Climate change trends in some of the rubber growing regions of North-East India

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Abstract
Climate change analysis has been conducted using daily surface meteorological datasets in respect of nine parameters from five rubber growing locations in the East and North-East India. Monthly, seasonal and annual variability in meteorological parameters showed decreasing trends in relative humidity, sunshine hours and pan evaporation rates coupled with increasing temperature extremes. Rise in mean temperature was seen to be highest (0.34 °C per decade) for Dhenkanal, Odisha state, India which experiences dry sub-humid type of climate. The data on relative humidity and temperature also revealed the fact that warm surface temperatures, along with limited moisture availability, may lead to lower relative humidity in the future, since all the stations are away from the moist coastal belts. Decreasing trends in sunshine hours were mainly observed during winter and post monsoon seasons with decreasing number of days even with the optimum required daily sunshine hours. The fact that there were no significant changes in the amount of rainfall or the number of rainy days was in conformity with several earlier reports in the northeast. Mean monthly decadal variations have also been tested with earlier and recent sets. With long term trends in most of the weather parameters, being lesser when compared to that of the traditional rubber growing regions in India, it is imperative that for rubber cultivation to thrive in this non-traditional belt, future policy inputs will have to be based depending on the magnitude of climate change effects.

Keywords: Climate change, decadal variations, Mann-Kendall, rubber

Introduction
The North Eastern (NE) region of India falls under the high rainfall zone with a subtropical type of climate. The varied physiological features and altitudinal differences gives rise to varied types of climates ranging from near tropical to temperate and alpine (Anup Das et al., 2009). The North Eastern Region (NER) comprises of the states of Arunachal Pradesh, Assam, Manipur, Nagaland, Meghalaya, Mizoram, Sikkim and Tripura. The region stretches between 21°50’ and 29°34’ N latitude and 85°34’ and 97°50’ E longitude. The region has a geographical area of 26.2 million hectares, which is 8 per cent of the total area of the country. Assam is situated in the center and the hill states (except Sikkim) are situated around it. Annual rainfall in the region is mainly received from the South-West monsoon i.e., from the middle of May and continues till October. On an average, the NE region receives about 2450 mm of rainfall. The rainfall in the Cherrapunji-Mawsynram range receives 11,500 mm annually. Temperature varies from 15 to 32 °C in summer and 0 to 26 °C in winter. In the absence of scientific data about the vulnerability of the region to climate change, proper and timely agro-management practices, efficient use of inputs and latex harvesting methods are some of the management options that need to be popularized among the rubber farming community to mitigate the impact of climate change.

Climate change study mainly focuses on the changes in climatic variability over temporal scales. Climate change studies in Kerala state had revealed that local changes were different from the large
spatial scale averages (Indrani and Abir, 2009). Even a slight rise in maximum temperature by 0.4 °C affected black pepper, cocoa and cardamom in the absence of soil moisture (Rao, 2009). Studies on monsoon rainfall in India showed a decreasing trend over east Madhya Pradesh and adjoining areas, North-East India and parts of Gujarat and Kerala (Kumar et al., 2002). Rainfall and number of rainy days showed declining trends during the southwest monsoon (June to September) period at four different locations in Kerala (Krishnakumar et al., 2008a). Rise in maximum and minimum temperature was noticed since the last 49 years over Kerala (Rao et al., 2008). Unlike seen in the rise of temperature trends, rainfall trends were uncertain at several locations in Kerala. (Krishnakumar et al., 2008b; Rao et al., 2009).

In a climate change study undertaken within rubber plantations in the traditional region of Kerala, it was found that there was a rising trend in the mean, maximum and minimum temperature, rainfall was becoming more skewed, and also a decreasing trend in bright sunshine hours per day (Raj et al., 2011). Impact of climate change was felt most strongly through changes in climate extremes. In tandem with the expansion of rubber cultivation in the NE, it is imperative that crop management, improvement and protection strategies are to be adopted in tune with projected climate change to sustain rubber production in future. The following study would be assessing the major climatic factors affecting rubber cultivation in the different rubber growing regions in India. The study could also be useful as a fore-runner in addressing problems of decrease in survivability and yield depression, shift in climatically favourable areas or increase in the gestation period of rubber.

**Materials and methods**

Daily datasets ranging from 16 to 30 years duration collected by the Rubber Research Institute of India (RRII) from five different agrometeorological stations in the NE region have been

| Location                  | Latitude | Longitude | MSL | Duration      |
|---------------------------|----------|-----------|-----|---------------|
| Agartala (Tripura)        | 23°57’N  | 91°21’E   | 30 m| 1984-2013 (30 years) |
| Guwahati (Assam)          | 26°03’N  | 91°53’E   | 103 m| 1989-2013 (25 years) |
| Tura (Meghalaya)          | 25°34’N  | 90°14’E   | 405 m| 1995-2013 (19 years) |
| Nagrakata (West Bengal)   | 26°51’N  | 88°57’E   | 69 m  | 1995-2013 (19 years) |
| Dhenkanal (Odisha)        | 20°02’N  | 72°54’E   | 69 m  | 1998-2013 (16 years) |

| Month | \( T_x \) | \( T_n \) | \( A_t \) | \( R_d \) | \( R_s \) | \( S_s \) | \( E_v \) | \( R_I \) | \( R_d \) |
|-------|---------|---------|--------|--------|--------|--------|--------|--------|--------|
| Jan   | \( \downarrow \) | \( \uparrow \) | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) | \( \uparrow \) |
| Feb   | \( \downarrow \) | \( \uparrow \) | \( \downarrow \) | \( \downarrow \) | \( \uparrow \) |
| Mar   | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) | \( \uparrow \) |
| Apr   | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) |
| May   | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) |
| Jun   | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) |
| Jul   | \( \uparrow \) | \( \uparrow \) | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) |
| Aug   | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) |
| Sep   | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) |
| Oct   | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) |
| Nov   | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) |
| Dec   | \( \downarrow \) | \( \uparrow \) | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) | \( \downarrow \) |
| Annual| 0.043   | ns      | 0.026  | -0.1   | ns     | -0.049 | -0.092 | ns     | ns     |

(ns – not significant)
utilized for the study. These agro-meteorological stations situated in rubber growing areas comprises five stations viz., Agartala (Tripura), Guwahati (Assam), Tura (Meghalaya), Nagrakata (West Bengal) and Dhenkanal (Odisha). The details of the RRII station and data duration are given in Table 1. The Tura station is situated in a comparatively higher altitude compared to the other stations. Dhenkanal is situated in lower latitude while Nagrakata is situated in the foothills of the Himalayas in the north.

The average monthly, seasonal and annual period based parameters chosen were rainfall amount ($R_f$), number of rainy days ($R_d$), maximum temperature ($T_x$), minimum temperature ($T_n$), average temperature ($A_t$), morning relative humidity ($R_{h1}$), afternoon relative humidity ($R_{h2}$), bright sunshine hours ($S_h$) and pan evaporation ($E_v$). Slopes based on linear regression method and the non-parametric Mann-Kendall trend statistics (Gemmer et al., 2004; Liu et al., 2008; Yang et al., 2010) were applied to the time series data sets.

Table 3a. Slopes of linear trend equations of observed seasonal meteorological factors for five different rubber growing stations in the NE India

|                      | Agartala | Guwahati | Tura  | Nagrakata | Dhenkanal |
|----------------------|----------|----------|-------|-----------|-----------|
| **Maximum temperature** |          |          |       |           |           |
| Winter               | 0.000    | *0.073   | 0.053 | 0.053     | 0.126     |
| Pre-monsoon          | 0.031    | **0.042  | *0.066| **0.058   | **0.226   |
| Monsoon              | *0.029   | 0.045    | 0.021 | 0.013     | 0.114     |
| Post-monsoon         | 0.010    | ***0.065 | 0.004 | 0.002     | **0.162   |
| Annual               | 0.043    | ***0.057 | **0.052| 0.027     | 0.001     |
| **Minimum temperature** |          |          |       |           |           |
| Winter               | 0.009    | -0.029   | -0.006| **0.185   | -0.076    |
| Pre-monsoon          | **0.029  | 0.004    | -0.017| 0.038     | -0.018    |
| Monsoon              | 0.022    | 0.022    | -0.036| 0.118     | -0.075    |
| Post-monsoon         | **0.050  | -0.028   | -0.036| 0.168     | -0.018    |
| Annual               | -0.010   | 0.000    | -0.120| ***0.009  | **0.077   |
| **Average temperature** |          |          |       |           |           |
| Winter               | 0.010    | 0.024    | 0.018 | *0.019    | 0.040     |
| Pre-monsoon          | 0.022    | 0.015    | 0.021 | *0.025    | 0.039     |
| Monsoon              | *0.027   | 0.011    | 0.041 | **0.033   | *0.039    |
| Post-monsoon         | *0.029   | 0.015    | -0.012| 0.009     | 0.032     |
| Annual               | **0.026  | 0.010    | 0.018 | **0.010   | 0.034     |
| **Relative humidity (Morning)** |          |          |       |           |           |
| Winter               | ***-0.240| -0.137   | 0.107 | 0.085     | 0.241     |
| Pre-monsoon          | -0.058   | 0.087    | 0.051 | 0.020     | 0.096     |
| Monsoon              | -0.072   | -0.020   | **0.233| 0.097     | -0.125    |
| Post-monsoon         | ***-0.150| 0.088    | 0.050 | 0.082     | *0.275    |
| Annual               | ***-0.100| 0.036    | *0.157| 0.082     | -0.007    |
| **Relative humidity (Afternoon)** |          |          |       |           |           |
| Winter               | 0.099    | *-0.092  | 0.183 | -0.068    | -0.78     |
| Pre-monsoon          | -0.009   | *-0.098  | 0.023 | *-0.314   | -0.522    |
| Monsoon              | 0.110    | -0.242   | *0.478| -0.123    | -0.763    |
| Post-monsoon         | **0.193  | -0.312   | 0.104 | -0.486    | -1.000    |
| Annual               | 0.128    | *-0.230  | **-0.255| -0.292    | -0.077    |

*significant at 0.1 level; **significant at 0.05 level; ***significant at 0.001 level
Table 3b. Slopes of linear trend equations of observed seasonal meteorological factors for five different rubber growing stations in the NE India

| Bright sunshine hours | Agartala | Guwahati | Tura | Nagrakata | Dhenkanal |
|-----------------------|----------|----------|------|-----------|-----------|
| Winter                | ***-0.071| *-0.058  | **-0.090 | **-0.152 | -0.023    |
| Pre-monsoon           | -0.008   | 0.026    | -0.023 | 0.003    | -0.017    |
| Monsoon               | **-0.052 | 0.000    | -0.075 | *-0.053  | *-0.090   |
| Post-monsoon          | ***-0.083| -0.015   | ***-0.102| ***-0.138| *-0.086   |
| Annual                | *-0.049  | -0.003   | -0.029 | **-0.075 | ***-0.090 |

| Evaporation           |          |          |      |          |          |
|-----------------------|----------|----------|------|-----------|-----------|
| Winter                | ***-0.056| *-0.033  | -0.016 | -0.031   | **-0.267  |
| Pre-monsoon           | ***-0.080| **-0.084 | -0.019 | -0.038   | 0.334     |
| Monsoon               | ***-0.128| **-0.082 | -0.042 | 0.034    | **-0.410  |
| Post-monsoon          | **-0.040 | -0.013   | *-0.031| -0.016   | *-0.178   |
| Annual                | ***-0.092| **-0.057 | 0.002 | -0.031   | -0.031    |

| Total rainfall        |          |          |      |          |          |
|-----------------------|----------|----------|------|-----------|-----------|
| Winter                | -1.141   | -1.266   | 0.000 | -2.750    | *11.700   |
| Pre-monsoon           | -1.955   | -9.351   | 29.067| 39.300    | **-60.331 |
| Monsoon               | -1.924   | -4.267   | 23.800| -7.610    | 28.542    |
| Post-monsoon          | -3.881   | -0.120   | 0.7540| -2.913    | -0.825    |
| Annual                | -28.183  | -16.453  | -18.914| 25.357    | -14.867   |

| No. of rainy days     |          |          |      |          |          |
|-----------------------|----------|----------|------|-----------|-----------|
| Winter                | -0.073   | -0.133   | 0.000 | -0.133    | **3.500   |
| Pre-monsoon           | -0.257   | 0.028    | -0.455| -0.100    | 1.333     |
| Monsoon               | -0.243   | -0.273   | 0.400 | 0.083     | *5.786    |
| Post-monsoon          | -0.083   | 0.000    | 0.000 | -0.308    | *4.857    |
| Annual                | -0.250   | -0.333   | 0.000 | -0.375    | -0.429    |

*significant at 0.1 level; **significant at 0.05 level; ***significant at 0.001 level

The non-parametric Mann-Kendall and Sen’s methods were used to determine whether there was a positive or negative trend in weather data with their statistical significance. It was established that the results of using the Mann-Kendall and Sen’s tests demonstrated good agreement of performance in detection of the trend for meteorological variables (Milan and Slavisa, 2012).

The four seasons considered for the analysis were winter (January-February), pre-monsoon (March-May), monsoon (June-September) and the post-monsoon (October-December) season. The frequency (days) of annual extreme climatic events has been calculated by considering the respective thresholds for each parameter as the sum of long-term mean plus its standard deviation and termed as extremes in this study. In the case of rainfall and relative humidity, the threshold represents the mean of the long term values. The study shows changes in the duration of extremes observed over a long-term period at a place. In order to compare the long duration decadal variability in the case of Agartala, monthly data from 1968 to 1978 obtained from the India Meteorological Department (IMD) were supplemented for the study. The month-wise decadal variations were compared with that of the recent decade to identify any discernible changes between the temperature curves.

Results and discussion

Monthwise trends

The study was carried out even for the rubber growing areas of Tura, Nagrakata and Dhenkanal, despite having a low duration of dataset, primarily
because of absence of long-term data from the IMD in such remote rubber growing stations. A 30 year period is long enough to filter out any inter-annual variation or anomalies, but also short enough to be able to show longer climatic trends. Long-term averages would converge to a constant state given a sufficiently long averaging period (WCDMP, 2007). Therefore, a closer time scale of monthly time series analysis has been shown for Agartala in Table 2. Significant increasing trend in \( T_x \) was seen only during the July month. As a whole, the annual trend showed an increase of 0.43 °C per decade in Agartala. The mean annual temperature showed an increasing trend of 0.26 °C per decade. With no particular significance of monthly trends in \( T_x \), the annual mean temperature trend increase could be a result of the increasing trends mainly contributed by the \( T_x \). Annual \( R_h \) showed a decreasing trend, while there was no change for \( R_{h2} \). Annual negative trend of bright sunshine hours was mainly contributed by the winter and post monsoon seasons. While \( E_v \) showed negative trends on almost every month, the rainfall amount did not show any significant change. The monsoon month of July registered a decreasing trend in the number of rainy days although no annual trends were noticed. This shows that in Agartala either there is a possibility of a slow tendency of a shift in the peak rainfall

| Stationwise climatic parameters | Threshold | Slope | Significance level |
|---------------------------------|-----------|-------|--------------------|
| **Agartala**                    |           |       |                    |
| Maximum temperature             | days > 34.0 °C | 1.235 | **                 |
| Minimum temperature             | days > 25.8 °C | 1.429 | ***                |
| Average temperature             | days > 29.6 °C | 0.600 | ns                 |
| Relative humidity (morning)     | days > 90%  | -3.692| ***                |
| Relative humidity (afternoon)   | days > 63%  | 0.250 | ns                 |
| Bright sunshine hours           | days > 9.3 h | -4.000| ***                |
| Evaporation                     | days > 4.2 mm day\(^{-1}\) | -4.222 | ***                |
| Rainfall                        | days > 20.3 mm day\(^{-1}\) | -0.067 | ns                 |
| **Guwahati**                    |           |       |                    |
| Maximum temperature             | days > 33.8 °C | 1.633 | **                 |
| Minimum temperature             | days > 23.6 °C | 0.261 | ns                 |
| Average temperature             | days > 28.4 °C | 0.714 | ns                 |
| Relative humidity (morning)     | days > 88%  | -0.171| ns                 |
| Relative humidity (afternoon)   | days > 68%  | -2.809| *                  |
| Bright sunshine hours           | days > 8.5 h | -2.721| ***                |
| Evaporation                     | days > 3.3 mm day\(^{-1}\) | -4.393 | ***                |
| Rainfall                        | days > 15.1 mm day\(^{-1}\) | -0.207 | ns                 |
| **Tura**                        |           |       |                    |
| Maximum temperature             | days > 32.3 °C | 1.000 | ns                 |
| Minimum temperature             | days > 22.3 °C | 0.529 | ns                 |
| Average temperature             | days > 27.0 °C | 0.000 | ns                 |
| Relative humidity (morning)     | days > 86%  | 2.000 | ns                 |
| Relative humidity (afternoon)   | days > 68%  | 1.600 | ns                 |
| Bright sunshine hours           | days > 8.4 h | -5.286| ns                 |
| Evaporation                     | days > 4.0 mm day\(^{-1}\) | -4.429 | ***                |
| Rainfall                        | days > 27.4 mm day\(^{-1}\) | 0.727 | ns                 |

ns – not significant; *significant at 0.1 level; **significant at 0.05 level; ***significant at 0.001 level
Table 4b. Linear trend slopes of the annual frequency (days) of extreme climatic events (based on thresholds) for Nagrakata and Dhenkanal rubber growing stations

| Stationwise climatic parameters | Threshold | Slope | Significance level |
|--------------------------------|-----------|-------|--------------------|
| **Nagrakata**                  |           |       |                    |
| Maximum temperature            | days > 33.2 °C | 1.333 | *                  |
| Minimum temperature            | days > 24.4 °C | 1.900 | ns                 |
| Average temperature            | days > 28.5 °C | 1.000 | *                  |
| Relative humidity (morning)    | days > 92%  | 2.000 | ns                 |
| Relative humidity (afternoon)  | days > 65%  | -2.769| ns                 |
| Bright sunshine hours          | days > 8.4 h | -4.824| ***                |
| Evaporation                    | days > 2.9 mm day⁻¹ | -2.692| ns                 |
| Rainfall                       | days > 35.8 mm day⁻¹ | 0.400 | ns                 |
| **Dhenkanal**                  |           |       |                    |
| Maximum temperature            | days > 38.0 °C | 2.464 | *                  |
| Minimum temperature            | days > 26.0 °C | -1.582| ns                 |
| Average temperature            | days > 31.5 °C | -1.000| ns                 |
| Relative humidity (morning)    | days > 88%  | 2.036 | ns                 |
| Relative humidity (afternoon)  | days > 59%  | -5.439| *                  |
| Bright sunshine hours          | days > 9.4 h | -3.958| *                  |
| Evaporation                    | –          | –     | –                  |
| Rainfall                       | days > 13.0 mm day⁻¹ | -1.958| ns                 |

*significant at 0.1 level; **significant at 0.05 level; ***significant at 0.001 level

Period or that the rainfall amount is getting skewed (Raj et al., 2011).

Seasonal trends

Seasonal level change in slopes of the nine parameters is given in Tables 3a and 3b for the five rubber growing stations. Excepting Agartala, all other stations showed increasing trends in T during the pre-monsoon season. In Dhenkanal, it was more reflected on the highly decreasing trend of the pre-monsoon season Rf (Table 3b). Annual increase of T was found only in Nagrakata and Dhenkanal. The climate types (Koppen’s classification) for Nagrakata and Dhenkanal are warm temperate and dry sub-humid respectively. In Nagrakata, the increasing trend in At was seen in all seasons except the post-monsoon season. Tendency of rise in annual mean temperature was seen to be highest for Dhenkanal (0.34 °C per decade). Highly significant decreasing trends were observed for both the morning and afternoon relative humidity values for Agartala during the post monsoon season. Warmer surface temperatures, along with limited moisture availability, may lead to lower relative humidities in the future than are experienced today (Pierce et al., 2013). This could have an effect on hydrological and ecological processes that are sensitive to humidity, such as evapotranspiration (Friend, 1995), runoff, and plant growth (Leuschner, 2002). Strong indications of decreasing trends in daily sunshine hours were seen for all seasons except the pre-monsoon season for almost all stations. The projection in negative slope was more pronounced in Dhenkanal.

Solar radiation (sunshine duration) has profound influence on surface temperature, evaporation, the hydrologic cycle and ecosystems and it is the primary source of energy required for sustenance of life on this planet. It has been proved that sunshine duration over India has decreased for all months and the decreasing trends were significant at 99 per cent for January to May and October to December (Jaswal, 2009). Table 3b shows that the results obtained for the slopes of $S_h$
and monsoon seasons. No significant changes in the annual rainfall components (rainfall amount and rainy days) were noticed under the study period.

**Extreme climatic events**

Table 4a and 4b shows results of extremes obtained for the same station-wise parameters after estimating the annual frequency of days above the thresholds as shown. Annual extremes in $T_x$ of $>2$ days were observed in Dhenkanal compared to all other stations excepting Tura. However, extremes in $T_n$ was observed only in Agartala at 99 per cent level. Only Nagrakata showed significant annual increase of $A_t$ by $>1$ day compared to other stations. With decreasing trends noted in the value of relative humidity, the $R_h$ factor for only Agartala showed a highly significant decreasing trend of extremes ($>90\%$) over 3 days. Decreasing trend in $R_h$ has an important bearing on the exploitation of the rubber tree crop, where early morning high relative humidity helps in maximizing exploitation of the crop through tapping. Extremes of $S_h$ showed that

are in conformity with that of Jaswal, (2009) and the decreasing trends were mainly observed during winter and post monsoon seasons. While only a 0.3 per cent decrease in annual sunshine hours was noticed in Guwahati, the highest decrease of 9 per cent was observed for Dhenkanal. $E_v$ showed a decreasing trend for all seasons in Agartala with a projection of an annual decrease of 0.92 mm per decade followed by Guwahati (0.57 per decade). Jhajharia et al. (2009) in a study found that out of 11 sites, nine sites showed decreasing $E_v$ trends in the monsoon and pre monsoon seasons in the NE India. Chattopadhyay and Hulme (1997) also reported that $E_v$ decreases mainly in pre-monsoon periods in Agartala
all stations except Tura experienced a negative trend. The annual decrease in extreme sunshine days for the stations studied was 3 to 4 days.

It has already been established that a daily sunshine duration of >5.6 hours is optimum for rubber yield (Rao et al., 1998). Therefore, the annual frequency of days with >5.6 sunshine hours have been plotted and significant decreasing trends were observed in Agartala, Tura and Nagrakata as shown in Figure 1. The negative slope was highest for Nagrakata. Tendency of extremes of $E$ showed an overall reduction over four days in a year for Agartala, Guwahati and Tura. Rainfall as expected from the previous results did not show any significant change in its extremes for any station.

**Long-term events**

The comparison of mean monthly maximum and minimum temperature over the first decade of the available data (1969-78) with that of the recent (2004-13) are shown in Figure 2. The difference between the two decades was significant (0.9°C) during the monsoon season for the maximum temperature (Fig. 2a) while it was 1.2 and 1.1°C respectively for the pre monsoon and post monsoon seasons (Fig. 2b).

**Conclusion**

The study reveals some impending facts about the level of climate change occurrences that could be of reasonable concern in the context of future expansion of rubber cultivation in this non-traditional area. Decreasing trends in relative humidity, sunshine hours and pan evaporation rates, coupled with increasing temperature extremes, will result in adopting changes in the agro-management and practices in rubber cultivation which will likely prove to be a challenge to the small holder farmers of this region. The study necessitates further analysis with long-term datasets on a larger geographical extent so as to accurately project climate variability effect on rubber growing areas.

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