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Research Paper

Long-term trend analysis of temperature in Meghalaya

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Abstract

In this paper, the trend in average (mean) temperature, maximum temperature, and minimum temperature are analyzed for five zones of Meghalaya using historical data from 1901 to 2002. A non-parametric, Mann-Kendall test is applied to check the significant trend and magnitude of trend is determined using Sen's slope estimator for monthly, annually, and on a seasonal basis. The annual mean, maximum and minimum temperature data showed a positive trend of 0.6 to 0.7 °C /100 years, 0.6 to 0.7 °C /100 years, and 0.4 to 0.7 °C /100 years respectively in all five zones. Also, on a seasonal basis, a positive trend is observed among the zones. A positive monthly trend is observed for all the months except for July and September a very small negative or no trend is observed. The result is due to the significant deforestation and urbanization over the last 100 years.

Keywords: Average temperature, Mann-Kendall test, Maximum Temperature, Minimum Temperature, Sen's Slope.

Introduction

Temperature is one of the most significant climate variables responsible for global warming. In the last few decades researcher on climate change has indicated an increase in greenhouse gas concentration thereby warming earth's atmosphere both locally and globally (Schneider et al., 1989). The latest estimates by IPCC (Intergovernmental Panel on Climate Change, Parry, et al.,

2007) reports the average surface temperature of earth has increased by 0.74°C from 1901 to 2005. While the IPCC AR5 (Fifth Assessment Report) concluded a global increase in average temperature by 0.72°C from 1951 to 2012 (IPCC, Field et al., 2014). Moreover, the net impact of climate change in India showed a net excess of temperature and a net deficit of rainfall (Mondal et al., 2015). All India mean annual temperature had shown a significant warming trend of 0.05 °C /10 years during the period 1901–2003 and the period 1971–2003 had shown relatively accelerated warming of 0.22°C /10 years, which is largely due to unprecedented warming during the last decade (Kothawale et al., 2005). Moreover, the trend analysis of temperature data from 1941-2012 for 125 ground-based weather stations across the country was found to follow a positive trend of 0.44 °C /100 years, 0.51 °C /100 years and 0.19 °C /100 years for average, maximum and minimum temperatures respectively (Ray et. al. 2019). Numerous studies have been performed on trend detection by various researchers across India (Kothawale et al., 2010; Rao et al., 2005).

The bio-diverse mountain ecosystem of the North-Eastern Region (NER) has a humid subtropical climate with hot, humid summers, severe monsoons, and mild winters (Das et al., 2009; Jain et al., 2013). Studies on long-term analysis of temperature data 1871–2008 for NER had shown a rising trend for all the four temperature variables (maximum, minimum, and mean temperatures and temperature range) and the post-monsoon season, the increase rate was 0.019, 0.011, and 0.015 °C/year for the maximum, minimum, and mean temperature, respectively (Jain et al., 2013). Lots of studies on Climate Change detection has been done by various researchers from different institutions all over the world. But on the regional level, very little studies have been done for the state of Meghalaya.

The state of Meghalaya nested at the North-Eastern corner of India, is a unique region in many aspects. An important is its climate, boasting one of the highest rainfalls in the world (Jennings, 1950). The average temperature trend showed an increase of 0.031 °C/year in the period from 1981-2012, which indicates the warming of the region (Meghalaya Climate Change Centre, 2017). A very detailed study is thus required at the regional level of the very diverse state. This paper aims to study a detailed long-term trend of temperature over a century for Meghalaya.

Study Area

The study area includes 5 zones of Meghalaya viz East-Khasi Hills (EKH), West-Khasi Hills (WKH), Jaintia Hills (JH), East-Garo Hills (EGH) and West-Garo Hills (WGH). Since partitioned from Assam in the year 1972 the hilly terrain of Meghalaya has been parted into three mainlands comprising of Khasi Hills, Jaintia Hills and Garo Hills. The zones were divided following these three mainlands. Each zone has unique geographical and climatic conditions.

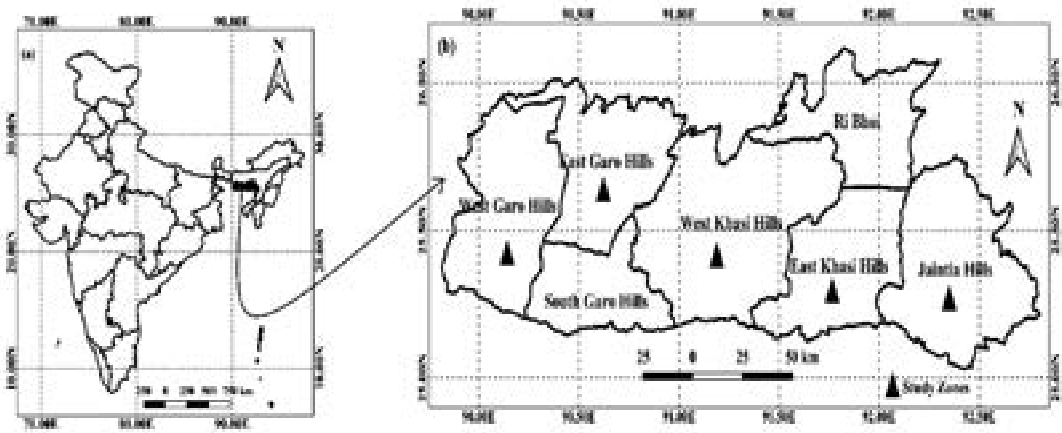

Fig. 1. Location of the study area [(a) India, (b) Meghalaya]

Data and Methodology

Data Used

The monthly data of average, maximum, and minimum temperature of all the five zones for 102 years (1901-2002) were obtained from the Indian Meteorological website Indiawaterportal (Met Data, indiawaterportal). There was no missing record in the data set. Basically, the dataset consists of interpolated (on a 0.5 degree latitude-longitude grid) global monthly temperature, data, from 1901 to 2002 which is known as Climate Research Unit Time-Series 2.1 (CRU TS 2.1) and is publicly available (Mitchell and Jones, 2005). The annual and seasonal values of all three temperature parameters have been estimated using the arithmetic mean method. Season wise the country is divided into four major seasons by Indian Meteorological Department (Met Glossary – IMD, Pune). Winter season includes the months of January and February. Pre-Monsoon season consists of March, April, and May. The Monsoon season is being from June to September, which is also known as JJAS Monsoon. And the Post-Monsoon includes the rest of the months: October, November, and December.

In a time series of meteorological data, the trend in the variables i.e. their rise or fall with time can be determined using regression analysis (for parametric time series) and using Sen's slope estimator method (for non-parametric time series) (Sen, 1968). Regression analysis gives a linear trend of the form y = mx + c, where slope (m) is the magnitude of a trend. On the other hand, Sen's slope estimator method which also gives a linear trend is a robust method to determine the slope in time series of hydro-meteorological data (Yue et al., 2003).

Sen's Slope Estimator

At first, the slope of n data pairs is calculated as follows (Sen, 1968):

$$d_k = \frac{x_j - x_i}{j - i} \qquad \text{For } k = 1, 2, 3\ldots\ldots, n, \qquad (1)$$

Where X_i and X_j are the data values at the corresponding times i and j ($1 \leq i < j \leq n$) respectively. Then the median of all those d_k value gives the Sen's Slope which is calculated as,

$$ß = \begin{cases} d\frac{n = 1}{2} & n \text{ is odd} \\ \frac{1}{2}\left(d\frac{n}{2} + d\frac{n+2}{2}\right) & n \text{ is even} \end{cases} \qquad (2)$$

Thus a positive value of β indicates an upward (increasing) trend and a negative value of β indicates a downward (decreasing) trend.

Mann-Kendall trend test

Whether the trend in a time series is statistically significant or not that can be determined using a non-parametric Mann-Kendall (MK) test. This is one of the robust methods to ascertain the presence of statistical significance in climate variables. The MK test is based on the Statistics, which is defined as (Kendall 1975; Mann 1945),

$$S = \sum_{k=1}^{n-1} \sum_{j=k=1}^{n} sgn\,(X_j - X_k) \qquad (3)$$

With

$$sgn(x) = \begin{cases} 1 & \text{if } x > 0 \\ 0 & \text{if } x = 0 \\ -1 & \text{if } x < 0 \end{cases} \qquad (4)$$

Where X_j and X_k represents sequential data values at times j and k respectively. For higher n (≥ 10), the S statistics assumes a normal distribution with mean as zero and variance computed as follows (Partal and Kahya, 2006):

$$a^2 = \{n(n - 1)\,(2n + 5) - \sum_{j=1}^{p} t_j\,(t_j - 1)\,(2t_j + 5)\} \,/\, 18 \qquad (5)$$

Where, p is the number of the tied groups in the data set and t_j is the number of data points in the j^{th} tied group. Then the normalized test statistics Z is computed as follows:

$$Z = \begin{cases} \frac{S - 1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S + 1}{\sigma} & \text{if } S < 0 \end{cases} \qquad (6)$$

The null hypothesis (no trend) is rejected if $|Z| > Z_{\alpha/2}$ (i.e. Z>1.96) at a significance level of α (95%). In our study we have rejected the null hypothesis if Z value is found to be greater than 95% significance level.

Results

Average Temperature

The result of the trend analysis of average temperature showed all the possible three trends. Magnitude of Sen's Slope for average temperature for the five zones are shown in table 1. The result showed a positive trend ranging from 0.2 to 1.4 °C /100 years for all the months except for July and September month. Both the months showed a slight negative trend of 0.1 °C /100 years or no trend. On a seasonal and annual basis, the trend is positive of 0.2 to 0.9°C /100 years.

However, a significant positive trend is observed for February, March, June, November, and December. Over the hundred years, the average temperature of all the zones for February and March had changed up to 1.2 to 1.4°C and 0.8 to 1.0°C. This is attributed due to the effect of urbanization, forest fire, less rainfall, and most importantly higher exposure of solar radiation during these months. Moreover, the month of November and December also showed a significant positive trend ranging from 0.6 to 1.0 °C/100 years and 0.8 to 1.2 °C/100 years. No significant trend was observed for seasonal and annual analysis except for some seasons of few zones. Only for the winter season, East Garo Hills showed a significant positive trend of 0.8 °C /100 years and for the post-monsoon season, only East Garo Hills and West Khasi Hills showed a significant positive trend of 0.9 °C /100 years and 0.7 °C /100 year.

Table 1. Magnitude of Sen's Slope (per 100 years) for Average Temperature of five zones of Meghalaya (1901-2002).

Time	EKH	WKH	JH	EGH	WGH
Jan	0.4	0.4	0.3	**0.6***	0.5
Feb	**1.2***	**1.2***	**1.2***	**1.4***	**1.4***
Mar	**1.0***	**1.0***	**0.8***	**1.1***	**0.9***
Apr	0.7	0.6	**0.9***	0.7	0.7
May	0.2	0.1	0.3	0.4	0.2
Jun	**0.6***	**0.6***	**0.7***	**0.6***	**0.5***
Jul	-0.1	-0.1	0.0	0.0	0.0
Aug	0.2	0.2	0.3	0.3	**0.3***
Sep	-0.1	-0.1	-0.1	0.0	-0.1
Oct	0.4	0.4	**0.4***	**0.4***	**0.5***
Nov	**0.6***	**0.7***	**0.7***	**0.9***	**1.0***
Dec	**0.8***	**0.9***	0.8	**1.1***	**1.2***
Annual	0.6	0.6	0.6	0.7	0.6
Winter	0.6	0.6	0.5	**0.8***	0.7
Pre-Monsoon	0.6	0.6	0.7	0.8	0.6
Monsoon	0.2	0.2	0.3	0.3	0.3
Post-Monsoon	0.7	**0.7***	0.6	**0.9***	**0.9***

*value is statistically significant at the level of 95%. + Sign indicates increasing trend whereas – sign indicates decreasing trend.

Maximum Temperature

The maximum temperature also showed almost the same variation as shown by average temperature. The magnitude of the trend is represented in table 2. All of the zones showed a positive trend annually, seasonally, and all the months throughout the year except for the month of May in case of WKH and WGH; and July and September for all five zones. From the analysis, it is found that the variation range of positive trend is like 0.1-1.4 °C /100 years among the zones for monthly, annually, and seasonally. Only May (for WKH and WGH only), July, and September are the 3 months which showed a negative trend of 0.1 °C/100 years or no trend.

Table 2. Magnitude of Sen's Slope (per 100 years) for Maximum Temperature of five zones of Meghalaya (1901-2002).

Time	EKH	WKH	JH	EGH	WGH
Jan	0.2	0.2	0.2	0.5	0.4
Feb	**1.2***	**1.2***	**1.1***	**1.4***	**1.3***
Mar	**1.0***	**0.9***	0.8	**0.9***	0.8
Apr	0.8	0.6	0.9	0.7	0.6
May	0.1	-0.1	0.2	0.2	0
Jun	**0.7***	**0.7***	**0.7***	**0.7***	**0.6***
Jul	-0.1	-0.2	0	-0.1	-0.1
Aug	0.4	0.3	**0.5***	**0.4***	**0.4***
Sep	0	-0.1	0	0	-0.1
Oct	**0.6***	**0.5***	**0.6***	**0.5***	**0.6***
Nov	**0.7***	**0.8***	**0.7***	**1.0***	**1.0***
Dec	**0.7***	**0.8***	0.7	**1.0***	**1.0***
Annual	0.7	0.6	0.7	0.7	0.6
Winter	0.4	0.4	0.3	0.6	0.5
Pre-Monsoon	0.7	0.6	0.7	0.8	0.6
Monsoon	0.2	0.1	0.4	0.1	0.2
Post-Monsoon	**0.7***	**0.7***	**0.7***	**0.9***	**0.9***

*value is statistically significant at the level of 95%. + Sign indicates increasing trend whereas – sign indicates decreasing trend.

However, the significant positive trend was observed only for the months of February, June, October, and November for all five zones; March for EKH, WKH, EGH zones; August for JH, EGH, WGH zones; December for all five zones except JH. The change in maximum temperature was highest for the month of February with a variation of 1.1 °C /100 years to 1.4 °C /100 years among the zones. Over the past century, February month showed a drastic change which is basically due to a long duration of sunshine hours. An annual significant trend is not observed for any of the zones. On a seasonal basis, only the Post-Monsoon season showed a significant positive trend for all the zones. EKH, WKH, and JH zones recorded 0.7 °C and EGH, WGH zones recorded a 0.9 °C increase in maximum temperature over the hundred years.

Minimum Temperature

In the case of minimum temperature the results of the MK test are also very similar to those of average and maximum temperature. All of the three possible trends are observed from the analysis. Only July and September were the months which showed a slight negative trend or no trend for all the zones. Except for these two months, the analysis indicated an increase of minimum temperature highest up to 1.6 °C/100 years for monthly, 0.7 °C/100 years for annually and 0.9 °C/100 years for seasonally in the various zones.

But the statistically significant positive trend is observed only for February and March for all the zones; months of January and November for EGH and WGH respectively; the month of April for JH; months of May and June for EGH, the month of December for WKH, EGH, and WGH respectively. Only February is the month where the magnitude of 102 years MK statistics has the highest change in minimum temperatures like 1.6, 1.5, 1.4, 1.4, and 1.3 °C/100 years for EGH, WGH, EKH, WKH, and JH respectively. There was no significant positive trend for either annual or seasonal minimum temperature except the winter season of EGH showed a significant increase of 0.9 °C/100 years. The trend magnitudes for all five zones are shown in table 3.

Table 3. Magnitude of Sen's Slope (per 100 years) for Minimum Temperature of five zones of Meghalaya (1901-2002).

Time	EKH	WKH	JH	EGH	WGH
Jan	0.4	0.5	0.3	**0.8***	**0.6***
Feb	**1.4***	**1.4***	**1.3***	**1.6***	**1.5***
Mar	**1.1***	**1.1***	**1.0***	**1.2***	**1.2***
Apr	0.7	0.6	**0.8***	0.7	0.7
May	0.3	0.2	0.4	**0.6***	0.4
Jun	0.6	0.5	0.6	**0.6***	0.6
Jul	-0.2	-0.2	-0.1	0	0
Aug	0	0	0.1	0.2	0.2
Sep	-0.2	-0.2	-0.3	-0.1	-0.1
Oct	0.2	0.3	0.2	0.3	0.4
Nov	0.4	0.4	0.5	**0.7***	**0.8***
Dec	0.8	**0.9***	0.8	**1.1***	**1.2***
Annual	0.4	0.5	0.5	0.7	0.6
Winter	0.6	0.7	0.6	**0.9***	0.8
Pre-Monsoon	0.6	0.6	0.7	0.8	0.7
Monsoon	0.1	0.2	0.2	0.3	0.3
Post-Monsoon	0.5	0.5	0.5	0.7	0.8

*value is statistically significant at the level of 95%. + Sign indicates increasing trend whereas – sign indicates decreasing trend.

Discussion

Depending upon various geographical features like latitude, longitude, and location, surface temperature varies seasonally and annually. The rise in temperature mostly affects the hydrological cycle leading to rapid evaporation and evapotranspiration (Chattopadhyay et al., 1997; Dai et al., 2018). The 102 years of trend analysis showed an increase in all the three-temperature variable viz, average, maximum, and minimum temperatures for both annual and seasonal data in all of the 5 zones selected for this study. It is observed that February and March were the only months where the change of temperature was highest (@ up to 1.6 °C/100 years) in all the temperature variables for all five zones. One of the significant cause behind this may be due to long duration of sunshine hours as weather station at Umiam (25° 41' N latitude, 91° 55' E longitude) showed the longest duration of sunshine hours (@ 7.37±0.84 hrs/day) in the period 1983-2010 among all the months(Choudhury et al. 2012). Moreover during July to September dominance of overcast sky condition, least sunshine hours, and intense rainfall can stabilize the air temperature. These factors can be attributed to the negative trend or no trend for July to September as seen in table 1-3. That is why the Monsoon of Meghalaya had also shown a slight insignificant positive trend. Again the rainfall frequency starts decreasing from October to December and so sunshine hours rises (Choudhury et al. 2012). Hence the post-monsoon season witnessed a significant rising trend up to 0.9 °C/100 years in maximum temperature for all zones. The change in all the temperature variables is highest in both East and West Garo Hills zones as compared to other zones. This can affect Garo Hills resulting in severe heat waves.

The increase in air temperature can affect relative humidity and evaporation leading to severe drought situations which may affect the crop water demand (Suryavanshi et al., 2014). Increase rate of temperature intensifies wild forest fire which leads to defenestration and life-threatening for wild animals. A recent study on deforestation in Meghalaya suggests that more than 50% of forest area in the state has experienced a negative change in greenness during the period 2000-2016 (Meghalaya Climate Change Centre, 2019). Moreover, changes in climatic conditions may affect both human and animal heaths. An increase in air temperature makes favorable conditions for harmful pathogens to survive in the environment which can cause diseases like Malaria, Dengue, etc. (Bhattacharya et al. 2006). Hence the adverse effect of global warming and climate change has impacted the state regionally.

Conclusion

Overall, the Mann-Kendall trend analysis of three temperature variables in Meghalaya from 1901 to 2002 showed an increased rate of temperature throughout the years except for July and September months only. This analysis revealed that though Monsoon of Meghalaya was not affected by the warming of the globe, the increasing rate of temperature for the rest of the seasons indicates that this part of the globe is also under threat to climate change.

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