Analysis of temperature variability and trends over Tripura

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ABSTRACT. Attempts have been made to study the temporal variations and trends in monthly, seasonal and annual temperature over two stations - Agartala and Kailashahar in Tripura, India for the period 1969 to 2014. Analysis has been carried for four temperature indices, namely - minimum temperature ($T_{\text{min}}$), maximum temperature ($T_{\text{max}}$), mean temperature ($T_{\text{mean}}$) and diurnal temperature range (DTR). Non-parametric Mann-Kendall (MK) test was used to detect the trends and the magnitude of the trends were determined with Sen’s estimator of slope. The analysis of the temperature data revealed significant increasing trends in $T_{\text{min}}$, $T_{\text{max}}$ and $T_{\text{mean}}$ variables at both the stations on annual scale, while decreasing trend in DTR was significant over Agartala only. On the seasonal scale, the increasing (decreasing) trends were observed in $T_{\text{min}}$, $T_{\text{max}}$ and $T_{\text{mean}}$ (DTR) temperature indices in all the four seasons - winter, pre-monsoon, monsoon and post-monsoon except non-significant decreasing trend in $T_{\text{max}}$ in winter season over Agartala. On the monthly scale, significant rising trends in $T_{\text{min}}$, $T_{\text{max}}$ and $T_{\text{mean}}$ were observed in the most of the months and significant decreasing trend in DTR was found only in the months of January and December.

Key words – Temperature, Diurnal temperature range, Trend, Mann-Kendall test, Sen’s slope.

1. Introduction

Climate change is the single biggest environmental and humanitarian crisis being faced by the world in the present times. The Intergovernmental Panel on Climate Change (IPCC) has reported an increase of 0.74 °C ± 0.18 °C in global surface temperatures averaged over the land and sea during 1906-2005 (IPCC, AR4, 2007). IPCC report (2007) also states that the most of the observed increase in global average temperature during last 50 year period is likely due to observed increase in anthropogenic greenhouse gas concentration. This increase in temperature is larger than the trend observed during 1901 - 2000 (0.6 °C ± 0.2 °C) due to additional warm years in the second half of the century. The emission of anthropogenic green house gases are most influencing factor for increase in temperature on global scale but on regional scale, urbanization and changes in
Many researchers across the world have studied the evaporation and wind as well as ocean current, which in turn affects the patterns of precipitation, temperature of air, land, ocean and other water bodies. Reported rising as well as decreasing trends in increasing and consistent with the trends and magnitude (2007) reported that the temperatures over the country are unprecedented warming during the last decade. Dash 1971-2003 respectively. They have found that relatively 0.22 °C/10year during the period 1901-2003 and period significant warming trend of 0.05 °C/10year and 2012). Kothawale and Rupa Kumar (2005) has shown trends (Kothawale and Rupa Kumar, 2005; Roy and agreed that temperature trends are similar to global temperature fluctuations are not uniform on regional scale. Manton similar to Karl and Trenberth (2003), study by Wang et al. (2012) also found that urbanization is one of the most influencing factors for the warming of temperature on regional scale. Manton et al. (2001) reported significant increases (decreases) in the annual number of hot (cool) days and warm (cold) nights in Southeast Asia and South Pacific region.

However, temperature fluctuations are not uniform over the globe and varies from one region to another region. In the past, several researchers have studied the temperature variability and trends over India and most of them agreed that temperature trends are similar to global trends (Kothawale and Rupa Kumar, 2005; Roy and Balling, 2005; Dash et al., 2007; Jain and Vijay Kumar, 2012). Kothawale and Rupa Kumar (2005) has shown significant warming trend of 0.05 °C/10year and 0.22 °C/10year during the period 1901-2003 and period 1971-2003 respectively. They have found that relatively rapid warming seen in second time-series is largely due to unprecedented warming during the last decade. Dash et al. (2007) reported that the temperatures over the country are increasing and consistent with the trends and magnitude found over the globe. Jain and Vijay Kumar (2012) reported rising as well as decreasing trends in $T\text{max}$ and $T\text{min}$ data over India. However, some scientists (Srivastava et al., 1992; Rupa Kumar et al., 1994) have found that the decadal trends in temperature data over India are quite different from those observed over other parts of the globe. Srivastava et al. (1992) reported that increase in $T\text{max}$ is comparatively larger than $T\text{min}$ over a major part of India. Rupa Kumar et al. (1994) observed that the increase in the $T\text{mean}$ over India is almost solely contributed by the $T\text{max}$, with the $T\text{min}$ remaining practically trendless, leading to an increase in the DTR.

Several researchers have also investigated the spatial and temporal variability in surface temperature over Northeast India (Jain and Vijay Kumar, 2012; Jain et al., 2012; Jhajharia and Singh, 2011; Laskar et al., 2014). Jain and Vijay Kumar (2012) has observed that some stations in North and Northeast India showed falling trends in annual $T\text{mean}$ data. Jain et al. (2012) analyzed the temperature trends in Northeast India and found that all the four temperature variables ($T\text{max}, T\text{min}, T\text{mean}$ and DTR) showed rising trend. Jhajharia and Singh (2011) noticed decreasing as well as increasing trends in DTR over Northeast India. They have observed decreasing trends at four stations on yearly, seasonal (pre-monsoon and monsoon) and monthly (September) scale and increasing trends at other three stations on seasonal (monsoon and post-monsoon season) and monthly (June, October and December) scale.

Tripura is one of the states in northeast India covering an area of about 10,491 square kilometers. About 60% area of the state is covered by the forest with undulating topography and it is one of the important local factor influencing the weather and climate of the state. Climate of state is mainly subtropical and the monsoon season (June to September) is the rainiest season followed by the pre-monsoon season (March-May) and the post-monsoon seasons (October - December). The winter season (January - February) is mild and mainly dry. The temperature may fall to 3-4 °C for a few days in January when the cold winds from the Himalayan region blow over the State and make winter very cold. The state experiences moderately hot and humid summer season mainly in the months of April-May with daily average temperature around 32-34 °C. On occasions, the summer temperature may rise up to 38-40 °C.

In this part of India, the investigations of long-term variations and trends in temperature data are not getting enough attention even though this area is suffering from serious environmental, agricultural and water resources problems. In this study an attempt has been made to analyze the variability and trends of temperatures over Tripura. The daily surface temperature data from two stations, viz., Agartala and Kailashahar has been utilized for the analysis. The work is focused to investigate the trends in $T\text{max}, T\text{min}, T\text{mean}$ and DTR at annual, seasonal and monthly timescale.
2. Data and methodology

The present study area is confined to Tripura state using air temperature data of two stations, viz., Agartala and Kailashahar (Fig. 1) as there is no other station in the state with long period temperature data series. Agartala is the capital city of Tripura. Agartala observatory is a class-I meteorological observatory located at 23°53’ N and 91°15’ E with an elevation of 16 meter from the mean sea level. Kailashahar is a class-IIb meteorological

![Fig. 1. Map showing study area and location of the two stations](image)

**TABLE 1**

| Month/season | Agartala |          |          |          | Kailashahar |          |          |          |
|--------------|----------|----------|----------|----------|-------------|----------|----------|----------|
|              | $T_{\text{min}}$ | $T_{\text{max}}$ | $T_{\text{mean}}$ | DTR | $T_{\text{min}}$ | $T_{\text{max}}$ | $T_{\text{mean}}$ | DTR |
| January      | 10.3     | 25.4     | 17.8     | 15.1     | 10.4        | 25.6     | 18.0     | 15.2     |
| February     | 13.5     | 28.4     | 20.9     | 14.9     | 12.8        | 28.2     | 20.5     | 15.4     |
| March        | 19.0     | 32.1     | 25.6     | 13.2     | 17.5        | 31.9     | 24.7     | 14.4     |
| April        | 22.5     | 33.3     | 27.9     | 10.9     | 21.2        | 32.7     | 26.9     | 11.1     |
| May          | 23.6     | 32.8     | 28.2     | 9.2      | 23.0        | 32.1     | 27.6     | 9.1      |
| June         | 24.9     | 32.1     | 28.5     | 7.1      | 24.7        | 32.1     | 28.4     | 7.5      |
| July         | 25.0     | 31.7     | 28.3     | 6.6      | 24.9        | 32.1     | 28.5     | 7.2      |
| August       | 24.9     | 32.0     | 28.5     | 7.1      | 24.9        | 32.5     | 28.7     | 7.3      |
| September    | 24.6     | 32.0     | 28.3     | 7.4      | 24.5        | 32.1     | 28.3     | 7.7      |
| October      | 22.4     | 31.4     | 26.9     | 9.0      | 22.4        | 31.5     | 27.0     | 9.1      |
| November     | 17.2     | 29.6     | 23.4     | 12.3     | 17.4        | 29.6     | 23.5     | 12.1     |
| December     | 11.9     | 26.4     | 19.1     | 14.4     | 12.2        | 26.6     | 19.4     | 14.4     |
| Winter       | 11.9     | 26.9     | 19.4     | 15.0     | 11.6        | 26.9     | 19.2     | 15.3     |
| Pre-monsoon  | 21.7     | 32.7     | 27.2     | 11.0     | 20.6        | 32.2     | 26.2     | 11.5     |
| Monsoon      | 24.9     | 31.9     | 28.4     | 7.1      | 24.8        | 32.2     | 28.4     | 7.4      |
| Post-monsoon | 17.2     | 29.1     | 23.1     | 11.9     | 17.4        | 29.2     | 23.5     | 11.9     |
| Annual       | 20.0     | 30.6     | 25.3     | 10.6     | 19.7        | 30.6     | 25.1     | 10.9     |
observatory and located towards northeast of Agartala at 24°19′ N and 92°00′ E with an elevation of 29 meter from the mean sea level.

Daily $T_{\text{max}}$ and $T_{\text{min}}$ data for two stations, viz., Agartala and Kailashahar, have been taken from National Data Centre, IMD, Pune and Meteorological Centre, IMD, Agartala for the period 1969-2014. Daily $T_{\text{mean}}$ are obtained by averaging daily $T_{\text{max}}$ and daily $T_{\text{min}}$ data and daily DTR data are calculated by subtracting the daily $T_{\text{min}}$ from daily $T_{\text{max}}$. The Monthly, seasonal and annual temperature data are calculated by averaging the daily temperature data for the month, season and annual respectively.

Mann Kandall (MK) statistic (Mann, 1945; Kendall, 1975; WMO, 1966) and Sen’s estimator slop (Sen, 1968) were used to detect the trends and magnitude of the trends in the time-series of all temperature indices. In the present study the null hypothesis was tested at 95% significance level.

3. Result and discussion

3.1. Temperature characteristics

Based on the climatology of the region, the four seasons in India as defined by IMD are: winter season (January - February), pre-monsoon season (March to May), monsoon season (June to September) and post-monsoon season (October to December). The characteristics of monthly, seasonal and annual average temperatures are reported in Table 1. The coldest and hottest temperatures recorded at Agartala are 2.0 °C (30th December, 1972) and 40.2 °C (31st May, 1979) and at Kailashahar are 2.4 °C (15th January, 1976) and 38.9 °C (25th April, 2014) respectively.

The annual temperatures at the two stations are quite similar for the four temperature variables ($T_{\text{min}}, T_{\text{max}}, T_{\text{mean}}$ and DTR). The annual average $T_{\text{max}}$ is around 30.6 °C for both the stations. The annual $T_{\text{min}}$ are 20.0 °C & 19.7 °C, $T_{\text{mean}}$ are 25.3 °C & 25.1 °C and DTR are 10.6 °C & 10.9 °C for Agartala and Kailashahar respectively.

The seasonal $T_{\text{max}}$ is highest (32.7 °C) during the pre-monsoon season and lowest (26.9 °C) during the winter season. The seasonal $T_{\text{min}}$ is lowest (11.6 °C) during the winter season and highest (24.9 °C) during the monsoon season at two stations. The seasonal average $T_{\text{mean}}$ temperature varies from 19.2 °C to 28.5 °C and the highest (28.5 °C) is experienced during the monsoon season over both the stations. The seasonal mean DTR are also found highest (around 15 °C) during the winter season and lowest (around 7 °C) during the monsoon season.

At both station, the highest values (28-29 °C) of monthly $T_{\text{mean}}$ are observed during pre-monsoon season and monsoon season. At Agartala and Kailashahar, the monthly $T_{\text{mean}}$ is maximum during May-September period and June-September period respectively.

The monthly $T_{\text{max}}$ is highest in April and lowest in January. The highest monthly $T_{\text{max}}$ observed in April are 33.3 °C and 32.7 °C at Agartala and Kailashahar respectively. During pre-monsoon season and monsoon season, i.e., from March to September months the maximum temperature varies from 31.7 °C to 33.3 °C over two stations. January is the coldest month for both the stations with monthly minimum temperature at around 10 °C. The monthly $T_{\text{max}}$ are highest (24.5 °C to 25.0 °C) during June-to-September months (monsoon season) over both the stations.

The DTR values are highest during January-February months (winter season) and lowest during June-September months (monsoon season). At Agartala, DTR is highest in January (15.1 °C) followed by February (14.9 °C) and at Kailashahar, it is highest in February (15.4 °C) followed by January (15.2 °C). During June-September months (monsoon season) DTR varies from 7.1 °C to 7.7 °C at two stations.

3.2. Trend analysis of annual temperature

The yearly $T_{\text{min}}, T_{\text{max}}, T_{\text{mean}}$ and DTR time-series are presented in Fig. 2 and 3 for Agartala and Kailashahar respectively. The linear trend lines, linear regression equations and value of $R^2$ are also depicted in these figures to indicate the linear trends in annual temperature indices. MK test statistics and Sen’s slop for the annual temperatures indices namely; $T_{\text{min}}, T_{\text{max}}, T_{\text{mean}}$ and DTR are provided in Table 2.

At both the stations, the three indices, viz., annual $T_{\text{min}}, T_{\text{max}}$ and $T_{\text{mean}}$ show an increasing trend but DTR shows decreasing trends. The increasing trends in $T_{\text{min}}, T_{\text{max}}$ and $T_{\text{mean}}$ indices are statistically significant at both the stations whereas the decreasing trend in DTR is significant for Agartala only. Among the four temperature variables, the $T_{\text{min}}$ observed the highest rate of change at both the stations. Sen’s estimator of slop indicate increase of 1.3 °C and 1.2 °C during the period of study over Kailashahar (0.02774 °C/year) and Agartala (0.02547 °C/year) respectively (Table 2). The annual increase in $T_{\text{max}}$ indices is slowest at the rate of 0.01593 °C/year and 0.01146 °C/year for Kailashahar and Agartala respectively. The magnitude of increase in annual $T_{\text{mean}}$ is 0.02085 °C/year and 0.01735 °C/year over
Kailashahar and Agartala respectively. The comparatively higher increase in $T_{\text{min}}$ as compared to $T_{\text{max}}$ leads to significant fall of 0.01594 °C/year (0.7 °C during 1969-2014) in annual DTR over Agartala. At Kailashahar, the fall in annual DTR is similar (0.7 °C during 1969-2014) to that observed over Agartala but the trends are found non-significant as per MK test.

The above results are in contrast to the finding of Srivastava et al. (1992), Rupa Kumar et al. (1994) and Jain et al. (2012) but are consistent with the trends observed by other scientists over India (Kothawale and Rupa Kumar, 2005; Dash et al., 2007; Jhajharia and Singh, 2011) and over the globe (Karl et al., 1993; Jones et al., 1999) too.
TABLE 2

Sen’s slop (°C/year) for monthly, seasonal and annual temperature at Agartala and Kailashahar

| Month/season | Agartala | Kailashahar |
|--------------|----------|-------------|
|              | $T_{\text{min}}$ | $T_{\text{max}}$ | $T_{\text{mean}}$ | DTR | $T_{\text{min}}$ | $T_{\text{max}}$ | $T_{\text{mean}}$ | DTR |
| January      | 0.03297  | -0.02199    | -0.00076     | -0.05415 | 0.04032  | 0.00272  | 0.01996     | -0.03763 |
| February     | 0.02653  | 0.01000     | 0.02098      | -0.02351 | 0.03343  | 0.03262  | 0.03066     | -0.01353 |
| March        | 0.02129  | -0.01087    | 0.00659      | -0.02525 | 0.03032  | 0.01802  | 0.02581     | -0.00753 |
| April        | 0.01542  | 0.01500     | 0.01642      | 0.00182  | 0.01595  | 0.01971  | 0.01659     | -0.00467 |
| May          | 0.02304  | 0.02722     | 0.02665      | 0.00511  | 0.02553  | 0.00949  | 0.01895     | -0.00863 |
| June         | 0.02362  | 0.02596     | 0.02333      | 0.00294  | 0.01143  | 0.01030  | 0.01113     | -0.00594 |
| July         | 0.02241  | 0.03311     | 0.02568      | 0.01060  | 0.01801  | 0.02270  | 0.01978     | 0.00494  |
| August       | 0.02324  | 0.02564     | 0.02354      | 0.00072  | 0.01976  | 0.01336  | 0.01469     | -0.00285 |
| September    | 0.02778  | 0.02549     | 0.02597      | 0.00308  | 0.01833  | 0.01723  | 0.01706     | -0.00172 |
| October      | 0.03243  | 0.01861     | 0.02742      | -0.01333 | 0.02031  | 0.01822  | 0.02238     | -0.00119 |
| November     | 0.02250  | 0.01452     | 0.01690      | 0.00424  | 0.02929  | 0.02899  | 0.02093     | -0.00067 |
| December     | 0.06359  | 0.00124     | 0.03130      | -0.05766 | 0.05149  | 0.01183  | 0.03466     | -0.03561 |
| Winter       | 0.02591  | -0.00954    | 0.00823      | -0.03796 | 0.03678  | 0.01759  | 0.02454     | -0.02496 |
| Pre-monsoon  | 0.01512  | 0.00910     | 0.01355      | -0.01280 | 0.02236  | 0.01759  | 0.02039     | -0.01000 |
| Monsoon      | 0.02465  | 0.02591     | 0.02373      | 0.00098  | 0.01527  | 0.01545  | 0.01614     | -0.00243 |
| Post-monsoon | 0.03720  | 0.00972     | 0.02404      | -0.02954 | 0.04123  | 0.02082  | 0.03159     | -0.01503 |
| Annual       | 0.02547  | 0.01146     | 0.01735      | -0.01594 | 0.02774  | 0.01593  | 0.02085     | -0.01550 |

Positive and negative values show increasing and decreasing trends respectively. Bold values indicate statistical significance at 95% confidence level as per the MK test.

Fig. 4(a). Linear trends and times-series of maximum temperature ($T_{\text{max}}$) for four seasons over Agartala.
3.3. Trend analysis of seasonal temperature

Figs. 4(a-d) & 5(a-d) show the time series and linear trend in $T_{\text{min}}$, $T_{\text{max}}$, $T_{\text{mean}}$ and DTR variables for the four seasons- winter, pre-monsoon, monsoon and post-monsoon season over Agartala and Kailashahar respectively. During four seasons, the trends in $T_{\text{min}}$, $T_{\text{max}}$, and $T_{\text{mean}}$ are increasing over these two stations except decreasing trend observed in $T_{\text{max}}$ over Agartala during the winter season (Table 2). The analysis indicates that the increasing trends in three temperature variable namely- $T_{\text{min}}$, $T_{\text{max}}$ and $T_{\text{mean}}$ are significant during the monsoon season over both the stations. The increasing trends in $T_{\text{min}}$ and $T_{\text{mean}}$ indices over Kailashahar are statistically
significant for all four seasons. The highest rate of increase in $T_{\text{min}}$, $T_{\text{max}}$, and $T_{\text{mean}}$ indices are observed over Kailashahar in post-monsoon season. For post-monsoon season at Kailashahar, an increase of 1.9 °C, 1.0 °C and 1.5 °C was found in $T_{\text{min}}$, $T_{\text{max}}$ and $T_{\text{mean}}$ respectively. At Agartala, the largest increase in $T_{\text{min}}$ (1.7 °C) and $T_{\text{mean}}$ (1.1 °C) are seen in post-monsoon season whereas the largest increase in $T_{\text{max}}$ (1.2 °C) are observed during the monsoon season. So, analysis clearly indicates higher rate of change in $T_{\text{min}}$ than $T_{\text{max}}$ on seasonal scale over both the sites. The highest significant increase of 1.9 °C and 1.7 °C during the period 1969-2014 in $T_{\text{min}}$ are observed in the post monsoon season at Kailashahar and Agartala respectively.

The comparatively higher rate of increase in $T_{\text{min}}$ leads to fall in DTR values at two sites for all four seasons except during the monsoon season over Agartala, where,
rising trend in $T_{\text{max}}$ is slightly higher than $T_{\text{min}}$ (Table 2). The significant decreasing trends in DTR values are seen only over Agartala during the winter and post-monsoon season. During the period of study the DTR trends at Agartala in winter season and post-monsoon season indicates decrease of -1.7 °C and -1.4 °C respectively.

3.4. Trend analysis of monthly temperature

On monthly scale, the trend in $T_{\text{min}}$ data indicates increase in temperature for all the months over both the stations. Quantitatively, the highest magnitudes in trend values are also observed in $T_{\text{min}}$ as compared to magnitude
of trend in other three temperature indices ($T_{\text{max}}$, $T_{\text{mean}}$ and DTR) over both sites. At both the stations, the rate of increase in $T_{\text{min}}$ is highest during December followed by January. During the period of study Sen’s slope indicates a statistically significant rate of increase of about 2.9 °C and 2.4 °C in $T_{\text{min}}$ during December at Agartala and Kailashahar respectively (Table 2). The warming trends in $T_{\text{min}}$ over Kailashahar are significant for all months except for November and April, whereas trends over Agartala are significant for seven months.

The positive trend in $T_{\text{max}}$ also indicates increase in temperature over both the stations except for decreasing trends in January and March over Agartala. The statistically significant highest rates of increase in $T_{\text{max}}$ temperature are found in the month of July (0.03311 °C/year) and February (0.03262 °C/year) at Agartala and Kailashahar respectively. The decreasing trend over Agartala in the month of January (-0.02199 °C/year) is also found statistically significant.

There, therefore, at both the stations the magnitudes of increase in $T_{\text{max}}$ are higher than the magnitudes of increase in $T_{\text{min}}$ on all timescale. These findings are consistent with the result obtained by other meteorologist (Roy and Balling, 2005; Jhajharia and Singh, 2011). According to Roy and Balling (2005) the significant increase in clouds causes the rise in minimum temperature and hence fall in DTR over the most parts of India for winter and summer season. Correlation analysis performed by Jhajharia and Singh (2011) revealed that the different meteorological parameters (sunshine duration, pan evaporation,
temperature, rainfall and humidity) influence DTR in different seasons over different sites in Northeast India. They have also observed significant decreasing trends in the sunshine duration at annual, seasonal (winter and pre-monsoon) and monthly (January, February and March) scales and suggested that the decrease in sunshine duration may be one of the potential cause for decreased DTR values over Northeast India.

4. Conclusions

An important aspect of the present study is the warming trends in $T_{\text{min}}$, $T_{\text{max}}$, and $T_{\text{mean}}$ temperatures and decreasing trends in DTR over two cities of Tripura. At the two sites, the total numbers of statistically significant values in three temperature indices - $T_{\text{min}}$, $T_{\text{max}}$, and $T_{\text{mean}}$ are more than total numbers of non-significant values on annual, seasonal and monthly timescale.

All the trends in $T_{\text{min}}$ variable are increasing at both the stations on annual, seasonal and monthly scale. These increasing trends in $T_{\text{min}}$ are significant at annual, seasonal and monthly scales over Kailashahar except during November and April months and over Agartala it is significant at annual, seasonal (winter, monsoon, post-monsoon) and in the month of January, June-October and December. In general, the magnitudes of rate of change in $T_{\text{min}}$ are higher as compared to other variables on all time scale at both the stations.

The increasing trends in $T_{\text{max}}$ at Agartala are significant on annual scale, monsoon season as well as in June-to-October months whereas at Kailashahar these trends are significant on annual scale, monsoon season, post-monsoon season and in April, July, August, October, November months.

Similar to the trends observed in $T_{\text{min}}$ and $T_{\text{max}}$, $T_{\text{mean}}$ shows significant increasing trends on annual, seasonal (monsoon and post-monsoon) and monthly (except January to April) scale over Agartala and at Kailashahar the $T_{\text{mean}}$ also shows significant increase on annual, seasonal and monthly (except April, May & June) timescale.

DTR shows significant decreasing trends on annual scale, winter season, post-monsoon season and in January and December months at Agartala and in winter season and in January and December at Kailashahar.

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