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# Spatio-temporal Trend Determination of Temperature and Rainfall for Climate Change and Variability in Assam State, India

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**Abstract:** The effect of climate change differs significantly from region to region and it becomes pertinent to ascertain whether the characteristics of major components such as temperature and rainfall have been changing on the regional scale too. In this context, the present study mainly aims to investigate whether there are spatio-temporal changes in temperature and rainfall in Assam and if so, to what extent these changes have been happening. Both parametric and non-parametric methods have been used to study climate change and variability. The study finds that there is a significant increase in annual minimum temperature than the annual maximum temperature in Assam. The fluctuations in annual minimum temperature as shown by the coefficient of variation are also more than the annual maximum temperature. Though the rainfall trend is not significant, the decreasing trend of rainfall in most of the stations during the monsoon season prevails in Assam.

**Keywords:** Climate change; Mann Kendall test; Mann Whitney test; Serial correlation.

## Introduction

Climate change and climate variability are represented by changes in rainfall, temperature, and increased frequency of extreme events that affect agricultural production and thereby rural community that particularly depends on agriculture (Shiferaw et al., 2014). As still, agriculture provides large employment opportunities in developing countries and fewer resources available to adapt to climate change, developing countries will be the most vulnerable (Kumar et al., 1998; UFCC, 2007). India being a developing country where agriculture is the backbone of the rural economy is likely to be affected by the changes in the climate (Viswanathan et al., 2015). To understand climate change and variability, several attempts have been made worldwide to study the spatial and temporal variation of temperature and rainfall (Tabari et al., 2011; Gocic et al., 2013; Karmeshu, 2012; Hafi et al., 2019). Studies on climate change in India shows an irregular trend of rainfall and an increasing trend in temperature with regional variations in most of the states (Mall et al., 2006; Kumar and Parikh, 2001; Sonali and Kumar, 2013; Roy, 2019; Dubey et al., 2021). Other state-level climate change studies in India also found changing rainfall and temperature trend with seasonal variations in rainfall and temperatures (Patra et al., 2012; Duhan et al., 2013; Deshmukh et al., 2013).

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Within India, the north eastern part is highly prone to climate change due to its geological fragility and strategic locations (Nath et al., 2010). There are a few studies that investigate the climate trend pattern in North East India. The maximum and mean temperatures in North East India were found to be increasing for the period 1901 to 2003 (Deka et al., 2009). RupaKumar et al. (2003) have predicted that over the 21st century, there may be an increase in temperature above 4°C and an increase in the number of rainy days in North East India. Roy (2019) observes positive trends for all seasons except winter months during 1980-2010. De et al. (2015) observes that the average rainfall has been decreasing during 1983-2009 and rainfall in the monsoon season has shifted to post-monsoon season. Out of all northeastern states of India, Assam is mostly affected by the deficit in rainfall and high temperature (Das, 2010). Sreekesh et al. (2016) deals with monthly rainfall and temperatures using the non-parametric test for five stations in North East India and found an increasing trend in minimum temperature and post-monsoon rainfall in most of the stations. Though the above-limited studies have dealt with the climatic variation aspects of Northeast India, to the best of our knowledge, however, none of the available studies have addressed variations of climatic variables using both parametric and non-parametric tests. Moreover, for applying the non-parametric test, such as the MK test, the time series needs to be serially independent as the presence of serial correlation may lead to the trend tests being too liberal (Tabari et al., 2011). Thus, this study incorporates these suggestions by considering the serial correlation aspects among climatic variables in Assam. Moreover, we have also attempted to see the spatial differences among stations, if any.

The paper has been divided into five sections. The section, Data Sources and Aggregation, talks about the data source and compilation of the data while the section, Determining Trends of Climate Variables, discusses the methods involved to determine the trends in temperature and rainfall. Section, Statistical Characteristics of Climate Variables, deals with the illustration of annual trend changes of maximum and minimum temperature along with annual rainfall. We conclude our discussion in the Conclusion section.

## Data Sources and Aggregation

Long term meteorological data has been used in this study[1]. Data on monthly minimum temperatures, monthly maximum temperatures and monthly total rainfall for the period 1960-2010 has been collected from the Indian Meteorology Department, Pune and Regional Meteorology Department, Borjhar[2]. Meteorological stations are available for most of the districts in Assam. However, the availability of data is restricted to certain districts only. The stations which are having 30 years or more data for the period 1951-2013 are selected. Thus a total of 9 stations out of 14 stations representing different districts were selected for final analyses as reported in Table 1[3]. The study map with the location of all-weather stations has been presented in Figure 1.

## Determining Trends of Climate Variables

Generally, two categories i.e. parametric and non-parametric tests are used for trend detection[4]. Parametric tests are distribution dependent whereas non-parametric methods are distribution-free methods. Parametric tests are more powerful than non-parametric ones, but they require data to be independent and normally distributed. On the other hand, non-parametric trend tests require fewer assumptions about the data. It allows for missing data, seasonal effects and can tolerate outliers in the data. More specifically, the data distribution is significant in the choice between parametric and non-parametric procedures. But non-parametric tests can be used to detect trends and these only indicate the direction and not the magnitude of significant trends

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[1] One of the best ways to understand future climate change is to study past climate change (Mall et al., 2006).

[2] Indian Meteorology data sets are available for the period 1960-2010 but except for two stations, all other stations has large missing values and data gaps. Data are therefore again collected from Regional Meteorology Department which is more reliable and data gaps were less. Both the data set has been compared and then finally used for the study.

[3] These districts form a part of six Agro Climatic Zones of Assam. It is pertinent to mention that Assam is divided into six agro climatic zones based on patterns of rainfall, soil type, terrain and climatic conditions. They are North Bank Plain Zone, Upper Brahmaputra Valley Zone, Central Brahmaputra Valley Zone, Lower Brahmaputra Valley Zone, Barak Valley Zone and Hills Zone. Except for The Central Brahmaputra Valley Zone all other zones are represented by these districts.

[4] Many methods are used in literature for trend detection including simple correlation and various graphical techniques too (Helsel and Hirsch et al., 1992)

**Table 1: Stations selected for analyses with their codes**

| *Stations* | *District* | *Codes* | *Years taken* | *Sources* |
|---|---|---|---|---|
| Borjhar | Guwahati | GHY | 51(1960-2010) | IMD,RMD |
| Mohanbari | Dibrugarh | DIB | 51(1960-2010) | IMD,RMD |
| Tezpur | Sonitpur | TEZ | 51(1960-2010) | IMD,RMD |
| North Lakhimpur | Lakhimpur | LAK | 51(1960-2010) | IMD,RMD |
| Jorhat | Jorhat | JOR | 33(1981-2013) | RMD |
| Silchar | Cachar | CAC | 51(1960-2010) | IMD,RMD |
| Dhubri | Dhubri | DHU | 31(1980-2010) | IMD |
| Tangla | Darrang | TAN | 31(1980-2010) | IMD |
| Karbi Anglong | Karbi Anglong | KAN | 33(1981-2013) | RMD |

which parametric tests can. Statistics based on ranks of observations are one example of non-parametric tests. Some widely used rank-based non-parametric tests for detecting trends in the time series is the Mann Kendall (MK) test, Mann Whitney (MW) test, Spearman's Rho (SR) test, etc. Again linear regression is an example of parametric tests.

The presence of a single significant test result may only be weak evidence of change even if this test is highly significant. If more tests are found significant, then this provides stronger evidence of change, unless they are very similar, in which case multiple significance is not an extra proof of change. (Mozejko, 2012). There are studies that used only parametric tests to detect trends in many climatic time series (Kapoor and Shaban, 2014, Subbaramaya, 1987) and studies that have used both parametric and non-parametric tests to detect temperature and rainfall trends in Iran (Tabari et al., 2011), India (Deshmukh et al., 2013) and Rwanda (Safari et al., 2012). In a similar fashion, this study uses both parametric and non-parametric approaches to detect the trend in climatic data in Assam.

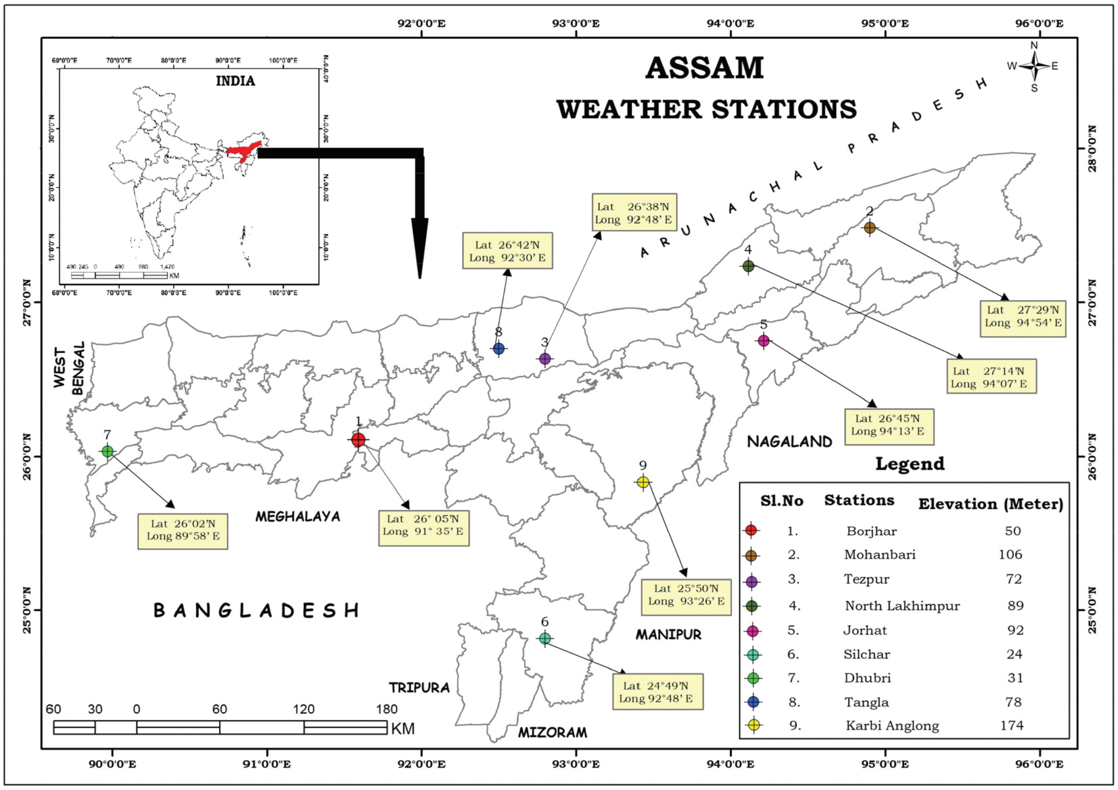

**Figure 1: Study map.**

Serial correlation is a problem often associated with meteorological and hydrological data like temperature, rainfall, stream flow, etc. Meteorological and hydrological time series more often exhibit positive serial correlation than negative (Yue et al., 2002)[5]. The presence of serial correlation can lead to misleading results in the MK test, especially when the serial correlation is positive (Tabari et al., 2011). Accordingly, in our study, we tackled the serial correlation problem before using a non-parametric test. Besides the parametric and non-parametric tests, graphical techniques such as residual plots and 5-year moving average have also been used.

The residual plot is used to capture if there are some odd data or curved trends in the plot. If there are high differences between the observed response variable ($Y_t$) and the value predicted by the regression line ($\hat{Y}_t$), then the plots will have more curved trends. The lesser the variability, the better is the prediction. Moving average is a procedure commonly used in climatology data to reduce the typical dispersal inherent to its variables. It calculates the average value of the series. It helps to smooth the data series. Besides accommodating nonlinearities in the underlying data, it can provide signals to turning points in trends (Billings, 2008). A 5-year moving average has been used in this study because averaging over 5 years conserve the trends.

## Statistical Characteristics of Climate Variables

In the following analyses, temporal variation in three main components of climate-maximum temperature (*T max*), minimum temperature (*T min*) and average rainfall (*Rainfall*) over the last three to five decades is being discussed.

The *T max*, *T min* and *Rainfall* as characteried by monthly mean and standard deviation (Table 2) reveals that among all stations, Silchar receives the highest mean of annual *T max* (mean (μ) = 29.60°C) as well as annual T min (μ = 19.99°C). The maximum *T max* for all the stations occurs in the month of August and September. The highest mean *T max* occurs in the month of August in Guwahati (μ = 32.39°C) and the lowest mean *T max* occurs in the month of January in Karbi Anglong (μ = 18.06°C). Again the monthly mean *T min* is highest in Lakhimpur (μ = 27.27°C) in September and is lowest in Tangla (μ = 8.75°C) in January. It is to be noted that the coldest month in Guwahati remains warmer than all other stations as shown by the minimum *T min* series. In the case of rainfall, the average rainfall in Assam starts increasing from the month of May and attains maximum during the month of June and July. The same pattern has also been observed by Das et al. (2009). Most of the stations have the highest rainfall in the month of July. The highest amount of mean rainfall is received by the station North Lakhimpur (647.6 mm) in the month of July. Rainfall is mostly scanty in the month of December. The lowest mean rainfall is recorded in Dhubri (5.75 mm) for the month of December. Altogether, North Lakhimpur receives the highest amount of annual rainfall (268.43 mm) followed by Silchar and Dhubri station. The high variability in rainfall is also responsible for an increased incidence of the occurrence of extreme events like drought and flood which is perishing a major part of agricultural crops in most of the districts of Assam[6].

The dispersion of annual average rainfall as shown by standard deviation values is found highest in Dibrugarh ($\sigma$ =195.42) followed by Guwahati ($\sigma$ = 142.16). This reflects a considerable yearly fluctuation of rainfall. Moreover, the variability as measured in terms of the coefficient of variation (C.V) of monthly mean *T max* is highest in Karbi Anglong (14.68 %) and that of monthly mean T min is highest in Tangla (24.5%) (Table 3). The variation of monthly average rainfall is highest in Dhubri (209.76%). For most of the stations in Assam, *T max* is more variable in April, February and November. Another point to be noted is that the variability is more for *T min* than for *T max* as shown by maximum C.V values. Variation of monthly average rainfall is highest for most of the stations in the month of December and lowest mostly in summer and monsoon i.e. in the month of May, July, September and August.

### Serial Correlation of the Climatic Data

Whether the climate data selected for the present study have serial correlation or not has been detected by calculating lag 1 serial correlation for different stations

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[5] With *positive serial correlation*, errors in one time period are positively correlated with errors in the next time period whereas with *negative serial correlations*; errors in one time are negatively correlated with errors in the next time period.

[6] Flood is a regular occurrence phenomenon in Assam. Majority of the districts are affected by floods every year. In the last two decades, some major flood took place in the district of Dhubri (2004, 2011, 2014), Sonitpur (2004), Dhemaji (2007, 2009, 2011, 2013), Lakhimpur (2008) Dibrugarh (2008). Moreover, several districts of Assam were badly affected due to drought like situations in 2005 and 2006 that had a signature of climate change on them as indicated by the IPCC report of 2007 (IPCC 2007a).

**Table 2: Climatic characteristics of stations during 1961-2013**

| *Stations* | *Mean T max (Degree Celsius)* | | | *Mean T min (Degree Celsius)* | | | *Rainfall Average (mm)* | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Max* | *Min* | *Annual* | *Max* | *Min* | *Annual* | *Max* | *Min* | *Annual* |
| GHY | 32.39 | 23.67 | 29.37 | 21.31 | 17.92 | 19.85 | 335.89 | 5.88 | 141.58 |
| | (0.74) | (0.93) | (3.10) | (5.13) | (5.33) | (5.55) | (114.69) | (11.99) | (142.16) |
| | (Aug) | (Jan) | | (May) | (Nov) | | (July) | (Dec) | |
| DIB | 31.64 | 22.96 | 29.44 | 24.95 | 9.25 | 18.48 | 523.57 | 14.52 | 212.41 |
| | (0.87) | (1.13) | (3.58) | (0.52) | (1.24) | (2.56) | (106.07) | (17.49) | (195.42) |
| | (Aug) | (Jan) | | (Aug) | (Jan) | | (July) | (Dec) | |
| TEZ | 32.18 | 23.68 | 29.19 | 24.42 | 10.57 | 18.73 | 317.81 | 9.25 | 142.96 |
| | (0.99) | (1.11) | (0.81) | (1.12) | (1.49) | (2.23) | (128.85) | (10.94) | (36.94) |
| | (Aug) | (Jan) | | (July) | (Jan) | | (July) | (Dec) | |
| LAK | 31.84 | 23.40 | 28.41 | 27.57 | 8.94 | 18.56 | 647.60 | 24.72 | 268.43 |
| | (0.94) | (1.23) | (0.61) | (1.21) | (1.14) | (2.33) | (180.68) | (27.57) | (38.48) |
| | (Aug) | (Jan) | | (Sept) | (Jan) | | (July) | (Dec) | |
| JOR | 31.61 | 21.60 | 29.33 | 26.81 | 13.5 | 18.94 | 362.72 | 10.84 | 152.06 |
| | (.514) | (.752) | (.446) | (.643) | (1.05) | (.530) | (90.13) | (13.56) | (20.67) |
| | (Sept) | (Jan) | | (Aug) | (Jan) | | (July) | (Dec) | |
| SIL | 31.98 | 24.57 | 29.60 | 25 | 12.07 | 19.99 | 575.32 | 12.12 | 262.18 |
| | (1.47) | (1.80) | (1.19) | (1.76) | (2.20) | (1.80) | (196.48) | (15.18) | (47.24) |
| | (Aug) | (Jan) | | (July) | (Jan) | | (June) | (Jan) | |
| DHU | 32.00 | 23.90 | 29.37 | 25.25 | 9.01 | 18.64 | 597.13 | 5.75 | 231.95 |
| | (0.75) | (0.95) | (0.47) | (0.28) | (1.84) | (0.69) | (244.30) | (12.21) | (57.79) |
| | (Aug) | (Jan) | | (Aug) | (Jan) | | (July) | (Dec) | |
| TAN | 31.69 | 23.03 | 28.15 | 24.5 | 8.75 | 18.05 | 383.37 | 11.01 | 145.95 |
| | (0.84) | (1.03) | (0.33) | (0.62) | (1.02) | (0.62) | (194.57) | (14.03) | (37.83) |
| | (Aug) | (Jan) | | (Aug) | (Jan) | | (June) | (Dec) | |
| KAN | 30.91 | 18.10 | 17.61 | 25.32 | 9.64 | 18.91 | 215.04 | 8.56 | 103.74 |
| | (4.89) | (1.15) | (1.15) | (0.64) | (1.04) | (0.72) | (98.85) | (13.11) | (14.19) |
| | (Sept) | Jan) | | (Aug) | (Jan) | | (July) | (Dec) | |

*Figures in parentheses indicates standard deviation values
*Source:* Authors computation

(Table 4) as well as plotting the same in Figure 2. As can be seen, most of the stations are showing a positive serial correlation for both seasonal and annual *T max* and *T min* series. The *T min* series is showing the highest positive significant serial correlation.

All the stations are showing serial correlation for summer in the *T min* series. Serial correlation for temperature is significantly negative only for Dhubri for summer *T max* and Summer *T min* series. For average rainfall, only a few stations are showing a significant positive as well as negative serial correlation. Dibrugarh and Silchar rainfall data are not showing any serial correlation. The highest serial correlation in climatic data was observed in Silchar and the lowest in Dibrugarh. As a whole, Summer *T min* has strongest and Annual Average *rainfall* and Post monsoon average *rainfall* has weakest serial correlation.

The annual and seasonal trends of *T max*, *T min* and average *rainfall* and their magnitude (in °C year$^{-1}$) have been obtained by Mann Kendall (MK), Mann Whitney (MW) and Simple Regression (SR) analyses. The statistical significance of the trend is being considered at 95% and 99% confidence levels (bold characters).

For the Mann Whitney test, the data has been divided into equal parts as-from 1960-1984 (pre-1985) and from 1985-2010 (post-1985) for Guwahati, Dibrugarh, Lakhimpur, Tezpur and Silchar. For Jorhat and Karbi Anglong, it has been divided as pre-1997 (1981-1997) and post 1997 (1997- 2013). Similarly, for Dhubri and Tangla, the period is pre-1995 (1981-1995) and post 1995 (1996-2010).

**Table 3: Coefficient of variation for climatic variables for the period 1961-2013**

| *Stations* | *Mean T max (in per cent)* | | *Mean T min (in per cent)* | | *Average Rainfall (in per cent)* | |
|---|---|---|---|---|---|---|
| | *Max C.V* | *Min C.V* | *Max C.V* | *Min C.V* | *Max C.V* | *Min C.V* |
| GHY | 5.8<br>(April) | 2.29<br>(August) | 10.79<br>(February) | 1.84<br>(August) | 195.35<br>(December) | 34.14<br>(July) |
| DIB | 13.31<br>(April) | 2.41<br>(August) | 13.96<br>(November) | 2.08)<br>(August) | 120.46<br>(December) | 20.25<br>(July) |
| TEZ | 13.98<br>(November) | 2.99<br>(August) | 14.68<br>(November) | 4.59<br>(July) | 121.31<br>(January) | 34.19<br>(May) |
| LAK | 8.15<br>(April) | 2.75<br>(August) | 11.42<br>(January) | 1.94<br>(July) | 111.52<br>(December) | 27.90<br>(July) |
| JOR | 6.46<br>(February) | 1.42<br>(November) | 8.518<br>(February) | 1.98<br>(August) | 125.14<br>(December) | 24.85<br>(July) |
| SIL | 7.73<br>(February) | 4.00)<br>(October) | 13.34<br>(December) | 3.37<br>(June) | 175.42<br>(December) | 27.88<br>(July) |
| DHU | 6.81<br>(April) | 2.35<br>(August) | 13.61<br>(January) | 1.92<br>(September) | 209.76<br>(December) | 36.17<br>(May) |
| TAN | 5.11<br>(February) | 2.30<br>(October) | 24.5(0.62)<br>(August) | 13.95<br>(December) | 195.62<br>(February) | 41.56<br>(August) |
| KAN | 14.68<br>(April) | 6.49<br>(August) | 10.79<br>(January) | 2.53<br>(August) | 153.17<br>(December) | 28.68<br>(September) |

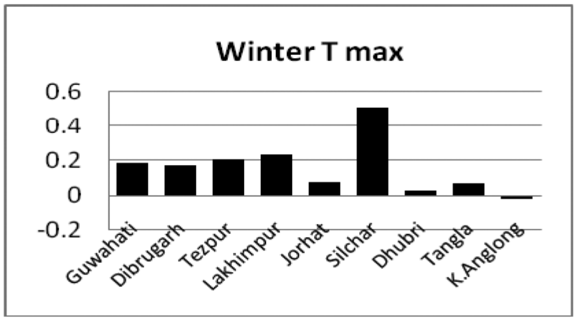
C.V indicates coefficient of variation

*Source*: Authors computation

**Table 4: Results of Lag 1 serial correlation of climatic variables in different stations**

| *Climate Variables* | *GHY* | *DIB* | *TEZ* | *LAK* | *JHT* | *SIL* | *DHU* | *TAN* | *KAN* |
|---|---|---|---|---|---|---|---|---|---|
| **Annual *T max*** | 0.463*** | 0.037 | 0.332*** | 0.579*** | 0.076*** | 0.775** | 0.146*** | 0.020 | 0.158*** |
| Winter *T max* | 0.190 | 0.175 | 0.209 | 0.234*** | -0.048 | 0.503*** | 0.031 | 0.060 | 0.143*** |
| Summer *T max* | 0.0690 | -0.126 | 0.328 | 0.022 | 0.261*** | 0.406** | -0.006*** | -0.256 | 0.102*** |
| Monsoon *T max* | 0.449*** | 0.022 | 0.043 | 0.160 | -0.029 | 0.791** | 0.234 | 0.160*** | -0.271 |
| Post monsoon *T max* | 0.557*** | 0.322 | -0.112 | 0.606*** | -0.274 | 0.754** | 0.395 | -0.095 | -0.019*** |
| **Annual *T min*** | 0.719*** | 0.767 | 0.846 | -0.140 | 0.329*** | 0.530** | 0.161 | 0.735** | 0.312*** |
| Winter *T min* | 0.495*** | 0.694 | 0.704 | 0.379 | 0.547** | 0.238 | 0.341** | 0.391*** | 0.322*** |
| Summer *T min* | 0.432** | 0.561*** | 0.677** | 0.422*** | 0.221*** | 0.447** | -0.066** | 0.431*** | 0.221*** |
| Monsoon *T min* | 0.711*** | 0.569*** | 0.698** | 0.781 | 0.055*** | 0.580** | 0.320** | 0.833 | 0.055*** |
| Post monsoon *T min* | 0.436*** | 0.461*** | 0.700** | -0.072 | 0.101*** | 0.403*** | 0.021** | 0.569*** | 0.101*** |
| **Annual *rainfall*** | -0.030 | -0.323 | -0.138 | 0.110 | -0.138 | -0.032 | 0.196*** | 0.310*** | -0.072 |
| Winter *rainfall* | 0.102*** | -0.107 | 0.398*** | 0.027 | 0.409*** | -0.116 | 0.218 | -0.136*** | 0.313*** |
| Summer *rainfall* | -0.108 | -0.171 | 0.020** | -0.199 | 0.020*** | -0.200 | -0.104 | 0.112*** | 0.165*** |
| Monsoon *rainfall* | -0.082 | -0.358 | -0.132 | 0.213*** | -0.140 | 0.004 | 0.412* | 0.003 | -0.014*** |
| Post monsoon *Rainfall* | -0.014 | 0.191 | -0.225 | 0.081 | -0.224 | -0.228 | 0.004* | 0.059*** | -0.193 |

***, **, * denotes serial correlation is significant at 99%, 95% and 90% confidence level.


Winter T max
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Dibrugarh
Tezpur
Lakhimpur
Jorhat
Silchar
Dhubri
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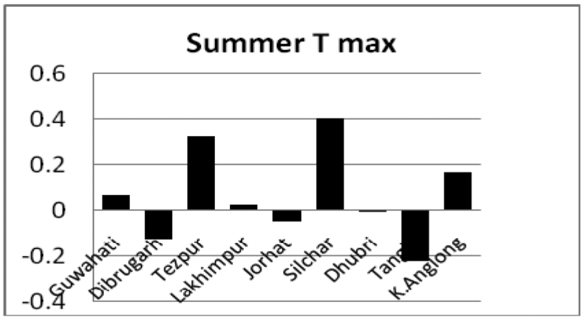
K.Anglong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Silchar
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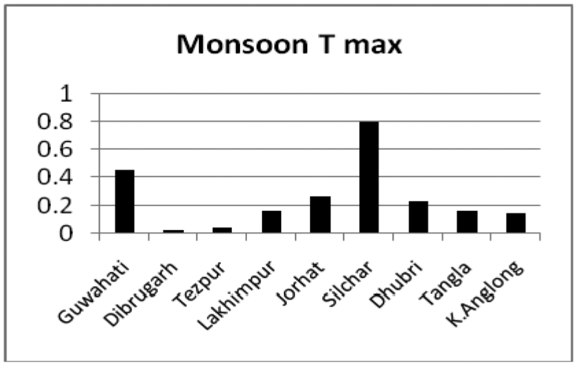
K.Anglong


Monsoon T max
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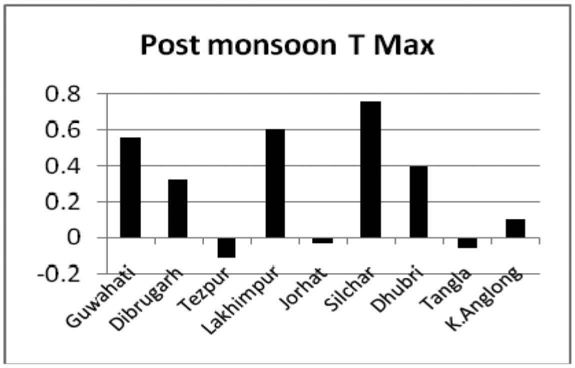
Post monsoon T Max
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Dibrugarh
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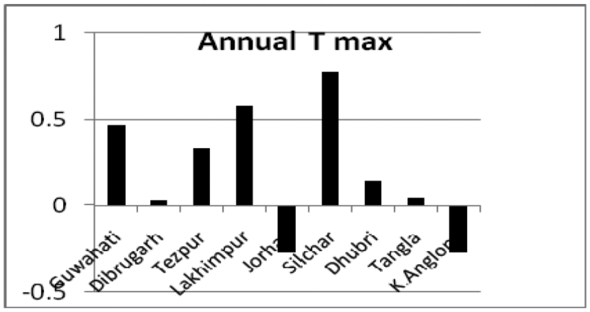
Dhubri
Tangla
K.Anglong


Annual T max
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Guwahati
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Tezpur
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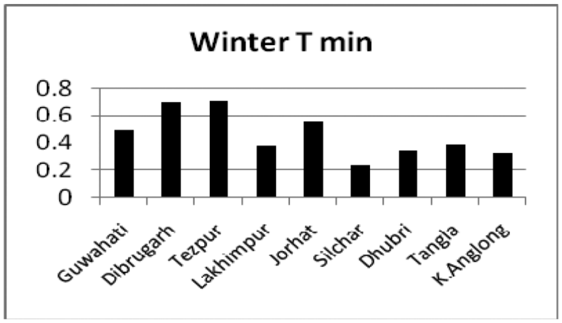
Silchar
Dhubri
Tangla
K.Anglong


Winter T min
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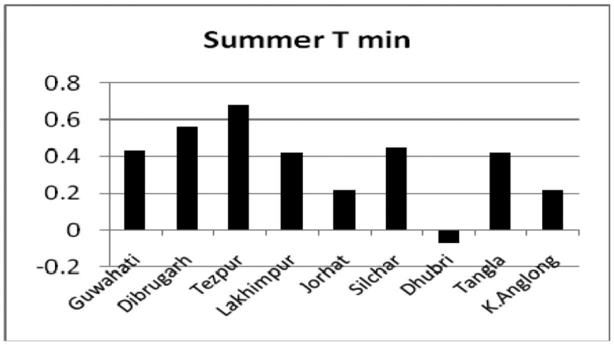
Summer T min
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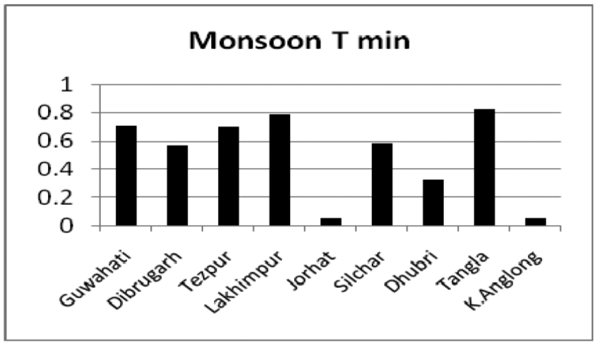
Monsoon T min
1
0.8
0.6
0.4
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Guwahati
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Tangla
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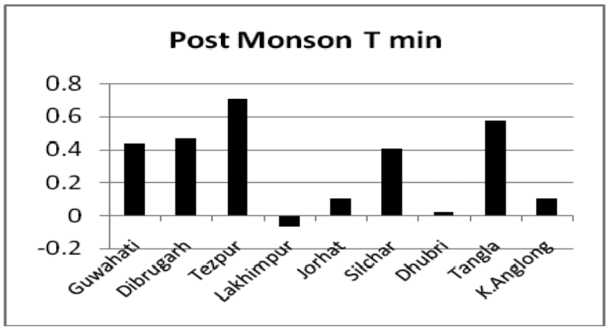
Post Monson T min
0.8
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0.4
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Guwahati
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Tezpur
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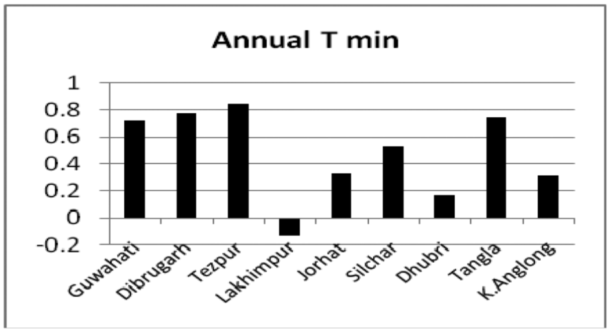
Jorhat
Silchar
Dhubri
Tangla
K.Anglong


Annual T min
1
0.8
0.6
0.4
0.2
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-0.2
Guwahati
Dibrugarh
Tezpur
Lakhimpur
Jorhat
Silchar
Dhubri
Tangla
K.Anglong

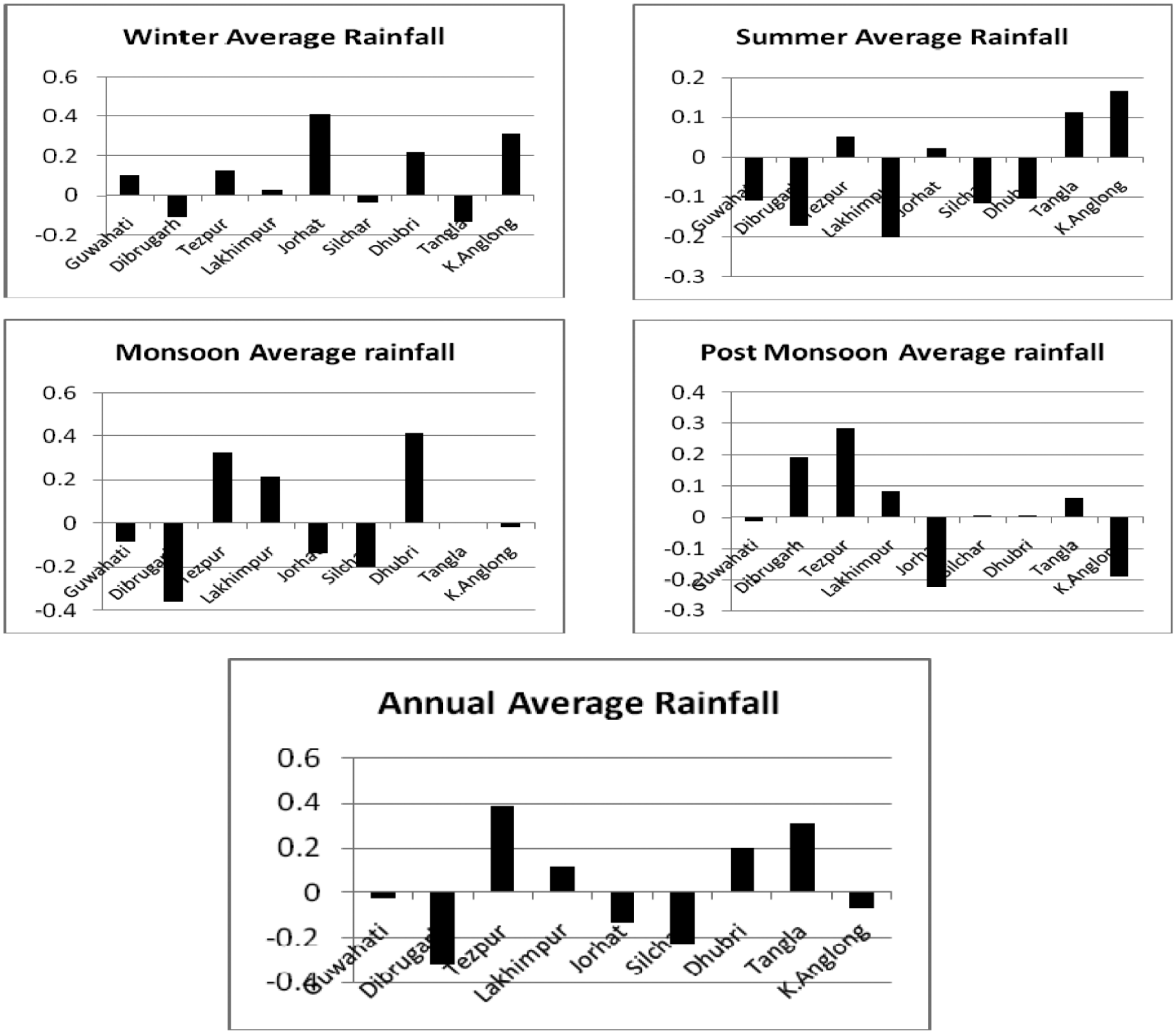


Figure 2: Lag-1 serial correlation coefficient of climate variables at different stations.

### Trends in Annual *T max* Series

The spatial distribution of annual *T max* is showing a warming trend in 7 out of 9 stations (Table 5). However, a statistically significant trend is observed in Guwahati, Dibrugarh, Lakhimpur, Jorhat, Silchar and Tangla. On the contrary, Tezpur is showing a significantly decreasing trend. The magnitude of the trend as can be seen from slopes of regression analyses ranges between 0.001°C per year at Tangla to 0.055°C per year at Silchar. The entire tests are giving almost similar results with 78% of stations showing significant trends for annual *T max*. Roy et al. (2013) have also found significant warming trend in temperature at four stations in Assam during 1980-2010 using the MK test without consideration of serial correlation. Only in the case of Tezpur station, our result contradicts the study by Roy et al. (2013). The reasons may be consideration of a longer time period (51 years) and elimination of serial correlation effect in our study.

The time series, along with the linear trend line and the 5-year moving average are graphically represented in Figure 3 for the climatic variables at each station. The residual plots (Figure 4) also show lesser variability in annual *T max* over the years which means temperature fluctuation is stable over the years. Except for Tezpur and Silchar, the fluctuation is between the range +1 and -1 for all other stations.

### Trends in Annual *T min* Series

The annual *T min* is showing an increasing trend in all selected stations and it is statistically significant in 8 out of 9 stations under all tests. As can be seen from the regression slope, the highest increase in annual *T min* is observed in Karbi Anglong with 0.075°C per year or

**Table 5: Results of the statistical test for annual *T max***

| *Stations* | *Mann Whitney Test* | | | *Mann Kendall Test* | | *Simple Regression* | |
|---|---|---|---|---|---|---|---|
| | *Median (Pre-1985)* | *Median (Post 1985)* | *P value* | *S* | *Z* | *b* | *$R^2$* |
| **GHY** | 29.24 | 29.37 | 0.160 | 264 | 2.14** | 0.013** | 0. 135 |
| DIB | 27.88 | 28.08 | **0.017** | 277 | 2.25** | 0.009* | 0.114 |
| TEZ | 29.38 | 28.85 | **0.002** | -297 | -2.42** | -0.021*** | 0. 162 |
| LAK | 28.07 | 28.59 | **0.004** | 433 | 3.50*** | 0.023*** | 0. 339 |
| **JOR** | 29.21 | 29.38 | **0.027** | 124 | 2.19** | 0.023** | 0.206 |
| **SIL** | 29.08 | 30.36 | **0.000** | 565 | 4.58*** | 0.055*** | 0.472 |
| DHU | 29.50 | 29.24 | 0.787 | -4 | -0.051 | -0.023 | 0.262 |
| TAN | 28.08 | 28.13 | **0.014** | 207 | 3.53*** | 0.001* | 0.011 |
| KAN | 28.28 | 28.53 | **0.021** | 82 | 1.44 | 0.023** | 0.154 |

b: slope of linear regression (°C/year),S, Z: statistic of Mann Kendall test
***,**,* statistical significance at 99%, 95% and 90% confidence level

**Table 6: Results of statistical test for annual *T min***

| *Stations* | *Mann Whitney Test* | | | *Mann Kendall Test* | | *Simple Regression* | |
|---|---|---|---|---|---|---|---|
| | *Median (Pre-1985)* | *Median(Post 1985)* | *P value* | *S* | *Z* | *b* | *$R^2$* |
| **GHY** | 19.05 | 19.95 | **0.000** | 749 | **6.08*** ** | **0.028*** ** | 0.599 |
| DIB | 18.10 | 18.99 | **0.000** | 804 | **7.18*** ** | **0.037*** ** | 0.726 |
| TEZ | 17.28 | 19.53 | **0.000** | 585 | **4.74*** ** | **0.072*** ** | 0.592 |
| LAK | 18.23 | 18.43 | **0.030** | 310 | **2.50*** ** | **0.021*** ** | 0.224 |
| JOR | 18.79 | 19.27 | **0.019** | 111 | **1.970** ** | **0.029** ** | 0.115 |
| SIL | 19.99 | 20.47 | **0.004** | 320 | **2.63** ** | **0.016** ** | 0.103 |
| DHU | 18.59 | 18.64 | 0.502 | 12 | 0.188 | 0.002 | 0.004 |
| TAN | 17.77 | 18.38 | **0.011** | 130 | **2.19** ** | **0.027*** ** | 0.206 |
| KAN | 16.99 | 18.53 | **0.000** | 188 | **3.336*** ** | **0.075*** ** | 0.308 |

b: slope of linear regression (°C/year),S, Z: statistic of Mann Kendall test
***,**,* statistical significance at 99%, 95% and 90% confidence level.

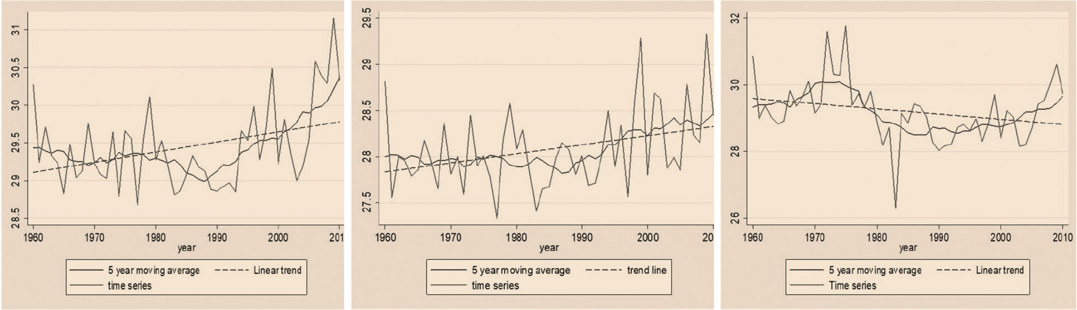
0.75°C per decade followed by Tezpur (0.072°C/year) and Dibrugarh (0.037°C/year). The results also depict that the significant increase in annual *T min* is more than annual *T max* and that the rate of increase is also more in most of the stations in Assam. The fluctuations in annual *T min* as shown by the **maximum values of** coefficient of variation (as discussed earlier in Table 3) was also found to be more than annual *T max*. A 5-year moving average is represented in Figure 5.

The annual *T min* is showing an increasing trend in all selected stations and it is statistically significant in 8 out of 9 stations under all tests (Table 6). The station wise residual plots have also shown some curve trends in the plots in annual *T min* (Figure 6) depicting a weak relationship between temperature and year especially in the stations Tezpur, North Lakhimpur, Silchar and Karbi Anglong. Earlier, Tezpur showed a significant decreasing trend in annual *T max* and now is showing a significant increase in annual *T min.*

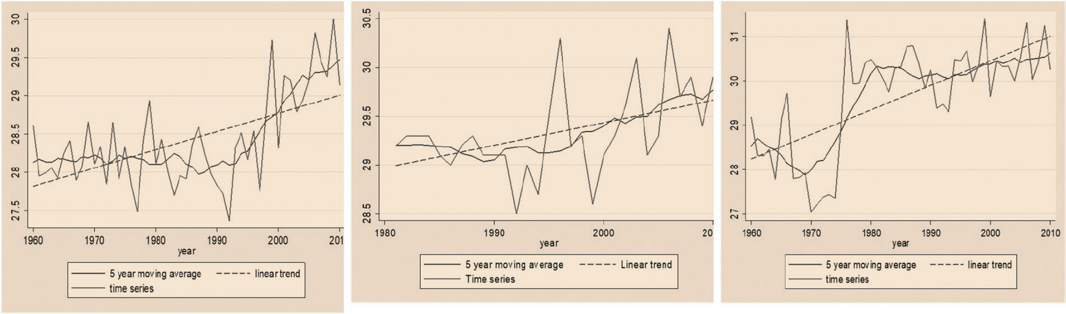
### Trends in Annual *Rainfall* Series

The annual average rainfall is showing both positive and negative trends in the last five decades in Assam (Table 7). But the results are not significant in any of the stations under all tests.

The 5-year moving average, trend line and time series also show no trend (Figure 7). However, the residual plots, as shown in Figure 8, show curved



Guwahati Dibrugarh Tezpur



Lakhimpur Jorhat Silchar

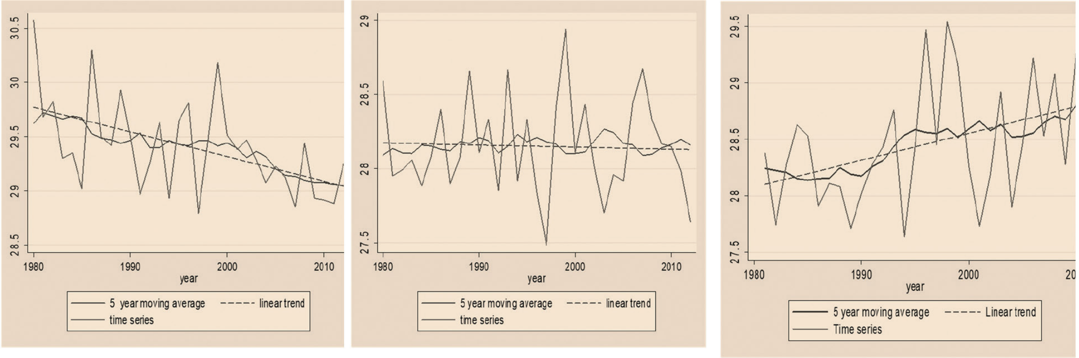


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**Figure 3: Observed 5 year moving average, trend line and time series graph for annual *T max*.**

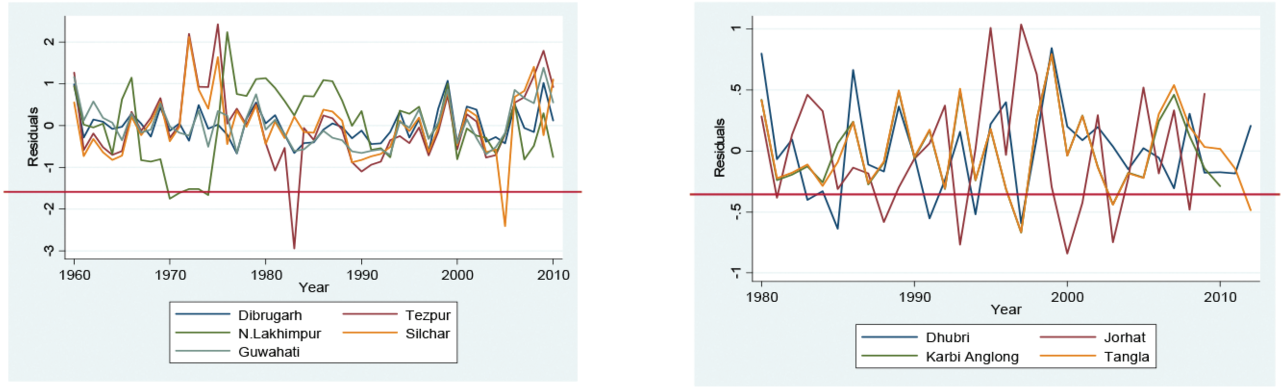
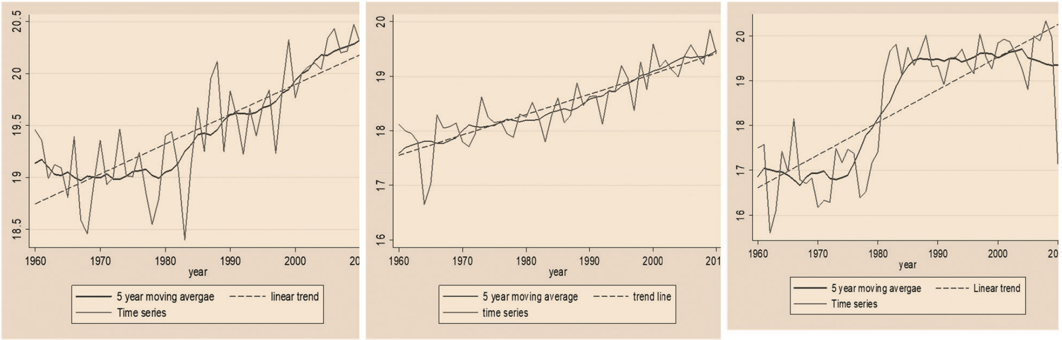
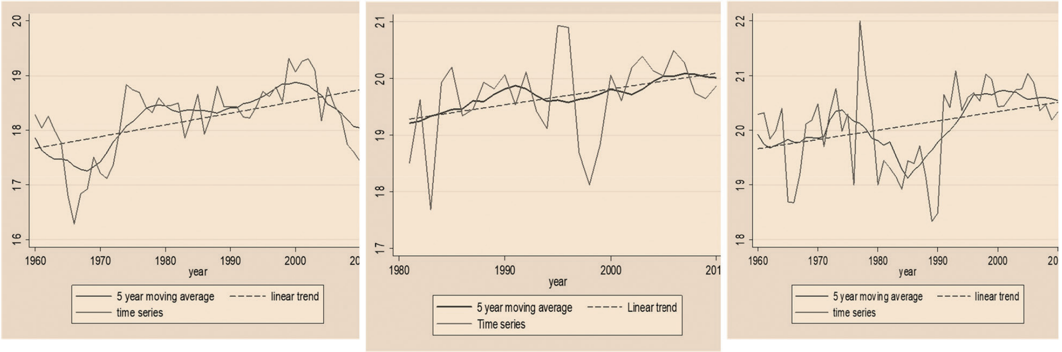


**Figure 4: Observed residual plots for the selected stations. (a) Dibrugarh, Tezpur, N.Lakhimpur, Silchar, Guwahati (1960-2010). (b) Dhubri, Jorhat, Karbi Anglong, Tangla (1980-2013).**



Guwahati Dibrugarh Tezpur



Lakhimpur Jorhat Silchar

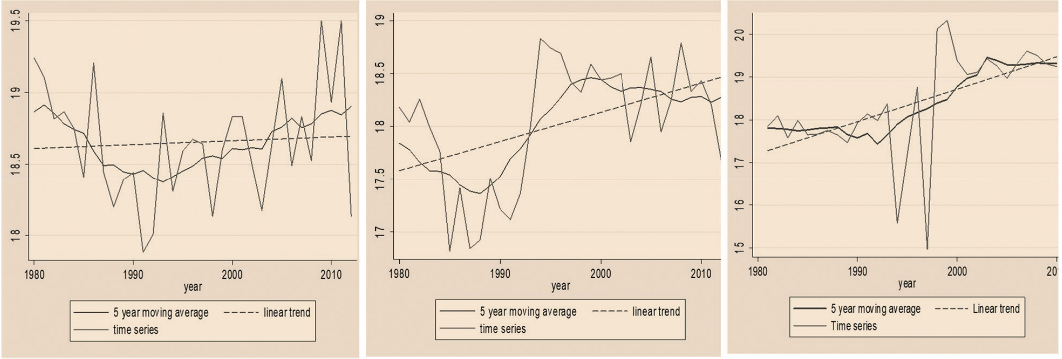


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**Figure 5: Observed 5-year moving average, trend line and time series graph for annual *T min*.**

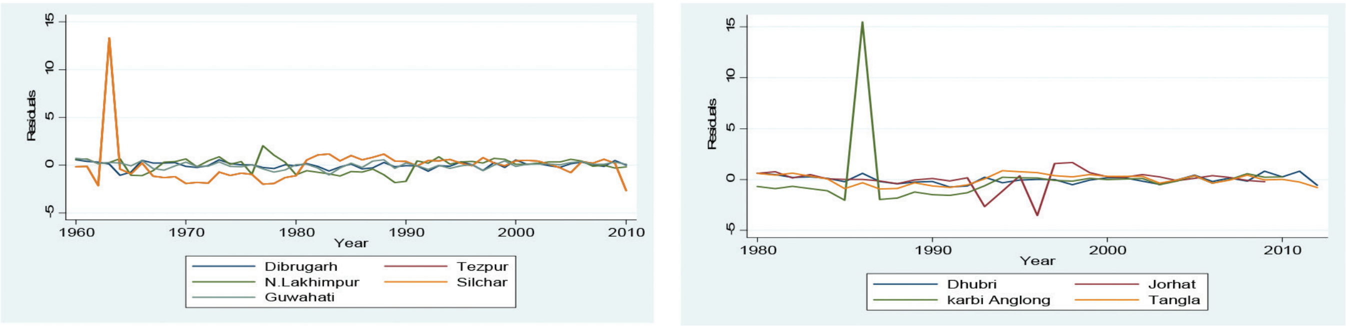
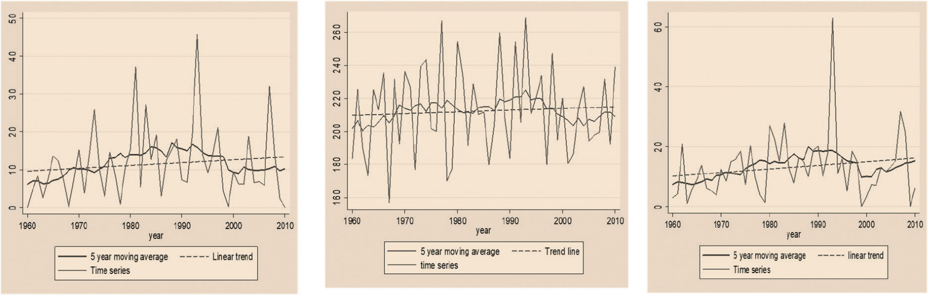


**Figure 6: Residual plots of selected stations for annual *T min*. (a) Dibrugarh, Tezpur, N. Lakhimpur, Silchar, Guwahati (1960-2010). (b) Dhubri, Jorhat, Karbi Anglong, Tangla (1980-2013).**

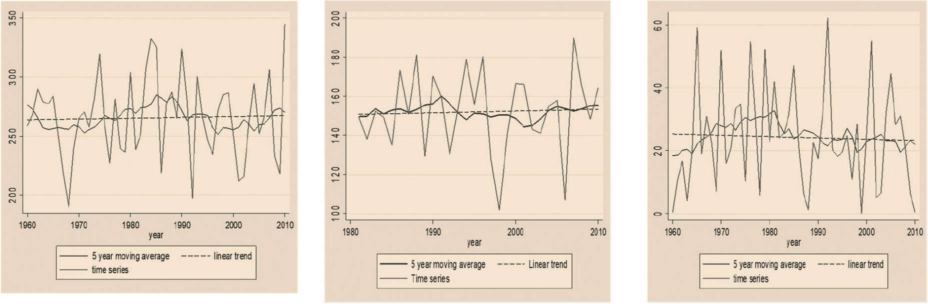
**Table 7: Results of statistical test for annual average rainfall**

| *Stations* | *Mann Whitney Test* | | | *Mann Kendall Test* | | *Simple Regression* | |
|---|---|---|---|---|---|---|---|
| | *Median (Pre-1985)* | *Median (Post 1985)* | *P value* | *S* | *Z* | *b* | $R^2$ |
| **GHY** | 136.26 | 147.12 | 0.155 | 113 | 0.917 | 0.153 | 0.011 |
| DIB | 212.39 | 208.72 | 0.920 | 55 | 0.446 | 0.105 | 0.003 |
| TEZ | 275.96 | 293.15 | 0.589 | 191 | 1.54 | 0.119 | 0.029 |
| LAK | 267.27 | 265.65 | 0.741 | 59 | 0.48 | 0.067 | 0.008 |
| JOR | 152.44 | 154.95 | 0.835 | 27 | 0.46 | 0.091 | 0.001 |
| SIL | 249.61 | 253.98 | 0.617 | -35 | -0.292 | -0.042 | 0.001 |
| DHU | 232.97 | 223.57 | 0.267 | -94 | -1.16 | -1.032 | 0.031 |
| TAN | 152.27 | 139.32 | 0.322 | 4 | 0.16 | 0.088 | 0.005 |
| KAN | 102.48 | 102.54 | 0.865 | -16 | -0.303 | -0.196 | 0.014 |

b: slope of linear regression (°C/year),S, Z: statistic of Mann Kendall test.
*,**,*** statistical significance at 90%, 95% and 99% confidence level.



Guwahati Dibrugarh Tezpur



Lakhimpur Jorhat Silchar

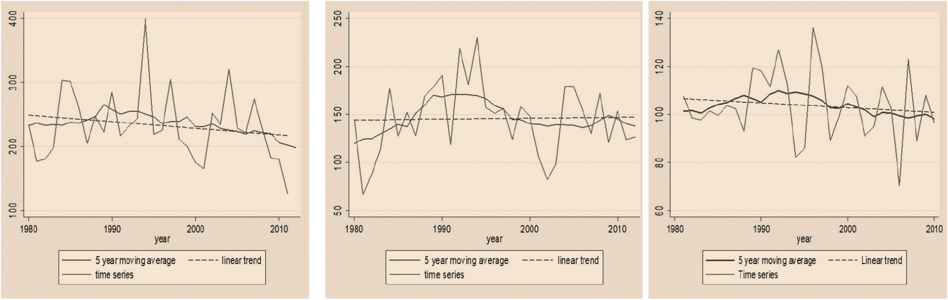


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**Figure 7: Observed 5 year moving average, trend line and time series graph for annual average rainfall for the stations.**

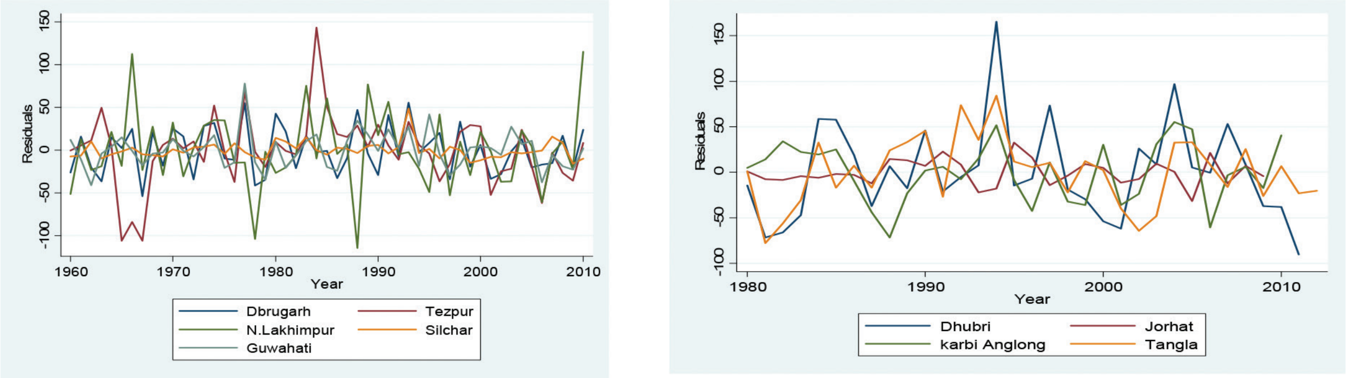

**Figure 8: Residual plots of stations for annual average rainfall. (a) Dibrugarh, Tezpur, N.Lakhimpur, Silchar, Guwahati (1960-2010). (b) Dhubri, Jorhat, Karbi Anglong, Tangla (1980-2013).**

trends signifying that there are differences between observed annual average rainfall and the value predicted by the regression lines. Therefore, the annual rainfall series and the time periods are not perfectly related in most of the stations. Earlier studies have also found no significant trend in rainfall in the North Eastern States (Guhathakuta et al., 2006; Rupa Kumar et al., 2003). De et al. (2015), however, found that the share of annual rainfall that occurred during peak monsoon months has been declining over the years. Despite this, the occurrence of floods has become erratic as heavy rainfall occurs within a few days during the monsoon. The condition even gets worse during the month of August in Assam when floods occur because of increased rainfall.

## Conclusion

The results revealed that all the nine selected stations in Assam have indeed experienced changes in both minimum and maximum temperatures over the last three to five decades. However, the changes are not equal for all the stations of Assam temporally. Trends in temperature show a much higher degree of statistically significant warming in minimum temperatures than maximum temperatures, reflecting a warming climate in Assam. Annual as well as minimum temperatures are rising more than the maximum temperature in Assam as depicted from magnitude as well as trend shown by different tests. In Assam, the annual maximum temperature trend is more or less stable with both positive and negative trends observed. In contrast to this, annual minimum temperatures are showing positive trends. Variability of rainfall is observed to be more than the temperature in Assam. Though the rainfall trend is not significant, the decreasing trend in most of the stations during the monsoon season is a cause of worry. Thus, we can conclude from the above observations that climate change is occurring in Assam with minimum temperature becoming warmer although it is not rising indefinitely. Moreover, though rainfall is not changing significantly, temperature changes can bring about variation in rainfall as well.

## Acknowledgement

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