in Kerala: Present and Future. *International Journal of Environment and Climate Change*, *12*(12), 1185–1195. https://doi.org/10.9734/ijecc/2022/v12i121558

Archana, D. S., Adarsh, S., Jayan, A., & Johnson, A. (2021). Multifractal fingerprinting of fine resolution daily gridded rainfall of Kerala meteorological subdivision, India using detrended fluctuation analysis. In *AIP Conference Proceedings* (Vol. 2336, No. 1). AIP Publishing.

Attri SD, Tyagi A. 2010. Climate Profile of India: Contribution to the Indian Network of Climate Change Assessment (National Communication-II), Ministry of Environment and Forests. Met Monograph No.Environment Meteorology-01/2010, India Meteorological Department, Ministry of Earth Sciences, New Delhi.

Bakar, N. A., &Rosbi, S. (2017). High volatility detection method using statistical process control for cryptocurrency exchange rate: A case study of Bitcoin. *The International Journal of Engineering and Science (IJES)*, *6*(11), 39–48. https://doi.org/10.9790/1813-0611013948

Banacos, P. C. (2011). Box and Whisker Plots for Local Climate Datasets: Interpretation and Creation using Excel 2007/2010. *Eastern Region Technical Attachment*, *Vol.1*, 2–20.

Boykoff, M. (2020). Digital cultures and climate change:'Here and now'. *Journal of Environmental Media*, *1*(1), 21-25.

Challinor, A. J., Watson, J., Lobell, D. B., Howden, S. M., Smith, D. R., & Chhetri, N. (2014). A meta-analysis of crop yield under climate change and adaptation. Nature climate change, 4(4), 287-291.

CSTEP. (2022). District-level changes in climate: Historical climate and climate change projections for the southern states of India. (CSTEP-RR-2022- 01).

Das J, Bhattacharya SK (2018) Trend analysis of long-term climatic parameters in Dinhata of Koch Bihar district, West Bengal. Spat Inf Res 26:1–10. https://doi.org/10.1007/s41324-018-0173-3

Das J, Gayen A, Saha P, Bhattacharya SK (2020) Meteorological drought analysis using standardized precipitation index over Luni Basin in Rajasthan, India. SN Appl Sci 2. https://doi.org/10.1007/s42452-020-03321-w

Das, J., Mandal, T., Rahman, A. T. M. S., & Saha, P. (2021). Spatio-temporal characterization of rainfall in Bangladesh: an innovative trend and discrete wavelet transformation approaches. *Theoretical and Applied Climatology*, *143*(3–4), 1557–1579. https://doi.org/10.1007/s00704-020-03508-6

DAS, L. C., Mohiul Islam, A. S. M., & GHOSH, S. (2022). MANN–KENDALL TREND DETECTION FOR PRECIPITATION AND TEMPERATURE IN BANGLADESH. *International Journal of Big Data Mining for Global Warming*, *4*(01), 2250001.

Dash SK, Jenamani RK, Kalsi SR, Panda SK. 2007. Some evidence of climate change in twentieth-century India. Climatic Change 85: 299-321.

De US, Dube RK, Prakasa Rao GS (2005) Extreme weather events over India in the last 100 years. J Indian Geophys Union 9(3):173–187.

Dimri, A., Roxy, M., Sharma, A., Pokharia, A., Gayathri, C., Sanwal, J., Sharma, A., Tandon, S., Pattanaik, D., & Mohanty, U. (2022). Monsoon in history and present. *Journal of Palaeosciences*, *71*(1), 45–74. https://doi.org/10.54991/jop.2022.463

Djaman, K., Koudahe, K., Bodian, A., Diop, L., & Ndiaye, P. M. (2020). Long-term trend analysis in annual and seasonal precipitation, maximum and minimum temperatures in the south-west United States. *Climate*, *8*(12), 1–20. https://doi.org/10.3390/cli8120142

George, J., and Athira P. (2020). Long-term changes in climatic variables over the Bharathapuzha river basin, Kerala, India. *Theoretical and Applied Climatology*, *142*(1–2), 269–286. https://doi.org/10.1007/s00704-020-03255-8

Hänsel, S., Petzold, S., &Matschullat, J. (2009). Precipitation trend analysis for central eastern Germany 1851–2006. *Bioclimatology and Natural Hazards*, 29-38.

Harris, I., Osborn, T. J., Jones, P., & Lister, D. (2020). Version 4 of the CRU TS monthly high-resolution gridded multivariate climate dataset. *Scientific Data*, *7*(1), 1–18. https://doi.org/10.1038/s41597-020-0453-3

Hartell J, Skees J. 2009. Pre-feasibility analysis: Index-based weather risk transfer in Mali. GlobalAgRisk, Inc.

Hong, S. J., & Seo, J. H. (2011). Climate change and human health. *Journal of the Korean Medical Association*, *54*(2), 149-155.

Hunt, K. M. R., & Menon, A. (2020). The 2018 Kerala floods: a climate change perspective. *Climate Dynamics*, *54*(3–4), 2433–2446. https://doi.org/10.1007/s00382-020-05123-7

India-Wris 2015. http://india-wris.nrsc.gov.in/wrpinfo/index.php?title =Kerala.

Intergovernmental Panel on Climate Change (IPCC). 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

IPCC, 2014. In: Core Writing Team, Pachauri, R.K., Meyer, L.A. (Eds.), Climate Change 2014: Synthesis Report, Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland, pp. 151. Geneva, Switzerland.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O.

Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896.

IPCC. Climate change 2007: Impacts, adaptation and vulnerability. In Working Group II Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change; Cambridge University Press: Cambridge, UK, 2007.

Jagadeesh, P. and Anupama, C. (2014) Statistical and trend analyses of rainfall: a case study of Bharathapuzha river basin, Kerala, India, ISH Journal of Hydraulic Engineering, 20:2, 119-132, DOI: 10.1080/09715010.2013.843280

Jain SK, Kumar V and Saharia M. 2012. Analysis of rainfall and temperature trends in northeast India. International Journal of climatology 33(4): 968-978.

Jan, P. S., Paneerselvam, S., Geethalakshmi, V., Ragunath, K. P., Dheebakaran, G., & Jagannathan, R. (2017). Centurial Rainfall Variability in Below Sea Level Farming Region of Kerala, India. *International Journal of Current Microbiology and Applied Sciences*, *6*(12), 2414–2422. https://doi.org/10.20546/ijcmas.2017.612.279.

Kampstra, P. “Beanplot: A boxplot alternative for visual comparison of distributions.” Journal of statistical software 28, no. 1 (2008): 1-9.

Kendall MG (1975) Rank correlation measures, vol 202. Charles Griffin, London, p 15

Krishnakumar, K. N., Prasada Rao, G. S. L. H. V., &Gopakumar, C. S. (2009). Rainfall trends in twentieth century over Kerala, India. Atmospheric Environment, 43(11), 1940–1944. https://doi.org/10.1016/J.ATMOSENV.2008.12.053

Krishnan R, Sanjay J, Gnaaseelan C, Majumdar M, Kulkarni A, Chakraborthy S (2020). Assessment of climate change over the Indian region: A report of the Ministry of Earth Sciences. Ministry of Earth Science of Government of India, New Delhi.

Lickley, M., and S. Solomon, 2018: Drivers, timing and some impacts of global aridity change. Environ. Res. Lett., 13, 104010, doi:10.1088/1748-9326/ aae013.

Madhu, V. Namboodiri, G.A. and Vijay, G. (2021). An analytical study of rainfall characteristics over Wayanad District of Kerala. *Turkish Journal of Computer and Mathematics Education (TURCOMAT)*, *12*(13), 1971–1979.

Maluvu, Z. M., Oludhe, C., Kisangau, P., & Maweu, J. M. (2023). Analysis of Rainfall and Temperature Trends and Their Implications on Green Gram Production in the Arid and Semi-Arid Lands of Kenya. *Science Letters*, *11*(2), 70–82. https://doi.org/10.47262/sl/11.2.132023400

Mann HB (1945) Non-parametric tests against trend. Econometrica 13(3): 245–259. doi:10.2307/1907187

Mendelsohn, R. (2009). The impact of climate change on agriculture in developing countries. Journal of Natural Resources Policy Research, 1(1), 5-19.

Murphy BF, Timbal B (2007) A review of recent climate variability and climate change in south eastern Australia. Int J Climatol. doi:10.1002/joc.1627

Nyatuame, M., Agodzo, S., &Amekudzi, L. (2022). Analysis of rainfall and temperature trend and variability of the Tordzie Watershed. *Ghana Journal of Science, Technology and Development*, *8*(1), 1-17. https://doi.org/10.47881/271.967x

Oommen, M., Gopakumar, C. S., Varghese, J. J., & Shree, A. B. R. (2022). Climate variability and change in the spices and plantation cropping systems in Kerala state, India. *Journal of Plantation Crops*, *50*(3), 169–179. https://doi.org/10.25081/jpc.2022.v50.i3.8237

Pal, I., & Al-Tabbaa, A. (2011). Monsoon rainfall extreme indices and tendencies from 1954-2003 in Kerala, India. *Climatic Change*, *106*(3), 407–419. https://doi.org/10.1007/s10584-011-0044-6

Parry, M., Canziani, O., Palutikof, J., Linden, P. van, & Hanson, C. (2007). C l i m a t e C h a n g e 20 0 7 : I m p a c t s , A d a p t a t i o n an d Vu l n e r a b i l i t y E d i t e d b y. *Climate Change 2007: Impacts, Adaptation and Vulnerability Edited*, 229.

Parthasarathy B, Munot AA, Kothawale D (1994) All-India monthly and seasonal rainfall series: 1871–1993. Theor Appl Climatol 49(4):217–224

Pearson ES, Hartley HO (1966) Biometrika tables for statisticians, vol 1, 3rd edn. Cambridge University Press, London

Pettitt AN (1979). “A non-parametric approach to the change-point problem”. *Appl. Statist*., 28, 126-135.

Rahman A. T. M. S, Jahan CS,Mazumder QH, Kamruzzaman Md, Hosono T, (2017) Drought analysis and its implication in sustainable water resource management in Barind area, Bangladesh. Journal of the Geological Society of India 89 (1):47–56.

Rahman A. T. M. S, Kamruzzaman MD, Jahan CS, Mazumder QH, Hossain A (2016) Evaluation of spatio-temporal dynamics of water table in NW Bangladesh: an integrated approach of GIS and Statistics. Sustainable Water Resources Management 2 (3):297–312

Rahman, H., Ishaque, F., Rashid, S., Rahman, J., & Hossain, A. (2022). An analysis of 50 years of seasonal rainfall and temperature pattern data in the Sylhet region of Bangladesh. *Multidisciplinary Science Journal*, *4*(4), 2022019. https://doi.org/10.31893/multiscience.2022019

Raj, P. P. N., & Azeez, P. A. (2022). Variations in temperature in a tropical town: A case study. *International Journal of Global Warming*. https://doi.org/10.1504/IJGW.2022.122434

Rajput, J., Kushwaha, N. L., Sena, D. R., Singh, D. K., & Mani, I. (2023). Trend assessment of rainfall, temperature and relative humidity using non-parametric tests in the national capital region, Delhi. *MAUSAM*, *74*(3), 593-606.

Rath, B. S. (2022). Climate Smart Livestock Management System: Livestock Advisories to Negate the Impacts of Climate Change. In *Impact of Climate Change on Livestock Health and Production* (pp. 27-33). CRC Press.

Safari B. 2012. Trend analysis of the mean annual temperature in Rwanda during the last fifty-two years. Journal of Environmental protection 3: 538-551.

Sen PK (1968) Estimates of the regression coefficient based on Kendall's tau. J Am Stat Assoc 63(324):1379–1389.

Serencam, U. (2019). Innovative trend analysis of total annual rainfall and temperature variability case study: Yesilirmak region, Turkey. *Arabian Journal of Geosciences*, *12*(23), 704.

Smadi MM, Zghoul A. 2006. A sudden change in rainfall characteristics in Amman, Jordan during the mid 1950s.American Journal of Environmental Sciences 2 (3): 84-91.

Sreeraj, A., Vijayakumar, S., & Vidyapeetham, A. V. (2021). *On the Analysis of Temperature changes over Kottayam district of Kerala Turkish Journal of Computer and Mathematics Education Research Article*. *12*(13), 1999–2004.

State Planning Board, Government of Kerala (2017). *Climate Change and Disaster Management Report, Agriculture Division*.

Tesfaye, K., Zaidi, P. H., Gbegbelegbe, S., Boeber, C., Rahut, D. B., Getaneh, F., ... & Stirling, C. (2017). Climate change impacts and potential benefits of heat-tolerant maize in South Asia. *Theoretical and Applied Climatology*, *130*, 959-970.

Thotli, L. R., Gugamsetty, B., Kalluri, R. O. R., Tandule, C. R., Kotalo, R. G., Akkiraju, B., & Lingala, S. S. R. (2022). Long-term (2001–2020) trend analysis of temperature and rainfall and drought characteristics by in situ measurements at a tropical semi-arid station from southern peninsular India. *International Journal of Climatology*, *42*(16), 8928–8949. https://doi.org/10.1002/joc.7783

UNFCC. (1992). *United Nations Framework Convention on Climate Change*, Article 1, Definitions: 1–33. Available at: https://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/conveng.pdf

Varadan, R. J., Kumar, P., Jha, G. K., Pal, S., & Singh, R. (2017). An exploratory study on occurrence and impact of climate change on agriculture in Tamil Nadu, India. *Theoretical and Applied Climatology*, *127*(3–4), 993–1010. https://doi.org/10.1007/s00704-015-1682-9

Vijay, A., Sivan, S. D., Mudbhatkal, A., & Mahesha, A. (2021). Long-Term Climate Variability and Drought Characteristics in Tropical Region of India. *Journal of Hydrologic Engineering*. https://doi.org/10.1061/(asce)he.1943-5584.0002070

Zhang W, Yan Y, Zheng J, Li L, Dong X, Cai H. (2009). Temporal and spatial variability of annual extreme water level in the Pearl River Delta region, China. Global and Planetary Change 69: 35-47.