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Research Paper

Temporal Trend Analysis of Temperature Data Using Mann-kendall Test and Sen's Slope Estimator

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ABSTRACT -
Climate change is one of the most important issues among researchers, scientists, planners and politicians in the present times. Of all the climatic elements, temperature plays a major role in detecting climatic change. In this paper, Mann-Kendall rank tests, Sen's slope estimator and Lag-one serial correlation are used to demonstrate any existence of possible temperature trends in Ranchi and Lohardaga district of Jharkhand by analyzing the time series data of annual, seasonal and monthly average, maximum and minimum temperature from 1901 to 2002. The statistical tests are applied to monthly, seasonal and annual average minimum and maximum temperatures records. The analysis indicates that the average, maximum and minimum annual temperature records have a warming trend over the period 1901 to 2002. The study of linear trend indicated increasing trends in annual maximum, annual minimum and annual average temperatures. During 1901–2002 annual average, annual maximum and annual minimum temperatures increased about 0.003^{0}C, 0.002^{0}C to 0.004^{0}C and 0.003^{0}C respectively.

Keywords: Temperature; Time series analysis; Trend analysis; Change detection; Ranchi and Lohardaga.

INTRODUCTION

Global surface temperature has increased over the past 100 years by 0.3-0.6 ^{0}C, presumably due to the enhanced greenhouse effect, caused as a result of the increasing concentration of carbon- dioxide and other greenhouse gases in the atmosphere. While changes in the global monthly mean surface temperature are a useful indicator of climate change and variability, changes in the monthly mean maximum and monthly mean minimum temperatures provide more information than the monthly mean alone. This is because trends in the mean surface temperature can be due to changes in either the maximum or minimum temperatures, or relative changes in both. An additional useful indicator of climate change is the diurnal temperature range. Most of the temperature trend studies and change point detection in India focus on the analysis of annual and seasonal temperature time series for a single observatory or a group of observatories. Detecting trends in hydrologic, as well as climatic and water quality has been explored for more than three decades now. Trend analysis has been extensively used to assess the potential impacts of climatic change and variability on hydrologic time series in various parts of the world. Temperature trends provide critical evidence for evaluating claims regarding anthropogenic climate change.

Air temperature is principle element of weather systems, so that examination of their behaviour is important for understanding of climate variability because they are highly variable spatially and temporarily at different local, regional and global scales. For the prediction of future climate conditions, level of variability of these two weather elements must be examined and understood. Therefore, recently, the focus on climate variability bases mostly on the detection of trends in instrumental records of temperature. Changes in the global temperature and rainfall pattern have raised concern regarding the present and possible future conditions. According to the IPCC (2007) reports, global climate change is probable in the 21st century if no mitigation measures are taken to control emission of greenhouse gases.

Many research works have been carried out to detect changes in weather parameters throughout the world. Stafford et al. (2000) examined temperature and precipitation records from 1949 to 1998 for 25 stations throughout the State of Alaska. Mean, maxima, and minima temperatures, diurnal temperature range, and total precipitation were analyzed for linear trends using least squares regressions. Annual and seasonal mean temperature increases were found throughout the entire state, and the majority were found to be statistically significant at the 95% level or better. Rusticucci and Barrucand (2004) analyzed changes in temperature extremes over a 40-yr period based on daily minimum and maximum temperatures over Argentina. Trend analysis was performed on seasonal means, standard deviations, and extremes (5th and 95th percentiles) over the 1959–98 periods. They observed negative trends in the number of cold nights and warm days per summer, while the number of warm nights and cold days increased at certain locations. Shirgholami and Ghahreman (2005) studied annual trend changes in 34 meteorological stations in Iran. Results showed that in 59% of the stations, temperature changes had a positive trend and in 41% of the stations, temperature changes had a negative trend.

Tank et al. (2006) studied changes of climate extremes on the basis of daily series of temperature and precipitation observations from 116 meteorological stations in central and south Asia. Averaged over all stations, the indices of temperature extremes indicate warming of both the cold tail and the warm tail of the distributions of daily minimum and maximum temperature between 1961 and 2000. For precipitation, most regional indices of wet extremes show little change in this period as a result of low spatial trend coherence with mixed positive and negative station trends. Relative to the changes in the total amounts, there is a slight indication of disproportionate changes in the precipitation extremes. Stations with near-complete data for the longer period of 1901–2000 suggest that the recent trends in extremes of minimum temperature are consistent with long-term trends, whereas the recent trends in extremes of maximum temperature are part of multidecadal climate variability. Many more works can be found in Seekell (2007), Karabulut et al. (2008) and Dhorde et al. (2009).

In India, Arora et al. (2009) studied trends in temperature time series of 125 stations distributed over the whole of India. The non-parametric Mann-Kendall test was applied to detect monotonic trends in annual average and seasonal temperatures. They observed that annual mean temperature, mean maximum temperature and mean minimum temperature have increased at the rate of 0.42, 0.92 and 0.09^0C $(100\ \text{year})^{-1}$, respectively. Kumar et al. (2013) analysed precipitation and temperature trend along eastern end of monsoon trough. The analysis of year wise and decade wise temperature data indicated that the maximum temperatures are rising at very slow rate but steadily. The monthly mean maximum temperature during the month of April for the period of 2001-2010 were 0.4^0C to 0.6^0C higher than during the period of 1991-2000 at. The maximum temperature was analyzed 40.08^0C during the month of April at Ranchi.

Pal and Tabbaa (2010) examined the long-term trends and variations of the monthly maximum and minimum temperatures and their effects on seasonal fluctuations in various climatological regions in India. The magnitude of the trends and their statistical significance were determined by parametric ordinary least square regression techniques and the variations were determined by the respective coefficient of variations. The results showed that the monthly maximum temperature increased, though unevenly, over the last century. Minimum temperature changes were more variable than maximum temperature changes, both temporally and spatially, with results of lesser significance. Jain et al. (2012) examined trends in monthly, seasonal, and annual rainfall and temperature on the subdivision and regional scale for the NER. Trend analysis of temperature data for 1871-2008 showed that all the four temperature variables (maximum, minimum, and mean temperatures and temperature range) had rising trend. Singh et al. (2013) studied the temperature changes at Dehradun city by analyzing the time series data of annual maximum, minimum and mean temperature from 1967 to 2007. The study of linear trend indicated increasing trends in annual maximum, annual minimum and annual mean temperatures. Roy and Das (2013) studied temporal variation in temperature over Guwahati, Tezpur, Dibrugarh (Mohanbari) and Silchar stations, Assam, India, during the period 1981–2010. The analysis reveals that majority of the trends, both annual and seasonal, showed increasing tendency in temperature during the period 1981-2010. Mondal et al. (2014) studied changes in rainfall trend in India for 141 years (1871–2011) and temperature trend for 107 years (1901–2007). Statistical non-parametric tests were performed to see the trend magnitude with the Mann-Kendall (MK) test and Sen's slope. Mann-Whitney-Pettitt (MWP) test was used for probable break point detection in the series, and change percentage was calculated over 30 sub-divisions and 7 broad regions. Rajitha and Narayana (2014) analysed of historical data of rainfall and temperatures at Warangal district, Andhra Pradesh for the period of 1960-2012.

The analyses of minimum and maximum temperatures are significant increasing trend at 95 % confidence level for Warangal district. Warwade et al. (2015) studied the trends in maximum (Tmax) and minimum (Tmin) air temperatures in the annual and seasonal time-scales for six stations in the hilly region of North East India during 1901-2000. They observed that the majority of the trends in the annual and seasonal Tmax and Tmin time series showed increasing tendency during the last decades while the increasing trends in the Tmin series were stronger than those in the Tmax series. Khavse et al. (2015) analysed the temperature and rainfall trends for meteorological data of Labandi station, Raipur district in Chhattisgarh, India over approximately last three decades stretching between years 1971 to 2013.

Various studies have been done in different parts of the world for detecting possible temperature trends and changes. Some of these have shown significant trends, especially during the last four decades (Karl et al., 1993). Studies in temperature elements in the districts of Chota nagpur plateau are rare. The statistical tests, Lag-one serial correlation, Sen's slope estimator and Mann-Kendall rank tests are used to demonstrate any possible trends. Human activities bring about a drastic change in climate, particularly in temperature which raised a hue and cry in the planet Earth. A global warming of approximately 0.7^{0}C has occurred over the past century, and is projected to cause a further 1 to 4^{0}C increase during the twenty first century, primarily as a result of increasing concentrations of greenhouse gases (IPCC, 2007). A specific warming period started around 1980 and continued at least until 2005, with a temperature increase of about 0.17^{0}C per decade. The aim of this study is to examine and clarify the general trend of this average, maximum and minimum temperature and to detect the % change in temperature with the change of atmospheric cycle in the area. The main research objective of this study is to study variations in significant trends of average, maximum and minimum temperature data on monthly, annual and seasonal basis.

MATERIALS AND METHODS

Description of study area

The study was conducted on two districts (Ranchi and Lohardaga) of Jharkhand for the period of 1901 to 2002. Ranchi lies at 23°22′N and 85°20′E. Its municipal area is 175.12 km^2 and its average elevation is 651m above mean sea level. Ranchi is located in the southern part of the Chota Nagpur plateau, which is the eastern section of the Deccan plateau. The Subarnarekha River and its tributaries constitute the local river system. The channels Kanke, Rukka and Hatia have been dammed to create reservoirs that supply water to the majority of the population. Ranchi has a hilly topography and its dense tropical forests a combination that produces a relatively moderate climate compared to the rest of the state. Lohardaga district is situated between 23^{0} 30' and 23^{0} 40' North Latitudes and 84^{0} 40' and 84^{0} 50' East Longitudes. The district covers an area of 1491 km^{2}. Lohardaga has an average elevation of 647 metres. The Major rivers flowing through Lohardaga district includes koyal, sankh, Nandani, sahi, fulshar etc. The average annual rainfall is 1200mm-1300 mm and total population of state is 26.91 million (2.65% of the country). The location of Ranchi and Lohardaga district is shown in Fig. 1.

Figure 1. Location of Ranchi and Lohardaga district of Jharkhand.

Climate

As this is study related with weather parameters and complete description of claimate of the region is essential. Although Ranchi and Lohardaga has a humid subtropical climate, its location and the forests surrounding it combine to produce the unusually pleasant climate for which it's known. Its climate is the primary reason why this region was once the summer capital of the undivided State of Bihar and was designated a preferable "hill station". There are four well-defined seasons: Winter season-Jan to Feb, Pre-monsoon season-Mar to May, Monsoon season-June to Sep and Post-monsoon- October to December. Soil is formed from the disintegration of rocks and stones. Summer temperatures range from 20 to 42^{0} C, winter temperatures from 0 to 25^{0}C. December and January are the coolest months, with temperatures dipping to the freezing point in some areas. The annual rainfall is about 1430 mm. From June to September the rainfall is about 1,100 mm. Lohardaga district has an annual average temperature is 23^{0} C and the district receives an annual average rainfall of 1000-1200 mm.

Data collection and preparation

The purpose of the analysis is to examine the data for linear trends. Linear trends have the advantage that confidence intervals are well defined, which aids in interpretation. In order to study the temporal trend of temperature, monthly meteorological data including monthly average, maximum and minimum temperature, was collected from Indian Metrological Department (IMD). Data of time series covered last 102 years from 1901 to 2002. Three different data time series of T (max), T (min), T (avg), for the specified study area were analyzed by Sen's slope estimator and Mann Kendall method. For this purpose, firstly data was compiled and T (max), T (min), T (mean), were calculated by monthly averages on seasonal and yearly basis. Data collected from IMD were converted into CSV (comma delimited) format for the purpose of input into the model Trend.

TREND Model Description

TREND is adopted for present study due to the following advantages:

1. Trend is easy to use and is based on statistical tests that are relatively robust and easy to understand.
2. It shows the statistical tests set up in an Excel spreadsheet.
3. Trend can be used to test for changes in hydrological data caused by climate change, land use change, change in management practices, etc.

TREND is designed to facilitate statistical testing for trend, change and randomness in hydrological and other time series data. The main Features of TREND:

- Allows easy statistical testing using different tests
- Supports various time series data input formats
- Provides simple statement of test result
- Displays test statistic and critical values for various statistical significance levels
- Performs resampling analysis to determine critical test statistic values
- Allows easy retrieval of test results.

Apart from TREND, XLSTAT was also employed to perform statistical calculations.

Mann–Kendall (MK) test

The MK test (Kendall 1975; Mann 1945) is the rank based nonparametric test for assessing the significance of a trend. This test has the several advantages over parametric methods. Some of these advantages include: (1) does not require the assumption of normality or the assumption of homogeneity of variance (2) compare medians rather than means and, as a result, if the data have one or two outliers, their influence is negated (3) prior transformations are not required, even when approximate normality could be achieved; (4) greater power is achieved for the skewed distributions (5) data below the detection limit can be incorporated without fabrication of values or bias.

This method has been used widely across the world to detect trend in ETo and other hydrological variables (Jhajharia and Singh, 2011; Zhang et al. 2005). It is based on the test statics S defined as

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

Where, X_1, X_2 … X_n represent n data points where X_j represents the data point at time j. A very high positive value of S is an indicator of an increasing trend, and a very low negative value indicates a decreasing trend.

$$sgn(x_j - x_i) = \begin{cases} 1 & if\ (x_j - x_i) > 0 \\ 0 & if\ (x_j - x_i) = 0 \\ -1 & if\ (x_j - x_i) < 0 \end{cases} \quad ....(2)$$

It has been documented that when n>10, the statistic S is approximately normally distributed with the mean

$$E(S) = 0 \quad ....(3)$$

and its variance is

$$VAR(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \quad ....(4)$$

Where n is the number of data points, m is the number of tied groups (a tied group is a set of sample data having the same value), and t_i is the number of data points in the *i*th group. The standardized test statistic (Z) is computed as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \quad ....(5)$$

The null hypothesis (H_0), means that no significant trend is present, is accepted if the test statistic (Z) is not statistically significant, i.e. $-Z_{\propto/2} < Z < Z_{\propto/2}$ where $Z_{\propto/2}$ is the standard normal deviate.

Theil–Sen's estimator

The slope of n pairs of data points were estimated by using the following equation:

$$\beta = Median\left(\frac{x_j - x_i}{j-i}\right)\ for\ all\ i < j. \quad ....(6)$$

In which $1 < j < i < n\ and\ \beta$ is the robust estimate of the trend magnitude. A positive value of β indicates an upward trend, while a negative value of β indicates a downward trend. The percentage change over a period of time can be estimated from Theil and Sen's median slope and mean by assuming the linear trend (Yue and Hashino, 2003) in the time series:

$$\%\ Change = \left(\frac{\beta * Length\ of\ Period}{Mean}\right) \quad ....(7)$$

RESULTS AND DISCUSSION :

Average temperature data

The Mann-Kendall test and Sen's estimator calculations were performed on average temperature data and the following results given in Table 1 and 2 were obtained for the Ranchi and Lohardaga district. If the calculated Z value is greater than the Table Z value, H_0 is rejected. Rejecting H_0 indicates that there is a trend in the time series while accepting H_0 indicates no trend was detected. On rejecting the null hypothesis, the result is said to be statistically significant. Both the table indicates that the Null Hypothesis was accepted for month (January, March, April, May, June, July, August and September), season (Pre-Monsoon and Monsoon) and rejected for month (February, October, November and December) season (Winter and Post-Monsoon) and annual time series. Further, result indicates that temperature increases monthly (0.001^{0}C/year to 0.014^{0}C/year), seasonally (0.005^{0}C/year to 0.007^{0}C/year) and annually 0.003^{0}C/year during 1901 to 2002.

Table1: Mann-Kendall test statistics (Z) and Sen's estimator of slope (°C/year) for monthly time series of average temperature data.

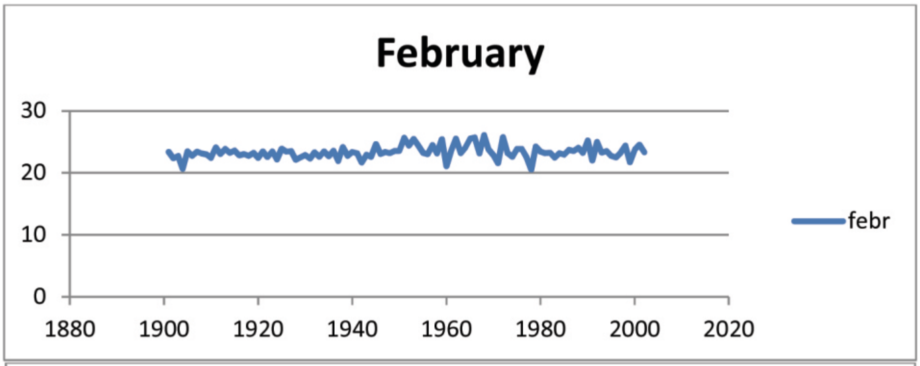
Station	Ranchi			Lohardaga		
Month	Mann-Kendall statistics Z	Sen's slope (°C/year)	Test Interpretation	Mann-Kendall statistics Z	Sen's slope (°C/year)	Test Interpretation
Jan	0.648	0.002	Accept H_0	0.304	0.002	Accept H_0
Feb	2.718	0.008	Reject H_0	2.666	0.008	Reject H_0
Mar	0.648	0.003	Accept H_0	0.879	0.004	Accept H_0
Apr	-0.665	-0.003	Accept H_0	-0.15	-0.00006359	Accept H_0
May	-1.411	-0.005	Accept H_0	-1.504	-0.005	Accept H_0
Jun	0.752	-0.002	Accept H_0	-0.729	-0.003	Accept H_0
Jul	-1.139	-0.002	Accept H_0	-1.255	-0.003	Accept H_0
Aug	0.636	0.001	Accept H_0	0.087	0.00005778	Accept H_0
Sep	-1.122	-0.001	Accept H_0	-1.475	-0.002	Accept H_0
Oct	2.03	0.005	Reject H_0	1.885	0.005	Reject H_0
Nov	3.024	0.009	Reject H_0	2.897	0.01	Reject H_0
Dec	4.302	0.012	Reject H_0	4.418	0.014	Reject H_0

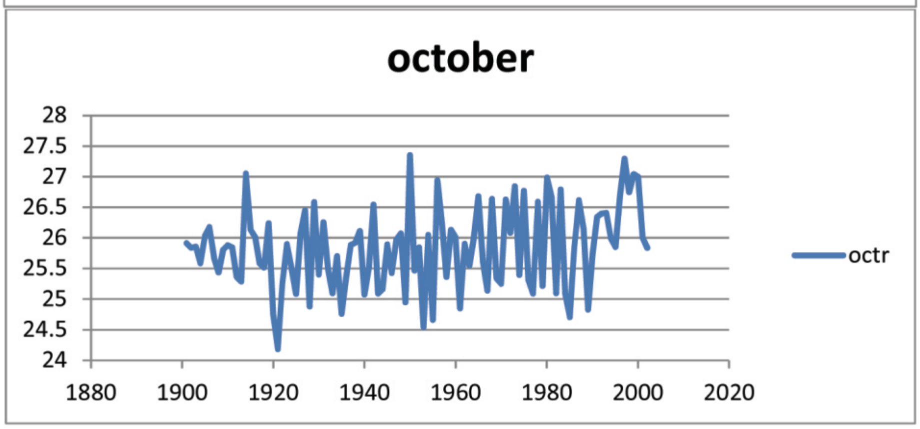
Table2 Mann-Kendall statistics (Z) and Sen's estimator of slope (°C/year) for seasonal and annual time series of average temperature data.

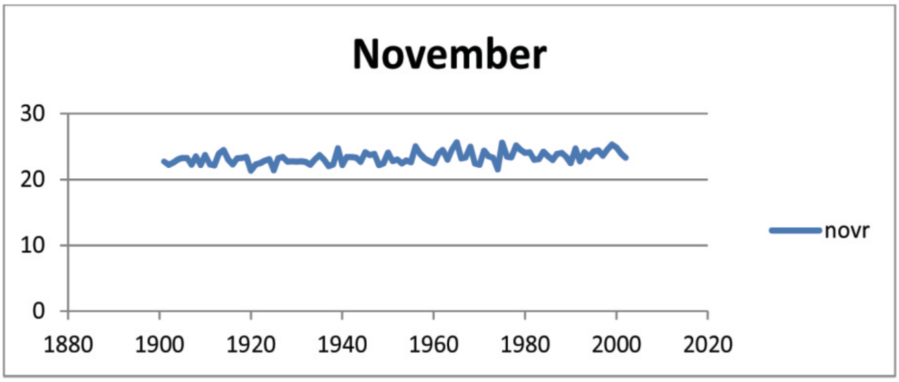
Station	Ranchi			Lohardaga		
	Mann-Kendall statistics Z	Sen's slope (°C/year)	Test Interpretation	Mann-Kendall statistics Z	Sen's slope (°C/year)	Test Interpretation
Annual	2.781	0.003	Reject H_0	2.354	0.003	Reject H_0
Winter	2.221	0.005	Reject H_0	2.03	0.005	Reject H_0
Pre-Monsoon	-0.769	-0.002	Accept H_0	-0.341	-0.00003481	Accept H_0
Monsoon	-0.434	-0.00003827	Accept H_0	-0.804	-0.001	Accept H_0
Post-Monsoon	3.354	0.007	Reject H_0	3.354	0.007	Reject H_0

Maximum temperature data

The Mann-Kendall test and Sen's estimator calculation were performed on maximum temperature data and the following results given in Table 3 and 4 were obtained. Both the table indicates that the Null Hypothesis was accepted for month (January, March, April, May, June, July and August), season (Winter, Pre-Monsoon and Monsoon) and annually and rejected for month (February, September, October, November and December) and Post-Monsoon seasonal time series. Only one decreasing significant trend has shown in month September. Further, result indicates that temperature increases monthly (0.001 ^{0}C/year to 0.014 ^{0}C/year), seasonally (0.002 ^{0}C/year to 0.009 ^{0}C/year) and annually (0.002 ^{0}C/year to 0.004 ^{0}C/year) during 1901 to 2002. Temperature decreases in month September with 0.002 ^{0}C/year in only Lohardaga district. Fig. 2 and Fig. 3 show the monthly significant increasing trend, whereas , Fig. 4 and Fig.5 show the annual and seasonal significant increasing trend for maximum temperature data in Ranchi and Lohardaga district respectively.







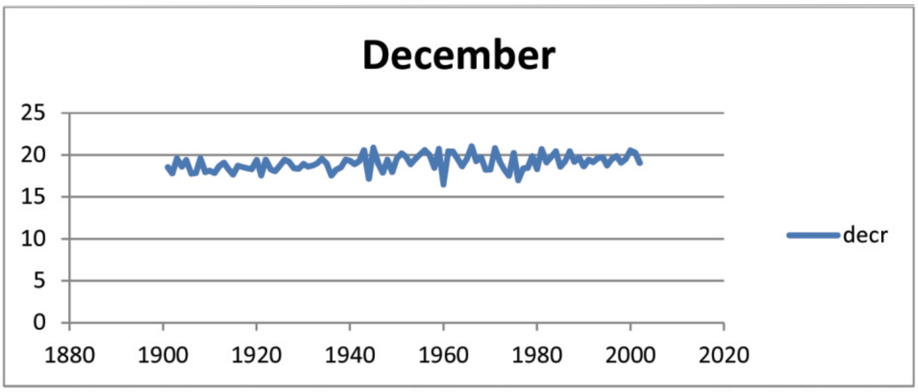
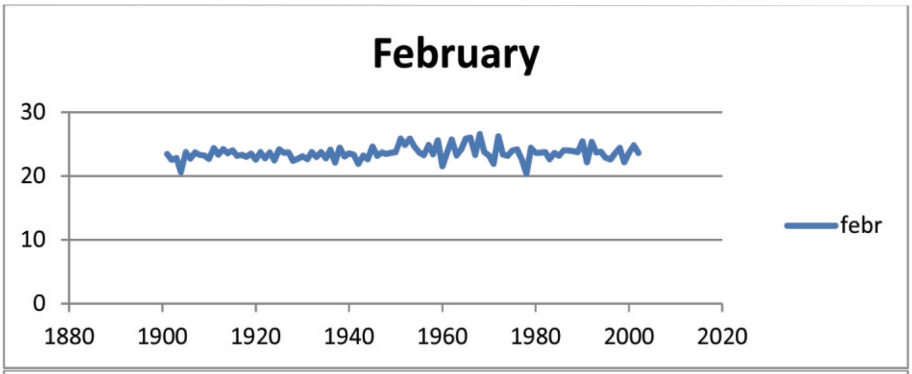
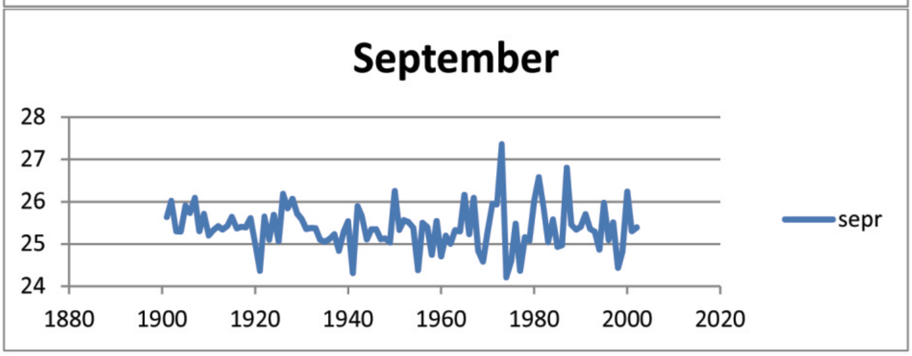
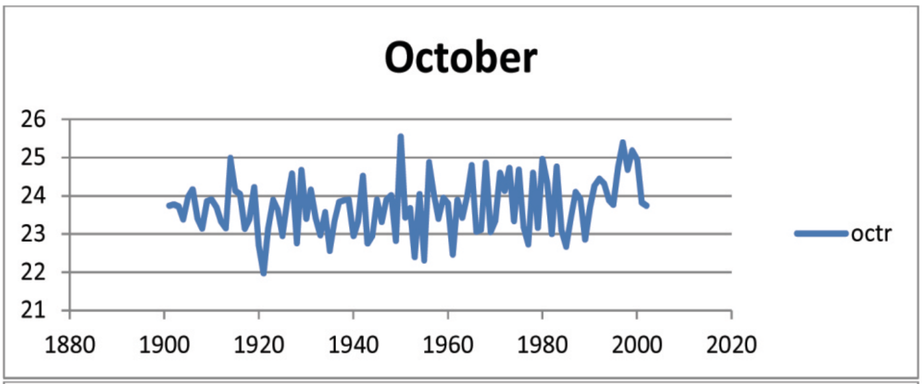


Fig. 2 Monthly significant increasing trend of maximum temperature data for Ranchi district.







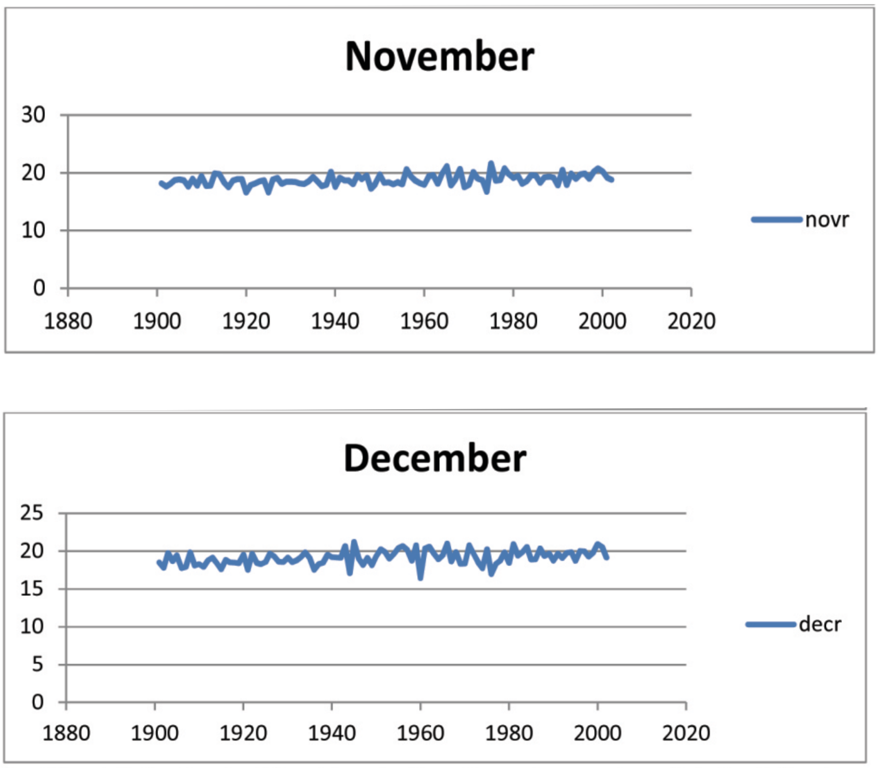


Fig. 3 Monthly statistically significant trend of maximum temperature data for Lohardaga district

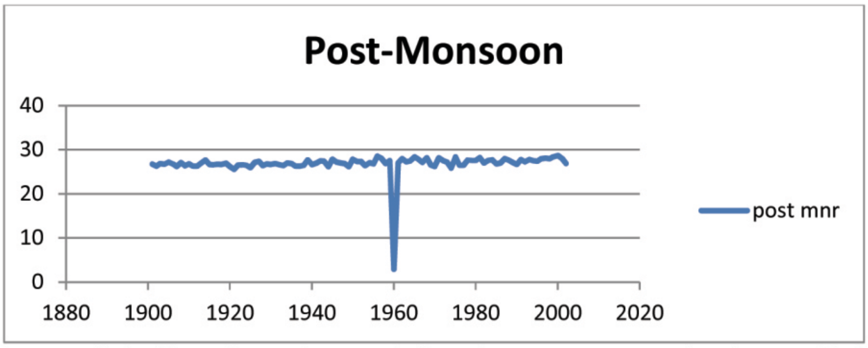


Fig. 4 Seasonal significant increasing trend of maximum temperature data for Ranchi district.

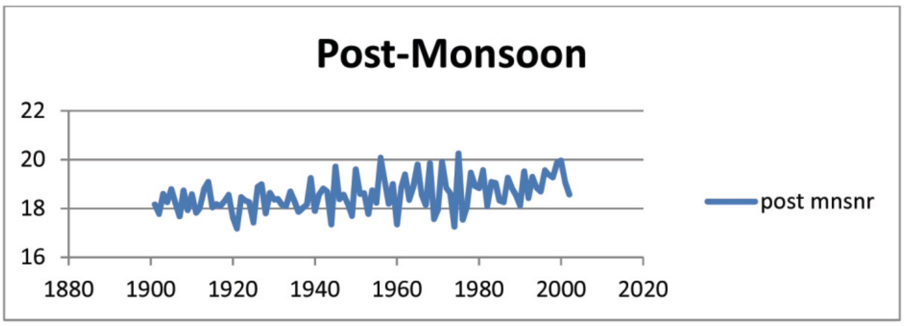


Fig. 5 Seasonal significant increasing trend of maximum temperature data for Lohardaga district.

Table 3: Mann-Kendall statistics (Z) and Sen's estimator of slope (^{0}C/year) for monthly time series of maximum temperature data.

Station	Ranchi			Lohardaga		
	Mann-Kendall statistics Z	Sen's slope (ºC/year)	Test Interpretation	Mann-Kendall statistics Z	Sen's slope (ºC/year)	Test Interpretation
Jan	0.463	0.002	Accept H_O	0.312	0.001	Accept H_O
Feb	1.96	0.006	Reject H_O	1.871	0.006	Reject H_O
Mar	0.341	0.002	Accept H_O	0.497	0.003	Accept H_O
Apr	-0.717	-0.003	Accept H_O	-0.492	-0.002	Accept H_O
May	-1.44	-0.005	Accept H_O	-1.544	-0.005	Accept H_O
Jun	-0.596	-0.002	Accept H_O	-0.578	-0.002	Accept H_O
Jul	-1.457	-0.004	Accept H_O	-1.318	-0.004	Accept H_O
Aug	-0.497	-0.00004128	Accept H_O	-0.619	-0.00006814	Accept H_O
Sep	-1.278	-0.002	Accept H_O	-1.758	-0.002	Reject H_O
Oct	1.995	0.005	Reject H_O	1.874	0.005	Reject H_O
Nov	4.406	0.014	Reject H_O	3.499	0.012	Reject H_O
Dec	3.753	0.012	Reject H_O	3.811	0.013	Reject H_O

Table 4 Mann-Kendall statistics (Z) and Sen's estimator of slope (^{0}C/year) for annual and seasonal time series of maximum temperature data.

Station	Ranchi			Lohardaga		
Annual/ Seasonal	Mann-Kendall statistics Z	Sen's slope (ºC/year)	Test Interpretation	Mann-Kendall statistics Z	Sen's slope (ºC/year)	Test Interpretation
Annual	1.504	0.004	Accept H_O	1.336	0.002	Accept H_O
Winter	1.318	-0.002	Accept H_O	1.284	0.004	Accept H_O
Pre-Monsoon	-0.792	-0.001	Accept H_O	-0.439	-0.00008066	Accept H_O
Monsoon	-0.931	0.013	Accept H_O	-1.11	-0.002	Accept H_O
Post-Monsoon	5.291	0.002	Reject H_O	3.892	0.009	Reject H_O

CONCLUSIONS

This study investigated temperature trends by analyzing data for annual, seasonal and monthly average, maximum and minimum temperature at two districts of Jharkhand. The Mann–Kendall test was applied to the monthly average temperature time series and the results showed that most of the months in Ranchi and Lohardaga had statistically significant trends in February, October, November and December. Analyzing annual average temperature demonstrated that both of the districts had significant positive trends. The Mann–Kendall test was further applied to the seasonally average temperature time series showed that statistically significant increasing trends in winter and Post-Monsoon. The results of the Mann–Kendall test for the annual, seasonal and monthly maximum temperature time series also revealed that most of the month had statistically no significant trend. Although the strongest trends in °C/year were observed in November and December. Only Lohardaga district had significant negative trends in September month, whereas February, October, November and December showed significant positive trends. Analyzing annual average temperature demonstrated that both of the districts had significant positive trends. The Mann–Kendall test which was applied to the seasonally average temperature time series showed significant increasing trends only in Post-Monsoon. The results of Mann–Kendall test for minimum temperature showed no significant positive trends in most of the months and significant positive trends in February, October, November and December. For Mann–Kendall test seasonally average temperature time series showed statistically significant increasing trends only in Post-Monsoon in both the districts. Analyzing annual average temperature demonstrated that both of the districts had significant positive trends.

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