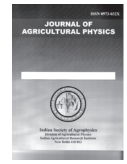
Vol. 12, No. 1, pp. 12-22 (2012)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in



Research Article

Trend Analysis of Long Term Weather Variables in Mid Altitude Meghalaya, North-East India

B.U. CHOUDHURY*, ANUP DAS, S.V. NGACHAN, A. SLONG, L.J. BORDOLOI AND P. CHOWDHURY

ICAR Research Complex for NEH Region, Umiam - 793 103, Meghalaya

ABSTRACT

Northeastern Hill Region (NHR) of India, by virtue of its strategic setting in the frail landscape of Eastern Himalaya falls in the most vulnerable zones of abrupt climate change. Despite this, little attention has been given to understand climate change impact implications. In the present study, long time (1983-2010) weather variables have been analyzed to detect trend changes using non-parametric Mann Kendall test in mid altitude of Meghalaya (Umiam: $25^{0} 41^{/}$ N latitude, $91^{0} 55^{/}$ E longitude, 1010m msl). Results revealed that total annual rainfall trend increased non-significantly at the rate of 3.72mm year^{-1}. Contribution of monsoon months (JJAS) declined marginally at the rate of 1.70 mm while pre - (MAM) and post- monsoon (ONDJF) months increased non-significantly at an annual rate of 3.18 mm and 1.16 mm, respectively. Probability analysis showed a high frequency of anomalies (p>0.6) of either deficit or excess in occurrence of normal monsoon rainfall. Number of rainy days and extreme rainfall events (RX1 day maximum>100mm) exhibited a non-significant increasing trend @ 1.7 days and 1.9 days per decade, respectively. Maximum temperature reflected a linear, significant rising trend (+ 0.086^{0}C year^{-1}) while minimum temperature enumerated a non-significant decreasing trend (-0.011^{0}C year^{-1}). Mean temperature also manifested a significant rising trend at an annual rate of 0.031^{0}C while annual evaporation loss significantly decreased (@ 5.75 mm year^{-1}). Correlation studies affirmed that atmospheric evaporative demand was relatively more sensitive to changes in sunshine duration(r=+0.63) followed by wind speed (r=+0.41) and vapour pressure deficit (r= 0.11). Climatic water balance studies (rainfall and PET) reflected an increasing trend of water surplus during May to July (Z: +0.08 to 1.56) whereas a reverse trend (declining, Z: -0.56 to -0.87) was observed during post monsoon months (December to February).

Key words: Northeastern hill region, Climate change, Weather variables, Trend analysis, Mann Kendall Test

In the past several decades, phenomenon of climate change has drawn wide attention across the world from all possible angles: from preservation of biodiversity, food security to environmental sustainability. However, the need for recognizing abrupt climate change and its far reaching adverse consequences on food security and livelihood of millions has been realized recently in India. This fact has also been authenticated adequately by generous scientific affirmation, mostly based on long term changes in precipitation and temperature trends (Aggarwal *et.al*, 2004; Mall *et al*., 2006; Rupa Kumar *et al*., 2006; Joshi and Rajeevan, 2006 and Samui and Kamble, 2009). As a result, reasonable amount of valuable information regarding climate change implications based on past and present scenarios,

*Corresponding author,
Email: burhan3i@yahoo.com

projections of possible changes in future climate scenario etc. has been generated for mainland as well as coastal areas of India.

Some of the most significant findings across India are the warming trend due to increase in temperature by 0.68 ^{0}C per century, non significant trend in rainfall on all-India basis, but decreasing/increasing trends at some locations, increase in extreme rainfall events in North-West during summer monsoon, lower number of rainy days along east coast over the last few decades and so on (Aggarwal *et.al.*, 2004; Mall *et al.*, 2006; Joshi and Rajeevan, 2006; Rupa Kumar *et al.*, 2006; Samui and Kamble, 2009).

Since rainfed agriculture dominates the food grain production chain of North-Eastern Hill Region; any abrupt change in climate variables, particularly rainfall patterns poses a serious threat to food and environmental security of the entire region. Aside few sporadic findings about climate change and its possible impacts in NEH region mostly based on only rainfall and to a lesser extent temperatures (Pant and Rupa Kumar, 1997; Mirza *et al.*, 1998; Das and Goswami, 2003; Das, 2004; Hussain *et al.*, 2009), the region is less explored and very little is known, making the future climate change scenarios more uncertain for devising any conclusive mitigation and adaptation measures. Non-availability of authentic and homogenous long time baseline data on weather variables at temporal and spatial scale is another bottleneck in assessing real time climate change implications. Lack of information on the implications of other potential climate change variables (e.g. atmospheric evaporative demand, sunshine duration, wind speed, water vapours etc.) has further compounded the problem of impact assessment. Knowledge of the duration of sunshine of any location is vital since it directly influences mass and energy balances, macro and micro-climates, biomass production and thus, radiation sensitive climate variables like atmospheric evaporative demand, temperature, rainfall etc. are very crucial. Similarly, water vapor is by far the largest and the most significant of the greenhouse gases which modifies energy budget of the earth and its atmospheric circulation, flooding and drought events (Elliott, 1994). Therefore, in detection and ascription studies of climate change repercussion, emphasis to relative humidity, sunshine duration, and atmospheric evaporative demand, apart from temperature and precipitation can help in portraying any conclusive findings. In this study, we have used long time scale data (1983-2010) of weather variables including sunshine duration, relative humidity and atmospheric evaporative demand to characterize the trend of climate sensitive weather variables at Umiam, NEH region of India. The outcome of this local observation would help in ascertaining the fact of climate change incidence if any at NE region and can thus, help in future projection studies, regional level planning and in devising location specific mitigation and adaptation strategies.

Material and Methods

Weather Data Used

The study area selected was Umiam (25^0 41$^/$ N latitude, 91^0 55$^/$ E longitude), Meghalaya located in the North-Eastern Hill Regions of India, representing mid altitude (1010 m msl) agro-climatic zone of mixed Subtropical hill and falls in AES-III zone. For trend analysis of climatic variables, daily weather data of 26-28 years for rainfall, maximum and minimum temperature, pan evaporation, wind speed, sunshine hours etc. were collected from meteorological observatory of I.C.A.R Research Complex for NEH Region, Umiam.

Meteorological Observations

To study intra-annual variations of different climatic variables at Umiam, the year was divided into three different seasons: pre-monsoon (March to May), monsoon (June to September) and post - monsoon (October to February) months. Inter annual and seasonal rainfall variations, anomaly from long period average (LPA) and number of rainy days (>2.5 mm per day) were also worked out. Extreme events for rainfall were considered when rainfall in a single day (24 hours) exceeds 100 mm (RX1day>100mm). The threshold level was considered as 100 mm, since 70-75mm single day rain is very common in North-Eastern Region of India (Joshi and Rajeevan, 2006). South-West monsoon rainfall was classified as deficient when the actual rainfall was less than LPA-CV, normal when actual rainfall was within LPA ± CV and excess when actual rainfall was more than LPA+CV of the corresponding year (Anonymous, 2009). Meteorological drought years were considered based on number of consecutive weeks (CW) in a year with rainfall less than the water requirements of rice crop during various growth stages i.e. 55 mm. The degree of severity was assessed in terms of low (2CWs), moderate (3CWs), severe (4CWs) and very severe (>4CWs) starting from 1983 to 2010 (Anonymous, 2009_a).

Besides annual maximum, minimum and average surface temperature trend analysis, long term changes in summer (April to October) and winter (November to March) seasons were also studied. Climatic water balance (monthly basis from 28 years average) was estimated based on balance between long term monthly average potential evapotranspiration (PET) and rainfall. Potential evapotranspiration (PET) was estimated based on Class A Pan method (Dorrenbos and Pruitt, 1977).

Trend Analysis of Long Time Weather Parameters

Trend analysis (increase or decrease) of all the independent weather parameters (*e.g.* annual and seasonal rainfalls, temperature, relative humidity, evaporation, wind speed, sunshine etc.) were statistically examined in two phases. Firstly, using the non parametric Mann-Kendall test, the presence of a monotonic increasing or decreasing trend was tested based on normalized test statistics (Z) value. The trend is said to be *decreasing* if Z is negative and *increasing* if the Z is positive. To test the level of significance (at 1, 5 and 10%), probability density function (pdf) was computed and if computed pdf is greater than the level of significance, the trend is said to be significant. In the second phase, the rate of increase or decrease in annual trend was estimated with the nonparametric Sen's slope estimator. The slope of the trend gave the annual rate and direction of change (Kendall, 1995; Helsel and Hirsch, 2002 and Salmi *et.al.*, 2002). Correlation coefficients of the meteorological variables and time were also computed to determine the strength of the linear relationship between the variables.

RESULTS AND DISCUSSION

Annual Rainfall Distribution Pattern

Long period average (LPA: 1983-2010) rainfall data revealed that Umiam receives an annual rainfall of 2410.4 mm (± 373.4), with a considerable variation (CV=15.5%) in total amount from as low as 1808.2 mm during 1998 (driest year) to as high as 3322.6 mm in 1988 (wettest year so far) (Table 1). Deviation analysis between LPA and total amount of rainfall received in every individual year reflected wide departure (+38.4% in 1988 to -24.7% in 1998) even in annual rainfall received at Umiam. Seventeen of the last twenty eight years received non-consecutively either higher (11-38%) or lesser (10- 25%) amount of annual rainfall

Table 1. Trend analysis of long period rainfall distribution and number of rainy days at Umiam (1983-2010)

Rainfall, mm	Total annual	Pre monsoon (MAM)	Monsoon (JJAS)	Post monsoon (ONDJF)	Rainy days
Min	1808.2	287.3	997.0	5.0	90.0
Max	3322.6	802.1	2062.0	702.1	146.0
Mean	2410.4	477.2	1546.7	386.6	128.3
Std	373.4	131.0	288.5	146.6	11.7
CV (%)	15.5	27.5	18.7	37.9	9.1
Z	+0.34	+1.01	-0.14	+0.41	+0.48
Sen's slope	3.72	3.18	-1.70	1.16	0.17

compared to LPA of 2410.1 mm (Figs.1 and 3) which is seldom experienced in other parts of the country (Samui and Kamble, 2009). Mann-Kendall test affirmed non-linear (r = +0.04), non-significant, annual increasing trend of total rainfall (Z value = +0.35) at the rate 3.72 mm/ year (Table 1). The trend was somewhat in consonance with the findings of Das and Goswami (2003) who reported absence of any significant trend in annual rainfall occurrence over Northeastern region of India. However, in other parts of India (West Coast and Central India), an increasing trend in annual rainfall has been observed (Rupa Kumar *et al*., 2006).

Seasonal Rainfall Distribution Pattern

Monsoon months (JJAS) contributed 64.2% of the total annual rainfall, although, it varied widely (CV=18.7%) from 50.35 (in 1990) to 77.4% (in 1984) (Fig 1). Contribution of pre-monsoon months (MAM) also varied widely (CV=27.5%) from 13% (in 1992) to 34.7% (in1990) with an average of 20% to the total annual rainfall. Post-monsoon months (ONDJF) play most significant role in crop intensification, particularly in rainfed agriculture of NE India. As anticipated, among the three seasons, the contribution of post-monsoon months to annual rainfall at Umiam was the lowest (15.9%), most erratic (CV=37.8%) and uncertain in behaviour (ranged from 0.2% in 2009 -26.8% in 1986) (Fig.1). As a consequence, Umiam frequently suffers from moisture scarcity during post-monsoon months and thus, cropping intensity hardly exceeds 114%.

Trend analysis showed non-significant, non-linear (r =-0.019) decreasing trend of monsoon months contribution (Z= -0.14) with an annual declining rate of 1.70 mm as against the reported annual declining rate of 1.10 mm for whole NE region (Mirza *et al*., 1998; Das, 2004). Decline in number of rainy days (JJAS: Z=-0.73) at an annual rate of 0.14 days might be partially responsible for this decreasing trend in monsoon rainfall. However, pre-monsoon months (MAM: Z=+1.01) contribution increased non-significantly at the rate of 3.18 mm annually. Contribution of post-monsoon months also enumerated a non-significant increasing trend (ONDJF: Z=+0.43) at the rate of 1.16 mm annually (Sen's positive slope) (Table 1). Increase in number of annual rainy days might have increased the contribution of pre-and post-monsoon months.

Rainfall Distribution and Meteorological Drought during South-West Monsoon Months

Categorization of South-West monsoon rainfall (JJAS) based on long period average (LPA) and coefficient of variation (CV) of the corresponding monsoon season at Umiam revealed that 11 out of 28 years received normal (within LPA ± CV), 9 years received excess (9-33% higher than LPA) and 8 years received

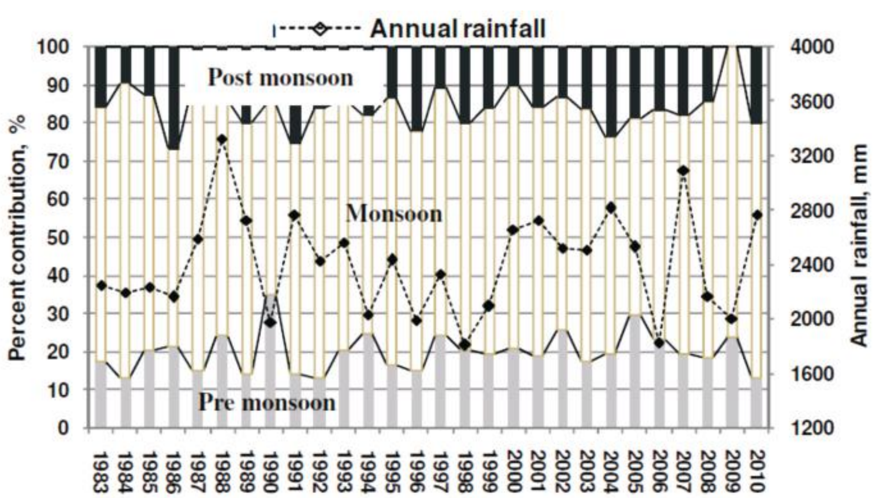


Fig. 1. Temporal variation in annual and seasonal rainfall distribution pattern at Umiam, Meghalaya

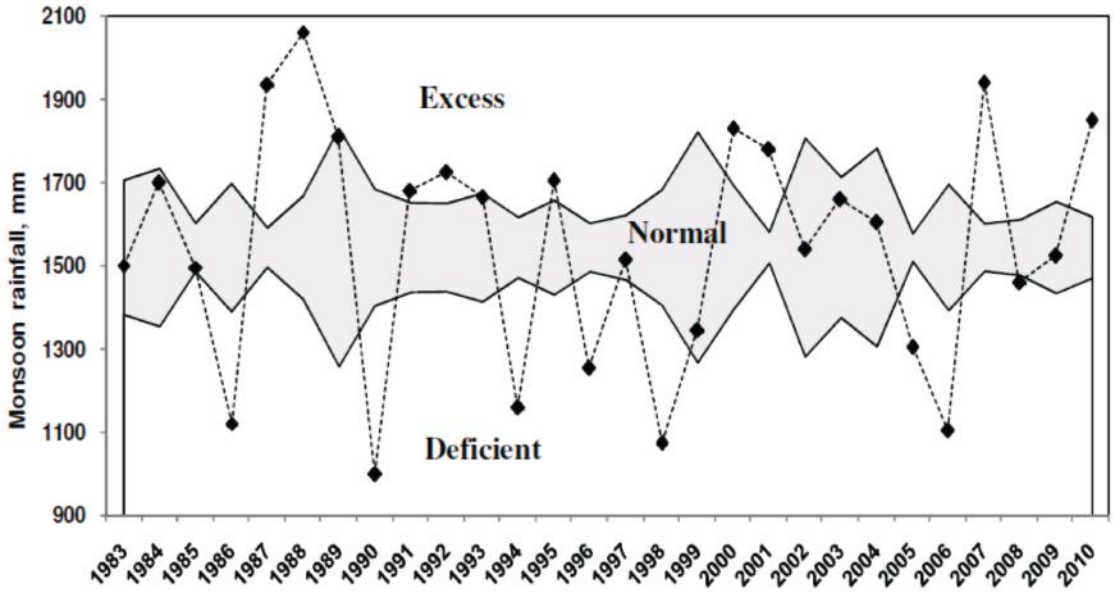


Fig. 2. Categorization of southwest monsoon as deficient, normal and sufficient at Umiam, Meghalaya

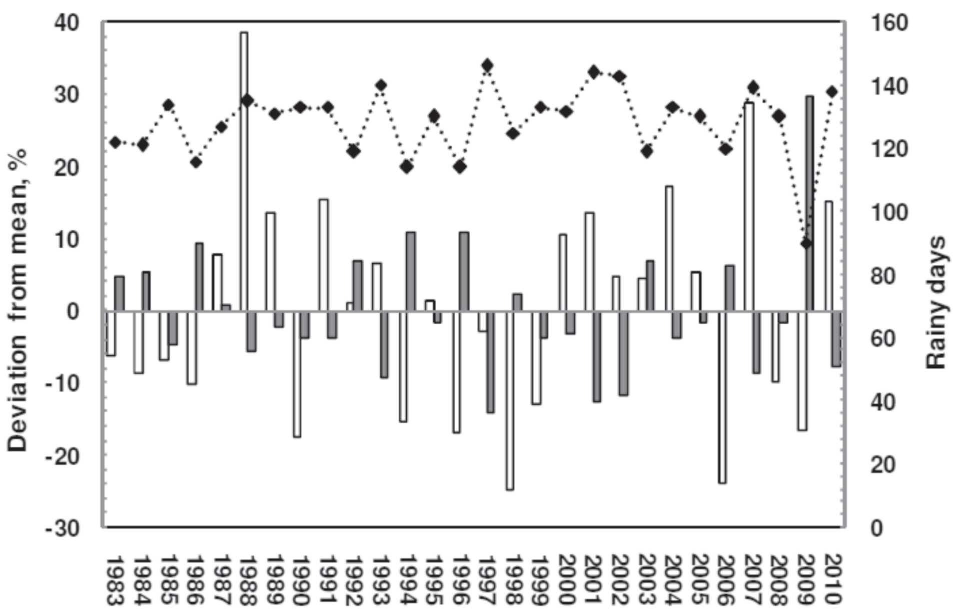


Fig. 3. Long period anomalies of annual rainfall, rainy days and total annual rainy days at Umiam, Meghalaya

deficient (6-36% less than LPA) monsoon season rainfall (Fig.2). This shows a higher probability (*p>0.6)* of occurrence of either deficit (<LPA ± CV) or excess monsoon season rainfall (>LPA ± CV) compared to the occurrence of normal rainfall at Umiam. Therefore, the stability in probability of occurrence of normal monsoon season rainfall stands to be less than 40% frequency.

Similarly, uneven distribution pattern of rainfall even within the four monsoon months (JJAS) were predominant. Early (June) and later (September) parts of monsoon months received relatively lesser amount of rainfall and as a result, Umiam experienced often meteorological drought (based on weekly rice water requirement: 55mm). In last 28 years, Umiam experienced 26 times different degrees (low to very severe) of

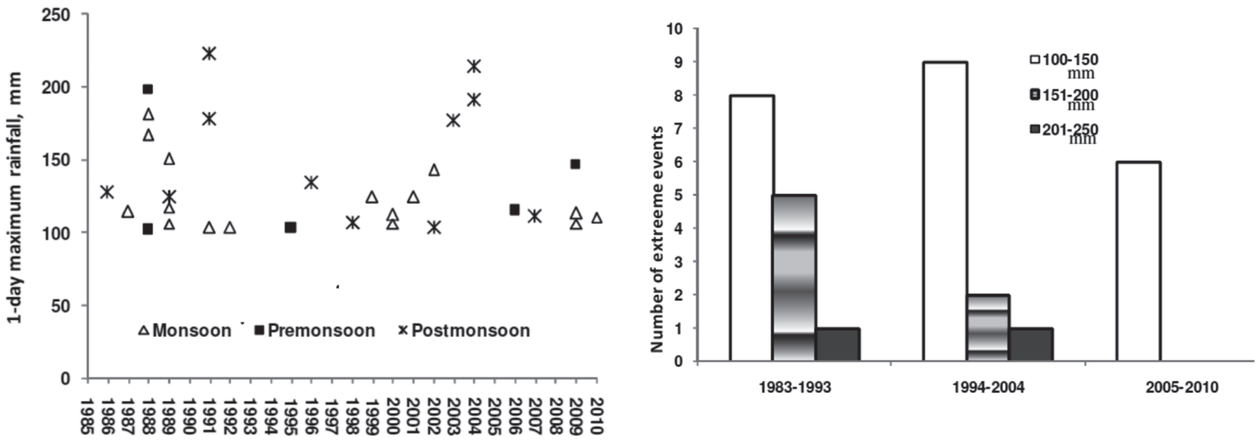


Fig. 4. Frequency of RX1-day maximum rainfall events at Umiam, Meghalaya

meteorological drought years, mostly in a row. Among them, 1990, 2002 and 2004 experienced extreme forms of meteorological drought, where more than 4 consecutive weeks received less than 55 mm of rainfall (very severe). If this trend continues in the near future, then the rainfed agriculture of NE region of India will certainly face partial to complete loss of even major kharif crops (e.g. rice) and thus, the long cherished desire of achieving self-reliance in food grain production will remain a distant dream. It has also been reported that during 2009-2010, nearly 40% of the rice cultivated area in NER experienced meteorological drought during South-West monsoon (Anonymous, 2009a).

Rainy Days and Extreme Eainfall Events

Annual rainy days varied widely (90 to 146 days), with an average value of 128.3 ± 11.7 days (Table1). The year 2009 experienced nearly 30% less rainy days while the year 1997 had 14% higher rainy days over LPA of 128.3 days. Average number of rainy days was maximum during monsoon (JJAS ~19 days/month) followed by pre (MAM~11 days/month) and post monsoon (ONDJF~5 days/month) months. Annual trend analysis exhibited a marginal, non-significant increasing trend in annual rainy days @ 0.17 days/year (Table 1). Seasonal distribution trend, however, revealed wide variation: decreasing trend during monsoon (Z=-0.73) while increasing trend during pre-(Z=+1.09) and post-(Z=+0.89) monsoon months. Wide deviation in annual rainy days (-30% to +14% of normal) might be one of the many reasons for considerable aberration in inter and intra annual as well as seasonal rainfall distribution pattern at Umiam.

Umiam experienced in all a total of 32 extreme rainfall events (RX1 day>100 mm) in the last three decades (1983-2010) of which 23 times 1-day maximum was less than 151 mm (>100mm >RX1day<151mm) and in the rest 9 times, it was higher than 151 mm (RX1day>150 mm). Sixteen out of thirty two times, 1-day maximum (RX1day>100mm) occurred during monsoon (JJAS) followed by 11 times in post monsoon (October-November) and 5 times in pre monsoon May months (Fig.4). Nevertheless, the annual frequency of occurrence of extreme rainfall events is relatively less at mid altitude Umiam (1.14); yet, the worry is annual increasing trend in those events, since RX1day maximum >100 mm exhibited an appreciable increasing trend (Z=+0.63). Non-significant increasing trend of extreme rainfall events over North-Eastern region was also reported by Joshi and Rajeevan (2006), although, frequency, magnitude and direction (+/-) of extreme rainfall events varied widely across other parts of India (Guhathakurta and Rajeevan, 2006; Mall *et al*., 2006 and Rupa Kumar *et al*., 2006).

Trend Changes in Surface Temperature

Maximum surface temperature varied from 22.08^{0}C to 26.47 ^{0}C, with a long term average of 24.81 ± 0.96 ^{0}C (Table 2). Similarly, minimum

Table 2. Statistical analysis of annual march of temperature trends at Umiam (1985-2010)

Temperature, ^0C	Maximum	Minimum	Mean	Summer (AMJJASO)	Winter (NDJFM)
Min	22.08	13.95	18.28	21.91	12.43
Max	26.47	16.70	20.78	23.94	17.19
Mean	24.81	15.75	20.26	23.04	16.32
Std	0.96	0.69	0.60	0.51	0.98
CV (%)	3.87	4.41	2.98	2.20	5.98
Z	+3.88	-0.485	+2.34	+1.59	+2.43
Sen's Slope	0.086	-0.011	0.031	0.021	0.055

surface temperature varied from 13.95 ^0C to 16.7 ^0C, with a mean of 15.75 ± 0.69 ^0C at Umiam (Fig.5). Annual trend analysis (using Mann-Kendall test) of maximum temperature reflected a linear (r=+0.64), significant (at 1% level) rising trend (Z=+3.88) at the rate of 0.086^0C per year. Minimum temperature, on the other hand, enumerated a non-linear (r= -0.19), non-significant, decreasing trend (Z = -0.485) at an annual rate of 0.011^0C (Table 2). Annual summer surface temperature (AMJJASO~ 23.04 ± 0.51 ^0C) increased (Z= +1.59) non-significantly at the rate of 0.02^0C per year. Similarly, winter temperature (NDJFM ~16.32 ± 0.98 ^0C) also exhibited an increasing trend (Z=+2.43) at the rate of 0.055^0C annually and was significant at 5% level of significance. Mean annual surface temperature (20.26 ± 0.6 ^0C) also manifested a linear (r=+0.41), significant (at 5% level) increasing trend (Z= +2.34) at an annual rate of 0.031^0C (indicated by Sen's positive slope).

The substantial rate of annual increase in maximum temperature (@ of 0.086^0C/year) at Umiam which was nearly 8 times higher than the reported rise over the North-Eastern region (0.011^0C/year) (Das, 2004; Pant and Rupa Kumar, 1997) provides sufficient evidence that Umiam is also very much within the arena of regional impact of climate change phenomena. Increasing rate of annual mean temperature (@0.031^0C/year) at Umiam, comparable to 0.04^0C annual rise aggregated over NE region (Das 2004, Pant and Rupa Kumar, 1997) and 3 times higher than the

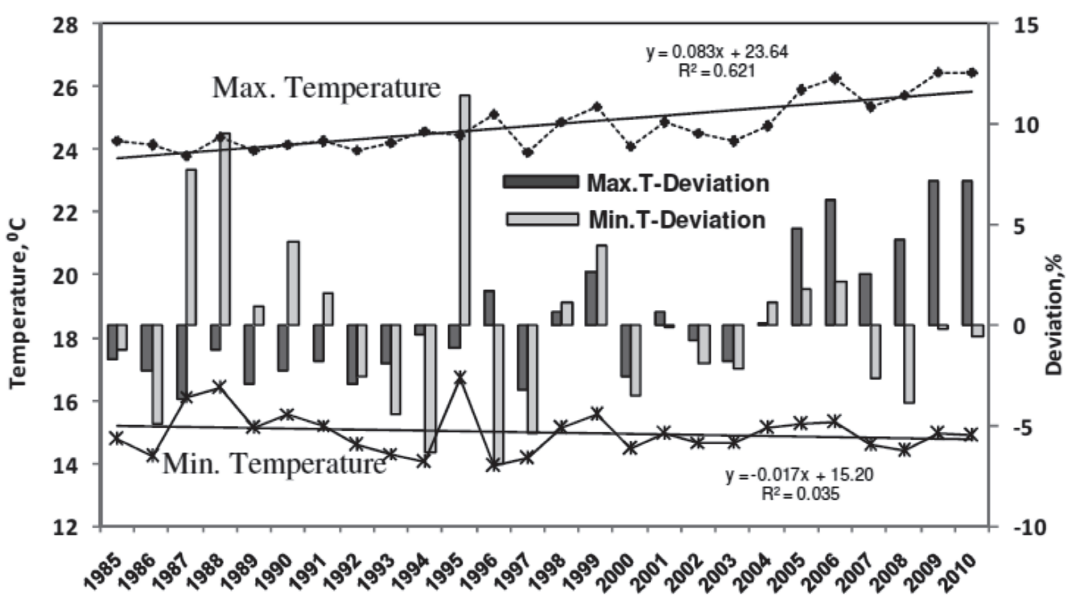


Fig. 5: Long term changes in minimum and maximum surface temperature at Umiam, Meghalaya

Table 3. Mann Kendall test statistics for trend analysis of the annual march of the climate variables at Umiam (1983-2010)

Climate Variables	E_{pan} (mm year^{-1})	E_{pan} rate (mm day^{-1})	Relative humidity (%)			Wind speed (km hr^{-1})	Sunshine duration (hr day^{-1})			
			Max.	Min.	Mean		Pre[#]	Monsoon	Post[&]	Mean
Min	847.4	2.06	68.00	60.58	66.92	2.58	5.35	0.88	2.85	4.07
Max	1227.7	4.60	84.67	87.17	84.04	4.39	9.63	4.31	7.58	7.16
Mean	1057.6	2.89	78.70	70.20	74.40	3.36	6.60	3.21	6.44	5.42
Std	101.9	0.26	3.97	8.62	3.91	0.44	0.96	0.74	1.18	0.66
CV	9.64	9.15	5.05	12.27	5.26	13.0	14.59	23.06	18.32	12.21
Z	-1.88	-2.27	+2.80	-2.86	-2.36	-2.82	-0.67	+0.17	-2.78	-2.06
Slope	-5.76	-0.02	0.291	-0.74	-0.21	-0.03	-0.02	0.003	-0.05	-0.05

[#]Pre: pre-monsoon, [&]Post: post-monsoon

global increasing rate (@ 0.013^{0}C/year) since last 50 years (1955-2005) (Das, 2004) further manifested the regional impact of climate change over whole NE region including Umiam.

Atmospheric Evaporative Demands

Trend analysis revealed a non-linear (r=-0.39), significant (at 5% level) decreasing trend (Z= -1.88) of total evaporation, at an annual declining rate of 5.75 mm (Table 3). It was expected that with the rising trend in mean temperature (@ of 0.031^{0}C/year), total evaporation loss would have been increased rather it followed a reverse trend of decline. This declining rate was rather closely related and better explained by the significant (at 5% level) annual declining trend of mean relative humidity (Z=-2.36, @ of 0.21% annually), sunshine duration (Z=-2.06, @ of 0.05 hrs/year) and average wind speed (Z=-2.82, @ of 0.033 km/hr/year) (Table3). Correlation studies further confirmed that atmospheric evaporative demand is relatively more sensitive to changes in sunshine duration (r=+0.63) followed by wind speed (r=+0.41) and lesser to vapour pressure deficit (r= 0.11). Similar observations of annual decline in total evaporation rate by 2-4 mm per year due to the significant influence of solar radiation, wind speed and vapour pressure deficit through complementary relationship over Northern hemisphere including the Indian Subcontinent were reported by several climate modelers and impact analysts (Gifford, 2005).

Climatic Water Balance Studies

Climatic water balance studies (Rainfall and PET balance) reaffirmed the erratic and extreme unevenness in seasonal rainfall distribution pattern at Umiam. During the post-monsoon months (December to February), acute water shortfall was observed, mostly due to inadequate rainfall occurrence which couldn't even meet 50% of the monthly potential evapotranspiration demand. This situation extended even up to pre - monsoon month March. Alternately, within the same year, half of the time (May to October), there was a plenty of water surplus which was even 3.5-6.7 times higher than the monthly PET requirement. Similar trend of acute shortage during post-monsoon months despite excessive surplus during monsoon periods was also observed even in the wettest (1988 received 38% higher annual normal rainfall) as well as driest (1998 received 25% less rainfall) years of last 28 years at Umiam, Meghalaya (Fig.6). Mann-Kendall test also confirms an increasing trend of water surplus during May to July (Z: +0.08 to 1.56) while a declining trend (Z: -0.56 to -0.87) during the post-monsoon months (December to February).

This may be one of the major reasons why Meghalaya which is considered as one of the highest rainfall receiving zones of Northeastern region of India suffers often from extreme water shortage during December to March very frequently. If this trend continues, the already

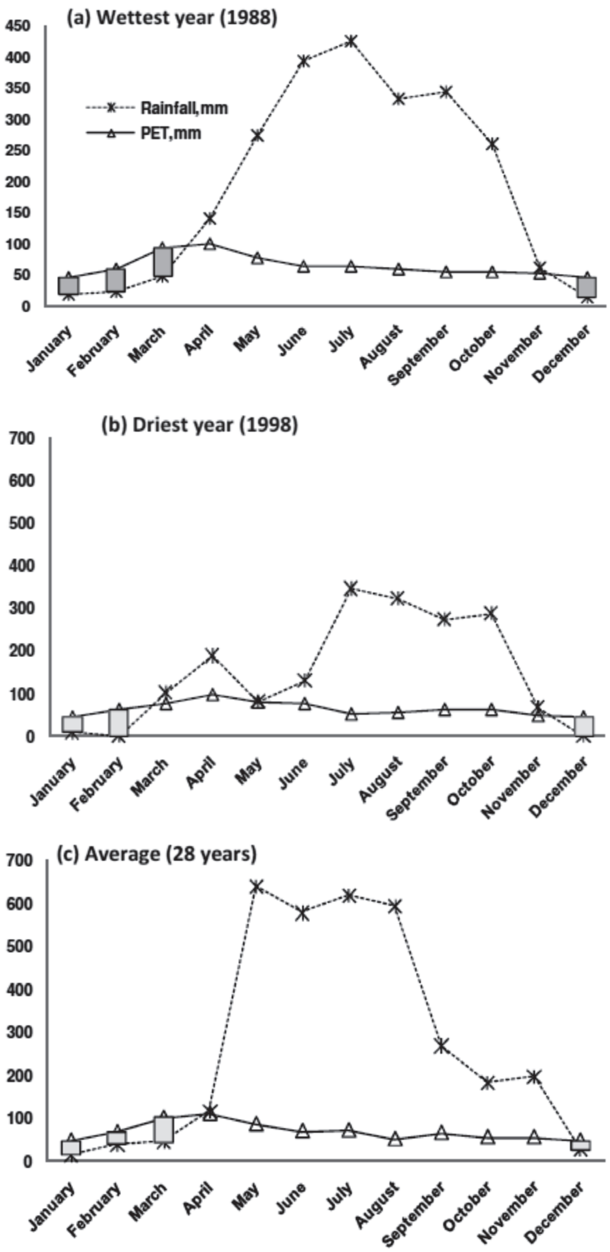


Fig. 6. Climatic water balance (rainfall-PET) in the extreme years and long period average (28 years) at Umiam, Meghalaya

dismal scenario on water balance front during post monsoon months will further worsen in NE region. To address such kind of exclusive situation, effective water conservation measures should be initiated to harvest maximum amount of rainwater during water surplus months and ensuring its availability during the water deficit months. This will arrest the primary and secondary adverse effects of extreme climate on chain of events of the ecosystems including degradation of soil and water resources at the same time enabling year around agricultural production activities, achieving thereby desired crop intensification and self sufficiency in food grain production.

Relative Humidity

Annual trend of maximum (morning) relative humidity (RH) at Umiam enumerated a linear (r=+0.57), significant (at 1% level) rise (Z=+2.80) at the rate of 0.29% annually while minimum relative humidity (evening) followed a reverse trend of significant (at 1% level), linear (r=-0.76) decline (Z=-2.86) at an annual rate of 0.74%. Despite an increasing trend in maximum RH, mean RH shrunk gradually at a significant (at 5% level) annual declining (Z= -2.35) rate of 0.21% (Table 3). Consistent decrease in minimum RH might have offset the increasing trend in maximum RH and thus, average RH also declined annually.

In general, with the increase in temperature, water holding capacity of the atmosphere increases at the rate of 7% per degree Kelvin. However, under the eventuality of limited water supply (like over many land surfaces), the actual moisture content of the atmosphere increases at a marginal rate which cannot sustain the water vapour content and thus RH decreases with the rise in temperature (Allen and Ingram, 2002; Trenberth *et al.*, 2005). This might be one of many possible reasons for significant declining trend observed in aggregated maximum and mean RH at Umiam since Umiam experienced a significant rise in maximum (@0.086^{0}C/year) as well as mean (@0.031^{0}C) surface temperatures.

Wind Speed

Mean annual wind speed at Umiam varied from 2.58 to 4.39 km hr^{-1}, with a mean value of 3.36 ± 0.44 km hr^{-1} (Table 3). In the month of April, average wind speed was maximum (5.47 km hr^{-1}) while minimum wind speed was recorded in the month of October (2.40 km hr^{-1}). Trend analysis reflected a significant (at1% level) decline (Z= -2.82) in aggregated mean wind speed at the rate of 0.033 km/hr/year (Table 3). Similarly, monthly average wind speed also exhibited an annual declining trend at varying levels (Z= -0.56 to -3.19) except June which experienced increasing trend (Z= +0.84). The declining trend was most prominent and significant (at 1% level) in the months of July (Z=-2.81), October (Z= -3.19) and December (Z= - 3.02).

Sunshine Duration

Annual march of the duration of sunshine hours at Umiam was maximum in the month of March (7.37±0.84 hrs/day) and minimum in July (2.86±1.06 hrs/day). Annual average duration, however, varied from 4.07 hrs to 7.16 hrs per day, with a mean value of 5.42 ± 0.66 hrs. Pre-monsoon months (MAM) had the highest duration of daily sunshine hours (6.6 ±0.96 hrs) followed by post-monsoon (ONDJF: 6.44±1.18 hrs) months. Monsoon months (JJAS), on the other hand, experienced lowest duration of sunshine hours (3.21±0.74 hrs). Mann Kendall test confirms an annual decreasing trend of sunshine duration in pre monsoon (Z=-0.67, @ 0.02hrs/day) and post monsoon (Z=-2.78, @ of 0.05hrs/day) months while a marginal increasing trend in monsoon months (Z=+0.15, @ of 0.003 hrs/day) (Table 3). Similarly, mean annual sunshine hours also reflected a significant (at 5% level) declining trend (Z=-2.06) at the rate of 0.045 hrs per day (Table 3).

It is assumed that due to the dominance of overcast sky condition (cloudiness) during monsoon months, more particularly in July, sunshine duration was minimum despite having maximum day length (in Northern hemisphere). This fact has been partially substantiated from the trend of rainy days since monthly average sunshine duration at Umiam reflected a highly negative correlation (r=-0.91) with average monthly rainy days. Regression analysis further affirmed that with every unit of increase in rainy days, sunshine duration decreased by 0.22 unit (R^2=0.83). As a result, July experienced highest number of rainy days (19.9) while lowest duration of sunshine hours (75.7 hrs). Similar trend of higher rainy days during monsoon months (~19.1/month) might have resulted in 50% reduction in duration of sunshine hours compared to pre-and post-monsoon months which recorded considerably less rainy days (~5.62/month). Anthropogenic environment degradation activities (like deforestation, *Jhum* cultivation and fossil fuel burning, coal mining and other infrastructural developments) across NER are resulting in release of GHG's and other pollutants beyond critical limit (Deka *et al*., 2009) which might be influencing this reduction in sunshine hours at Umiam.

Conclusion

Significant rise in surface temperature, confounding inter and intra-annual, seasonal rainfall amount, distribution and frequency variability, inconsistency in monsoon rainfall contribution, occurrence of meteorological droughts often, decline in atmospheric evaporative demand *via* complementary relationship with sunshine duration, wind speed and relative humidity etc. provides sufficient indication that like other parts of India and the globe, Umiam located at NE Region is also experiencing the regional impact of climate change, though the magnitude of change may not be the same. This local observation can be used as manifestation of climate changes occurring at NEH region and the findings of this study can be used for future projection studies as well as regional level planning. This would indeed help in forestalling the cascading consequences of adverse climatic change on the delicate hilly rainfed ecosystems of NE region and would help in exploiting its beneficial opportunities.

References

Anonymous. 2009. Annual Report of All India Coordinated Research Project on Agrometeorology. Central Research Institute for Dryland Agriculture, Santoshnagar, Hyderabad-500 059.pp.5.

Anonymous. 2009a. Weekly agricultural drought monitoring based on rainfall data (from IMD site, ISRO-AWS sites and TRMM multi-sensor data) June 11 to July- 22, 2009. North Eastern Space Application Centre (NESAC), Umiam, Meghalaya.

Aggarwal, P.K., Joshi, P.K., Ingram, J.S. and Gupta, R.K. 2004. Adapting food systems of the Indo-Gangetic plains to global environmental change: key information needs to improve policy formulation. *Environ. Sci. Policy*. **7**: 487-498.

Allen, M. R. and Ingram, W. J. 2002.Constraints on future changes in climate and the hydrologic cycle. *Nat*. **419**: 224– 232.

Das, P.J. 2004. Rainfall Regime of Northeast India: A hydrometeorological study with special emphasis on the Brahmaputra Basin. Unpublished Ph.D. Thesis. Guwahati University (accessed October 25, 2009).

Das, P.J. and Goswami, D.C. 2003. Long-term variability of rainfall over northeast India. *Indian J. Landscape Syst .Eco. Stud.* **26**(1):1-20.

Deka, R.L., Mahanta, C. and Nath, K.K. 2009. Trends and Fluctuations of Temperature Regime of North East India. In S. Panigrahy, S. S. Ray, J.S. Parihar (ed.) *Impact of Climate Change on Agriculture.* ISPRS Archives XXXVIII-8/W3 Workshop Proceedings. Space Application Centre, Ahmedabad. pp. 376-380.

Dorrenbos, J. and Pruitt, W.O. 1977. *Guidelines for Predicting Crop Water Requirements*. FAO Irrigation and Drainage Paper 24. Rome: Food and Agriculture Organization of the United Nations.

Elliott, W. E., Gaffen, D. J., Kahl, J. D. and Angell, J. K. 1994.The Effects of Moisture on Layer Thicknesses Used to Monitor Global Temperatures. *J. Clim.* **7**: 304-308.

Gifford, R.M. 2005. Pan evaporation: An example of the detection and attribution of trends in climate variables. Proceedings of a workshop held at the Shine Dome, Australian Academy of Science, Canberra 22-23 November 2004.

Guhathakurta, P. and Rajeevan. M. 2006.Trends in the rainfall pattern over India, NCC Research Report No 2/2006, May 2006, India Meteorological Department, Pune, pp. 23.

Helsel, D. R. and Hirsch, R. M. 2002. *Statistical Methods in Water Resources. Chapter A3.Book 4, Hydrologic Analysis and Interpretation*. Techniques of Water-Resources Investigations of the United States Geological Survey.

Hirsch, R.M., Slack, J.R. and Smith, R.A. 1982. Techniques of Trend Analysis for Monthly Water Quality Data. *Water Res. Res.* **18**(1): 107-121.

Hussain, R., Nath, K.K. and Deka, R.L. 2009. Climate Variability and yield fluctuations of some major crops of Jorhat (Assam). In S. Panigrahy, S. S. Ray, J.S. Parihar (ed.) *Impact of Climate Change on Agriculture.* ISPRS Archives XXXVIII-8/W3 Workshop Proceedings. Space Application Centre, Ahmedabad. pp. 402.

Joshi, U. R. and Rajeevan, M. 2006.*Trends in Precipitation Extremes over India.* National Climate Centre, India Meteorological Department, Research Report No: 3/2006, Pune, India- 411005

Kendall, M.G. 1995. "*Rank Correlation Methods"*, Charles Griffin, London.

Mall, R.K., Gupta, A., Singh, R., Singh, R.S. and Rathore, L. S. 2006. Water resources and climate change: An Indian perspective. *Curr. Sci.* **90**(12):1610-1626.

Mirza, M.M.Q., Warrick, R.A., Ericksen, N.J. and Kenny, G.J. 1998. Trends and persistence in precipitation in the Ganges, Brahmaputra and Meghna river basins. *J. Hydrol.* **43**(6):845-858.

Pant, G.B. and Rupa Kumar, K. 1997. Climates of South Asia. John Wiley and Sons, New York pp.320.

Rupa Kumar, K., Sahai, A. K., Krishna Kumar, K., Patwardhan, S. K., Mishra, P. K., Revadekar, J. V., Kamala, K. and G. B. Pant. 2006. High resolution climate change scenarios for India for the 21st century. *Curr. Sci*. **90**(3): 334-345.

Salmi, T., Maatta, A., Anttila, P., Ruoho-Airola, T. and Amnell, T. 2002. Detecting Trends of Annual Values of Atmospheric Pollutants by the Mann-Kendall Test and Sen's Slope Estimates - The Excel Template Application Makesens. Finnish Meteorological Institute Publications on Air Quality No. 31, Helsinki, Finland.

Samui, R.P. and Kamble, M.V. 2009. Indian Agriculture under Climate Change Scenario. In S. Panigrahy, S.S. Ray, J.S. Parihar (ed.) *Impact of Climate Change on Agriculture.* ISPRS Archives XXXVIII-8/W3 Workshop Proceedings. Space Application Centre, Ahmedabad. pp. 399-401.

Trenberth, K. E., Fasullo, J. and Smith, L. 2005. Trends and variability in column-integrated water vapor. *Clim. Dyn*. **24**: 741– 758.

Received: 9 February 2012; Accepted: 22 May 2012