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STATISTICAL ANALYSIS OF TEMPERATURE TRENDS AND IDENTIFICATION OF CHANGE POINTS IN NALGONDA DISTRICT, TELANGANA STATE, INDIA

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ABSTRACT

The main aim of this study was to analyse the trends and changes in long-term monthly and annual temperature patterns in Nalgonda district Telangana State, India. For this purpose, monthly temperature data from January 1995 to December 2023 was collected from the IMD website. The analysis employed both linear regression trend lines and non-parametric tests, including the Mann-Kendall test, Modified Mann-Kendall test, and Innovative Trend Analysis, to identify trends in the temperature data. Additionally, Pettit's test was applied to detect changes in temperature patterns, providing deeper insights into the overall trends. The Wallis and Moore test was used to assess the randomness of the temperature data under consideration, ensuring the reliability of the findings.

An Increasing trend pattern was seen in the linear regression trend method for given temperature data. The Modified Mann-Kendall test revealed that most parameters show non-significant increasing trends in temperatures, except pre-summer, which displayed a significant trend in the Nalgonda district of Telangana. Innovative Trend Analysis indicated that almost all trend slopes are positive, suggesting an overall increase in temperatures across the analysed months and seasonal periods. Pettit's test further highlighted that there were no significant shifts in temperature patterns across all parameters.

These findings are valuable for understanding climate patterns and can inform decision-making processes related to adaptation and mitigation strategies. They also assist in creating appropriate policy measures in advance.

Key words : Trend, Temperature, Modified Mann-Kendall test, Wallis-Moore test, Innovative Trend Analysis.

Introduction

The analysis of temperature trends and change points on a global scale is vital for understanding the broad patterns of climate change and its multifaceted impacts on ecosystems, economies, and human societies. With the increasing evidence of global warming, it is crucial to comprehensively assess how temperature patterns have shifted over time and identify specific points at which significant changes occurred. "One significant consequence is the increasing occurrence of extreme temperatures. Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer" IPCC 2014 (AR5 Synthesis Report: Climate Change 2014, IPCC). Climate change has caused a substantial alteration in the severity, recurrence and length of extreme weather events in many regions. The extreme temperature indices are shifting in trend, indicating that extreme temperature events are becoming more (Vijayakumar *et al.*, 2023). In recent years, information on the occurrence of extreme weather events has become increasingly vital for successful disaster management. As a result, research focused on changing extreme weather events is progressively gaining importance as one of the most popular subjects in the field of climate change. Many studies have already been undertaken in India on time-series analysis of extreme rainfall and temperature events (Manikandan *et al.*, 2019), which are found to vary across regions.

The analysis of temperature trends and identification of change points in Nalgonda district, Telangana, is crucial for understanding the local climate dynamics and its implications on agriculture, water resources and public health. Telangana, located in southern India, experiences significant seasonal variations and is characterized by a semi-arid climate. Nalgonda district, in particular has faced challenges related to water scarcity, drought and heat waves, which can profoundly impact the livelihoods and well-being of its residents. Temperature can have significant impact on various aspects of life and the environment. Fluctuations in temperature can also affect ecosystems, agricultural productivity and the distribution of plant and animal species. There is a general consensus among the researchers on the fact that there would be significant reduction in agricultural productivity in developing countries as a result of climate change (Anuradha *et al.*, 2017). In view of recent unprecedented occurrence of weather extremes at global as well as regional level, it is essential to examine climate variations at time scales of seasons to decades (Tammi Naidu *et al.*, 2016) Analyses of at least 30 years of data of these elements provide a proper understanding of the climate of a particular region (Ayoade *et al.*, 1983).

To study the variability in Temperature pattern, different trend analysis methods have been employed on temperature data of Telangana. The information gathered was tabulated, evaluated and statistically analysed in order to understand the trend in temperature of Nalgonda district in Telangana state.

Materials and Methodology

Study area

Nalgonda district, located in the state of Telangana, India, encompasses an area of 2,449.79 square kilometers (945.87 square miles) and has a population of 3,483,648, with 13.32% residing in urban areas as of the 2011 Census. It is the fourth largest district in Telangana, situated between latitudes 16°25' and 17°50' N and longitudes 78°40' and 80°05' E, covering a total area of 14,240 square kilometers. The district's agricultural landscape is characterized by the cultivation of primary crops such as paddy, jowar, groundnut, and chilies. It falls within two agro-climatic zones: The Southern Telangana Zone and the Northern Telangana Zone.

Nalgonda district is traversed by several rivers, including the Krishna River, Musi River, Aleru, Peddavagu, Dindi River, Halia River and Paleru. A significant concern for the district is the high fluorine content in its water, which affects both agriculture and public health.

Administratively, Nalgonda is divided into three revenue divisions: Nalgonda, Miryalaguda and Devarakonda. These divisions are further subdivided into 31 mandals, encompassing a total of 565 villages. For this study, the daily temperature data of Nalgonda district in Telangana state was considered from past 29 years *i.e.* from 1995- 2023 and data was collected from the IMD Website (IMDLIB.ipynb - Colaboratory (google.com)). Fig. 1 depicts the study area map of Nalgonda district.

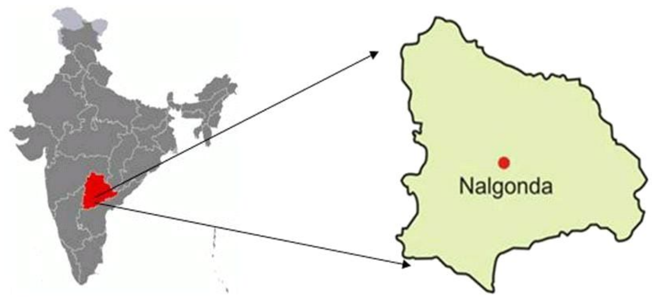

Fig. 1 : Study area map of Nalgonda district in Telangana state.

Trend Analysis

Trend analysis is widely used across various fields, from climatology to economics, for the purpose of identifying and predicting the patterns in time series data. It involves examining data points collected at different times to detect a consistent upward, downward, or neutral pattern, often referred to as the trend. This analysis is widely utilized across various domains, including finance, environmental science and public health, to support decision-making and predict future occurrences. Several methods are employed, depending on the nature of the data and the specific requirements of the analysis.

In this article, both parametric and non-parametric methods were employed to evaluate temperature patterns in Telangana state. The methods used include linear regression analysis, the Mann-Kendall test, Sen's slope estimator, the Modified Mann-Kendall test, and the Innovative Trend Analysis method. Additionally, Pettitt's test was applied for detecting change points.

Linear Regression analysis

Linear regression analysis is a fundamental statistical tool for modelling relationships between variables. It is commonly used for trend detection in time series data, providing a straightforward method for quantifying trends (Montgomery *et al*., 2012). It models the relationship between a dependent variable (Y) and an independent variable (t), in time series it is t, the linear regression equation is expressed as

$$y = a + mt \tag{1}$$

Where, Y represents the dependent variable, t is the time variable, m is the slope and a is the intercept. The slope m indicates the rate of change in Y for a unit change in t. The significance of the trend is often tested using a t-test, checking if the slope significantly differs from zero at a 5% significance level.

The Mann-Kendall's Trend Test

The Mann-Kendall (MK) test is a non-parametric test used to detect monotonic trends (either increasing or decreasing) in a time series. Its non-reliance on data distribution assumptions makes it versatile for various applications, especially in environmental and hydrological studies (Mann *et al*., 1945). It does not require the residuals to be normally distributed, making it suitable for datasets with non-normal distributions. The test statistic, S, is calculated based on the difference between data points:

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sign\left(x_j - x_i\right) \tag{2}$$

where, x_i and x_j are the data points at times i and j, respectively. For large samples, the standardized test statistic Z_{MK} is used to determine the presence of a trend.

Computing the MK test statistic, Z_{MK}, is performed as follows:

$$Z_{MK} = \frac{s-1}{\sqrt{VAR(S)}} \text{ if } S>0 \tag{3}$$

$$ZMK = 0 \text{ if } S=0 \tag{4}$$

$$Z_{MK} = \frac{s-1}{\sqrt{VAR(S)}} \text{ if } S<0 \tag{5}$$

Sen's Slope Estimator

Sen's slope is a robust method for estimating the true slope of a trend in time series data. It is particularly useful in environmental sciences, where data may contain outliers or non-normal distributions. It calculates the median of all slopes derived from pairs of data points:

$$(t) = Qt + B \tag{6}$$

Where, Q is the slope, B is a constant and t is time. To get the slope estimate Q, the slopes of all the data value pairs are calculated using the following equation:

$$Qi = \frac{x_j - x_k}{j-k} \tag{7}$$

Where, x_j and x_k are the data values at time j and $k(j>k)$, respectively. If there are n values x_j in the time series, there will be as many as $N = \frac{n(n-1)}{2}$ slope estimates Q. The N values of Qt are ranked from the smallest to the largest and the Sen's estimator is:

$$Q = \begin{cases} Q_{\left[\frac{n(n+1)}{2}\right]}, & \text{if } N \text{ is odd or} \\ \frac{1}{2}\left(Q_{\left[\frac{N}{2}\right]} + Q_{\left[\frac{N+2}{2}\right]}\right), & \text{if } N \text{ is even} \end{cases} \tag{8}$$

To obtain the estimate of B in equation (t) the n values of differences $x_i - Q_{ti}$ values are calculated. The median of the values gives an estimate of B.

Modified Mann-Kendall Test

The Modified Mann-Kendall test extends the traditional MK test by accounting for serial correlation in the data. This correction is crucial when analysing time series with autocorrelation, which can otherwise lead to incorrect conclusions about the significance of trends. The Modified Mann-Kendall test accounts for autocorrelation in time series data, providing more accurate trend detection when the data exhibits serial correlation (Hamed *et al*., 1998). The variance is adjusted using a correction factor n/n*, where n* represents the effective sample size.

$$V*(S) = V(S)\frac{n}{n^*} \tag{9}$$

Where, $\frac{n}{n^*}$ is a correction factor. V(S) is calculated as in the original MK test. The null hypothesis H_0 indicates that there is no trend in the given series.

Innovative Trend Analysis (ITA) method

Innovative Trend Analysis (ITA) is an advanced approach to identifying trends in time series data. Unlike traditional methods, ITA splits the data into two equal halves and plots them in increasing order. The Innovative Trend Analysis (ITA) method offers a novel approach for trend detection by splitting time series data into two parts and analysing them on a Cartesian plane (Sen *et al*., 2012). The first half is plotted on the X-axis, while the second half is on the Y-axis. The resulting plot helps visualize trends; points above the 1:1 line indicate an increasing trend, while points below suggest a decreasing trend. ITA is particularly effective in detecting subtle trends that may not be evident through conventional methods.

The trend indicator D is calculated as:

$$D = \frac{1}{2}\sum_{i=1}^{n} \frac{10(Y_j - Y_i)}{\mu} \tag{10}$$

Where, Y_i, Y_j data points from the first and second halves of the series and μ is Mean of the first subseries

Change Point Analysis

Change point analysis involves identifying points in a time series where the statistical properties of the data change significantly. This technique is crucial for understanding shifts in underlying processes, which may result from external factors or inherent changes in the system.

Pettitt's test

Pettitt's test is a non-parametric method used to detect a single change point in a time series. It is especially useful for continuous data in climate and hydrological studies. The test evaluates the null hypothesis that there is no change point against the alternative that a change point exists. The test statistic KT is defined as;

$$K_T = \max|U_{t,}| \tag{11}$$

Where,

$$U_{t,} = \sum_{i=1}^{t}\sum_{j=i+1}^{T} sign(x_i - x_j) \tag{12}$$

The significance of the change point is determined using the probability p, approximated by:

$$p \simeq 2\exp\left(\frac{-6K_T^2}{T^3 + T^2}\right) \tag{13}$$

Pettitt's test is particularly advantageous because it does not assume any specific distribution for the data, making it a versatile tool for various applications.

Results and Discussion

For this study, temperature data of Nalgonda district of Telangana state from 1995 to 2023 was collected and analyzed to estimate trends and perform further analysis. Descriptive statistics including mean, standard deviation (SD), coefficient of variation (CV), skewness and kurtosis are summarized and presented in Table 1.

The temperature variability appears to be relatively low, with the coefficient of variation (CV) of the average monthly temperatures ranging from 2.1% to 4.47%, indicating a narrow spread of data points. Skewness values range from -1.15 to 0.67, and kurtosis values range from -1.15 to 2.28. December shows the highest skewness (0.67), indicating a slight right skew, and july shows the highest kurtosis (2.28), indicating a leptokurtic distribution.

Table 1 : Descriptive statistics of monthly temperature data of Telangana state.

Month	Mean	SD	CV	Skewness	Kurtosis
January	30.57	0.94	3.07	-1.15	2.28
February	33.38	0.95	2.84	0.53	-0.32
March	36.69	0.95	2.59	-0.14	-0.49
April	39.35	1.20	3.04	0.12	-0.14
May	40.81	1.40	3.43	-0.54	-0.81
June	36.62	1.64	4.47	-0.12	-1.15
July	32.45	1.12	3.43	0.65	2.27
August	31.60	0.87	2.73	0.49	-0.55
September	32.10	0.78	2.40	0.03	-0.92
October	32.40	1.07	3.29	0.40	-0.45
November	31.26	0.65	2.10	0.26	-0.47
December	30.22	0.84	2.79	0.67	-0.25

Table 2 : Descriptive statistics of annual and seasonal temperature pattern.

	Mean	SD	CV	Skewness	Kurtosis
Summer	38.95	0.85	2.18	-0.03	-0.40
Pre summer	33.20	0.70	2.11	0.10	-0.54
Post summer	31.56	0.60	1.91	0.05	-0.38
Annual	33.95	0.48	1.42	0.24	-0.91

Table 2 summarizes the statistics for pre-summer, summer, post-summer, and annual temperatures. Pre-summer and summer seasons exhibit higher temperatures compared to post-summer. The highest standard deviation is observed in summer, indicating greater variability in temperatures during this period. The CV is relatively low across all seasons, indicating low to moderate relative variability. Skewness values suggest slight positive skewness in pre-summer, post-summer and Annual, while summer shows slight negative skewness. The annual temperature distribution is almost symmetric. Kurtosis values indicate that pre-summer, summer, post summer and annual distributions are platykurtic, indicating lighter tails and a flatter peak. These findings are consistent with previous studies (Ayoade *et al.*, 1983).

Trend of Annual temperature

Fig. 2 represents the monthly annual temperature of Telangana. Linear regression analysis was conducted for annual temperature from 1995-2023. The linear trend line indicates that approximately 3.1% of the variance in annual temperature can be explained by the linear

Table 3 : Wallis and Moore phase frequency test for seasonal and annual temperature data.

Parameter	Z transformed test statistic	p-value
January	0.68229	0.4951
February	-0.22743	0.8201
March	0.22743	0.8201
April	-0.22743	0.8201
May	2.0469	0.0407
June	0.22743	0.8201
July	0.68229	0.4951
August	0.22743	0.8201
September	0.22743	0.8201
October	0.68229	0.4951
November	0.22743	0.8201
December	-0.22743	0.8201
Summer	0.22743	0.8201
Pre summer	0.22743	0.8201
Post summer	0.68229	0.4951
Annual	0.68229	0.4951

Table 4 : Modified Mann-Kendall test of trend analysis of monthly temperature data.

Parameter	Corrrected Zc	P-value	Trend	Sen's slope
January	1.37	0.1709	NS	0.025906
February	0.43	0.6662	NS	0.011002
March	0.09	0.9253	NS	0.001843
April	0.28	0.7784	NS	0.008374
May	-0.09	0.9253	NS	-0.00413
June	0.02	0.9853	NS	0.000222
July	-1.22	0.2227	NS	-0.02567
August	1.44	0.1486	NS	0.034081
September	0.06	0.9551	NS	0.001070
October	1.86	0.0633	NS	0.052659
November	0.62	0.5359	NS	0.017076
December	1.03	0.3020	NS	0.023553

NS - non-significant trend * - significant trend.

relationship with time (R^2 = 0.031). This suggests that the linear regression method is not a strong fit for the data, as indicated by the relatively low R^2 value. Similar linear regression analysis for temperature variability from 1980-2019 in Jagtial district, Telangana state was found in earlier studies (Navatha *et al.*, 2021).

Table 3 shows that there is no significant difference in the variances of temperature between individual months or seasons, as evidenced by p-values exceeding 0.05.

However, a significant difference in the variance of annual temperature is observed with a p-value of 0.0407 according to the Wallis and Moore test. The modified

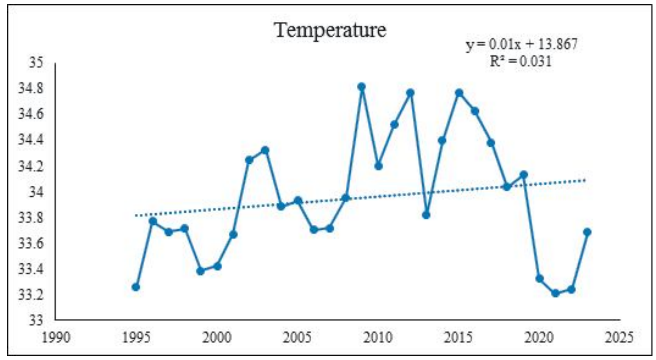

Fig. 2 : Trend of annual Temperature of Telangana from 1995-2023.

Table 5 : Modified Mann-Kendall test of trend analysis of annual and seasonal temperature data.

Parameter	Corrrected Zc	P-value	Trend	Sen's slope
Pre-summer	1.97	0.04888	*	0.03318092
Summer	0.21	0.8365	NS	0.00357661
Post-summer	-0.62	0.5359	NS	-0.0104296
Annual	1.11	0.2684	NS	0.01639405

NS - non-significant trend * - significant trend

Mann-Kendall test was employed for further analysis due to its enhanced efficiency in handling autocorrelation within the data (Jyostna *et al*., 2022).

Results of temperature Trend analysis using Modified Mann-Kendall Test and Sen's Slope estimator

The Modified Mann-Kendall test results for monthly temperature data are depicted in Tables 4 and 5. All parameters showing non-Significant trends (NS), ($p >$ 0.05) none of the parameter showing significant trends ($p < 0.05$).

Statistically significant trends (*$p < 0.05$) were found in pre-summer temperature patterns, with Sen's slopes of 0.0332. No significant trend (NS) was observed in summer temperatures, post summer and Annual temperature suggesting stability during this season. These results are consistent with previous studies (Addisu *et al*., 2015; Sonali *et al*., 2013; Laasya *et al*., 2024).

The results from both the Mann-Kendall test and the modified Mann-Kendall test exhibit a high degree of similarity. The Z values obtained from the modified Mann-Kendall test, which incorporates specific corrections, align closely with the standard Mann-Kendall Z values. This suggests that the corrections did not significantly alter the overall trend detection outcome.

Innovative Trend Analysis of temperature

The trend slope, trend indicator, Lower Confidence

Table 6 : Innovative trend analysis (ITA) of seasonal and Annual Temperatures of Telangana state.

Parameter	Trend slope	Trend Indicator	α = 0.10		α = 0.05		α = 0.01	
			LCL	UCL	LCL	UCL	LCL	UCL
January	0.04	0.18	-0.071	0.071	-0.008	0.008	-0.011	0.011
February	0.03	0.14	-0.004	0.004	-0.005	0.005	-0.006	0.006
March	0.04	0.14	-0.006	0.006	-0.008	0.008	-0.010	0.010
April	0.05	0.18	-0.008	0.008	-0.010	0.010	-0.012	0.012
May	0.03	0.12	-0.010	0.010	-0.011	0.011	-0.015	0.015
June	0.01	0.04	-0.008	0.008	-0.010	0.010	-0.012	0.012
July	-0.01	-0.07	-0.004	0.004	-0.005	0.005	-0.007	0.007
August	0.04	0.20	-0.005	0.005	-0.007	0.007	-0.009	0.009
September	-0.01	0.04	-0.006	0.006	-0.008	0.008	-0.010	0.010
October	0.05	0.22	-0.005	0.005	-0.006	0.006	-0.007	0.007
November	0.02	0.11	-0.004	0.004	-0.005	0.005	-0.007	0.007
December	0.02	0.10	-0.004	0.004	-0.005	0.004	-0.006	0.006
Pre- summer	0.03	0.15	-0.003	0.003	-0.004	0.004	-0.005	0.005
summer	0.04	0.15	-0.006	0.006	-0.007	0.007	-0.009	0.009
Post- summer	0.01	0.05	-0.006	0.006	-0.007	0.007	-0.009	0.009
Annual	0.03	0.12	-0.004	0.004	-0.005	0.005	-0.006	0.006

Table 7 : Change point detection of monthly and annual temperature (1995–2023).

Parameter		Pettit's test		Temperature	
	p-value	Year of shift	Pre	Present	Post
January	0.073	2004	30.96	30.03	31.17
February	0.506	2000	33.15	31.83	34.46
March	0.802	2008	36.39	35.17	37.17
April	0.899	1997	38.2	36.74	39.39
May	0.666	2019	41.97	41.28	41.44
June	1	1998	38.22	38.18	34.79
July	0.471	2019	31.68	33.27	32.3
August	0.204	2008	31.44	30.97	33.01
September	0.507	2018	32.62	33.01	31.11
October	0.169	2007	32.38	32.03	33.26
November	0.666	1999	30.28	31.16	31.98
December	0.374	2001	29.91	30.02	31.31
Pre summer	0.073	2005	31.41	31.3	31.8
Summer	0.374	2019	39.84	38.88	39.98
Post summer	0.755	2014	32.27	34.51	34.42
Annual	0.169	2001	33.43	33.67	34.25

Level (LCL) and Upper Confidence Level (UCL) at 90%, 95% and 99% of annual and seasonal temperatures for Telangana state are shown in Table 6.

The results indicate that most trend slopes are positive, suggesting an overall increasing trend in temperature for the analysed months and seasonal periods. However, some months (July, September) have trend slopes are negative, indicating no relatively stable temperatures during these periods. While the trends present in the data are generally small in magnitude, they are statistically significant for most months and seasonal periods. This suggests that the observed changes in temperature are not likely due to random variation but represent meaningful trends over time. The innovative trend analysis method accurately identifies these trends compared to non-parametric tests (Alifujiang *et al.*, 2020).

Results of Change Point analysis

The Pettit's test analysis indicates that while there are some identified years of shifts in temperature across different months and seasons, the majority of these changes are not statistically significant. This suggests that while there may have been minor variations in temperature, no strong evidence supports a significant change point in the overall temperature trends for the period 1995-2023. However, some months, particularly August and October, show a slight tendency towards potential change points, suggesting a need for further investigation or a more sensitive test to confirm these observations (Getahun *et al.*, 2021 and Moazed *et al.*, 2012).

Conclusion

This study employed non-parametric methods to identify long-term trends in monthly, seasonal, and annual temperature patterns in Telangana State from 1995 to 2023. Specifically, linear regression trend analysis, the Modified Mann-Kendall test and Innovative Trend Analysis were utilized.The Modified Mann-Kendall test revealed that all parameter shows non-significant increasing trend in temperatures. Pre-summer only shows the significant trend among all the parameters in Nalagonda district of Telangana. Innovative Trend Analysis indicated that almost trend slopes are positive, suggesting an overall increase in temperatures across the analyzed months and seasonal periods. The Pettit's test also highlighted all parameters are Non significant shifts in temperature for all parameter temperature patterns. The majority of the trend slopes were found to fall within statistically significant confidence limits, confirming these temperature trends. These findings provide valuable insights into the region's climate patterns, which are crucial for informing decision-making processes, related to climate adaptation and mitigation strategies. This comprehensive statistical assessment offers new insights into temperature trends and change points, particularly focusing on Nalgonda district in Telangana State. Understanding these temperature trends and change points can also aid farmers in better planning their crop schedules and management practices. Knowledge of evolving temperature patterns enables adjustments in planting dates, selection of crop varieties, and irrigation strategies, optimizing yields and minimizing risks associated with temperature extremes.

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