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Global Warming and the Pattern of Overall Climate Changes in Sub-Himalayan Assam Region of North-East India

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Abstract

This paper examines the changing pattern of climatic factors in Sub-Himalayan Assam region during last four decades. Sub-regional variation in climate indicators and their relation with the anthropogenic human activities like deforestation, mining and industrial developments is analysed. Also, inter-relation among the variation in major climatic components precipitation, temperature and humidity has been explained through various time series methods. The analysis reveals a growing uncertainty and erratic nature of yearly and seasonal rainfall, which is accompanied by significant inter-regional variations. The monsoon rainfall has been declining significantly, while the proportion of pre and post monsoon months' rainfall has been rising. Both maximum and minimum temperature has been increasing and trend rate of minimum temperature has been higher than that of maximum temperature and the rate is more during winter season. There is also uncertain variation in maximum-minimum gap of temperature over the years. Finally, significant cointegrated relation exists among all the climate variables.

Keywords: Climate Change, Global Warming, Uncertain Weather, Stationarity, Vector Auto-regression, Co-integration, Assam

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Background:

The study of climate change especially in the mountainous regions is important for its wide ranging effects on the environment, natural resources including biodiversity, and hence the socio-economic condition of the people living in that environment (Whiteman, 2000; Pathak et al., 2010). The human interventions in various forms are sometimes responsible for changes in the climatic conditions that again affect livelihood conditions of human beings. Even a little change in climate in the hilly region may lead to hazards like unpredictable floods, draughts, landslides, heavy soil erosion etc. that have deleterious impacts on biodiversity, availability of water and agriculture. The changing livelihood condition in the long run affects forest, water resources, wetlands and other natural resources and hazards that have far-reaching consequence on the local climate. For example, a slight shift in the monsoon precipitations may lead to increase in frequency and intensity of flood and draught, landslides and erosion and agricultural practices, especially in the downstream areas (Metz et al., 2001).

The climatic pattern of Indian sub-continent and particularly the North-Eastern region has been significantly controlled over the years partly by the existence of Himalayan range on the Northern and sub-Himalayan range on the Eastern side and partly by the Bay of Bengal, Indian Ocean and Arabian Sea on the East, South and West. Despite having a noticeable wind pattern, humidity and rainfall, the temperature of the region recorded a perceptible change over the years. In the hilly towns like Shillong, in winter, water used to freeze for longer hours in the morning even 40-50 years back (as viewed by many local senior citizens from their experience and observations of cracked water pipelines, heavy frosting and problems of water supply in the morning). In recent years, mild frosting hardly occurs during winter and that too very early in the morning. The global warming scenario is clearly perceived from a shortened winter and the pattern of dresses used by the people in the region. Apart from that, there are short-term erratic changes in behaviour of weather as reflected in occurrence of high rainfall before the usual monsoon or after it. The nature of human interventions in the region has changed rapidly with the changing geo-political scenario and resettlement of population as well which is manifested by the form of deforestation, mining activities, industrialisation and agricultural practices. Despite being a relatively temperate zone, this region is gradually experiencing extreme weather conditions.

As discussed earlier, the climate of Assam is very much dependent upon the existence of the Himalayan range in the North and the sub-Himalayan ranges in the South and East. This unique feature helps in generating high rainfall by concentrating the south-west monsoon current emerging from the Arabian Sea and Bay of Bengal during the summer and post-summer period. In turn, it helps in controlling the temperature and humidity throughout the year through the control of precipitation and blocking North-East currents in winter. Thus the whole region and particularly Assam has been blessed with a Himalayan climate (Johnson and Houze 1987; Clemens et al., 1991). The state has been experiencing high rainfall, relative humidity and controlled temperature that of course varies across its various zones due to the geographical positions and latitudinal as well as longitudinal positions with respect to the mountain range (Barry and Chorley, 2003). Within the state there are hilly, relatively colder zones and there exists relatively hot plain zones. The mighty Brahmaputra River, with full of rain fed and glacial melt, passes through the state from North-East to South-West dividing it into two long parts. Another major river, Barak, flows through the Cachar zone, and there are numerous tributaries that contributes to the local climatic conditions. All these contribute to the availability of water and river based landscape that is useful for the growth of various agricultural activities and thereby for the sustenance of the people in the region. Also, the state witnesses the occurrence of frequent flood of different intensity and timing over the years. It may be due to the erratic behaviour of weather and that is being perceived for a long period of time.

Meteorological records show a global warming trend of 0.74^{0}C in past 100 years (1906-2005) in the Eastern Himalayas i.e., by 0.0074^{0}C annually (IPCC 2007). On the other hand, higher Himalayan data from Nepal over the period from 1977-1994 show an increase in temperature of up to 0.06°C per year, which is much greater than the global trend (Shrestha et. al., 1999). A comparison of two previous example shows that warming rate has been much higher in the second case and thus showing the higher rate of temperature growth in the higher altitudes and faster in the recent times than that of earlier periods. The recorded rate of glacial retreat also varies across the Himalayan region and considered to be one of the reasons for the variability in monsoon intensity (Karma et. al., 2003).

The North-Eastern region of India, and more particularly the state of Assam, has however been experiencing the changes in activities like the growth of various mineral based, forest based and other industries along with population growth and many other service sectors including transport and communication. Like the other regions of the globe this area have also been experiencing a continuous change in climatic parameters and thus changes in the livelihood conditions by varying different crop and non-crop activities suitably. For example, rain jackets/coats, umbrella etc. are basic necessities, while working in open fields, riding bikes or going to office/institutions etc. in the areas with heavy rainfall which is also spread over a longer period than in areas with less rainfall. This calls for production of the goods which protects people from rain. Thus rain jacket/coat, umbrella or related items producing industries are found to be prevalent in such areas. Similarly, colder regions are likely to produce winter garments more. Most of the industries associated with agricultural sector are dependent on the weather pattern and its change over time. In turn, the trade composition is determined by the nature of production in the region. Agricultural activity pattern are also subject to continuous change depending upon the adaptability of the farmers with the changing weather pattern over the years and hence the risk and uncertainty (Ye et al., 2013). Finally, water transport industries are prevalent in areas with numerous rivers and rivulets.

Over the years, climatic conditions may record gradual changes in terms of temperature, rainfall and humidity and their spatial pattern. In the long run, the pattern of activities of people may also change accordingly. Some plants and animals have become extinct in course of time and some are about to be extinct. So, there is a need to continuously adapt with the changing conditions (like crop and non-crop activities) for their survival. There is always a fight for survival of living beings. The livelihood depends on how efficiently the living beings cope up with the vagaries of nature. Living beings have to adopt with the changing nature. Otherwise, there is a danger of becoming extinct.

In the nature, all the phenomena are interrelated. Change in one phenomenon necessitates changes in the other phenomena. So changes in temperature, is not confined to itself. It has effect on rainfall and other aspects like moisture content of the soil, humidity pattern etc. Rainfall in turn has effects on agricultural production, vegetation and livelihood of people and all other living organisms. Thus it is necessary to examine the changes in the climatic pattern in order to have an idea of future trend.

Global warming is relatively a recent phenomenon as compared to the life of earth and the time of onset of live forms in earth. The changes of climatic pattern in the last few decades are seen to be very fast and alarming. Global warming poses a threat to the existence of human beings.

Our aim in this paper is to examine whether there has been a significant change in the climate of Assam so far as temperature, rainfall and humidity are concerned. More specifically, we want to see whether the temperature in different zones of Assam shows a rising trend over the years (during last 4-5 decades). We also examine whether this change in temperature affects rainfall pattern and humidity in this area or whether the reverse causality exists.

Linkage between human intervention and climate change in the neighbourhood has been examined by several authors (Deka et al., 2011; Dev, 2011). There are studies on the impact of anthropogenic activities on the environment and climatic conditions. Also studies examined the effect of rising climatic uncertainty and extremeness weather on the economic activities, performance, livelihood condition and food security as well as adaptation measures required for the sustenance (TERI, 2003; Weitzman, 2009; Howitt et al., 2010; Pathak et al., 2010; UNESCO, 2012; CESPR, RGVN and INECC, 2012). Though there are studies on the trend and pattern of climate change (Christensen et al., 2007; Cruz et al., 2007; Ananthapadmanabhan et al., 2007; World Bank, 2008; Liggins, 2008), there is hardly any study on the relationships among the three major components of weather i.e., precipitation, temperature and humidity at the local level. Precipitation in an area may depend on the temperature and evaporation level and incoming wind from a distant place. In turn it affects the local temperature and humidity. It is not possible to capture all these aspects in the present paper. We shall however point out some of the anthropogenic activities in an area that may affect the local climatic factors and vice versa. We shall mainly concentrate on the complex interplay of three major weather factors here.

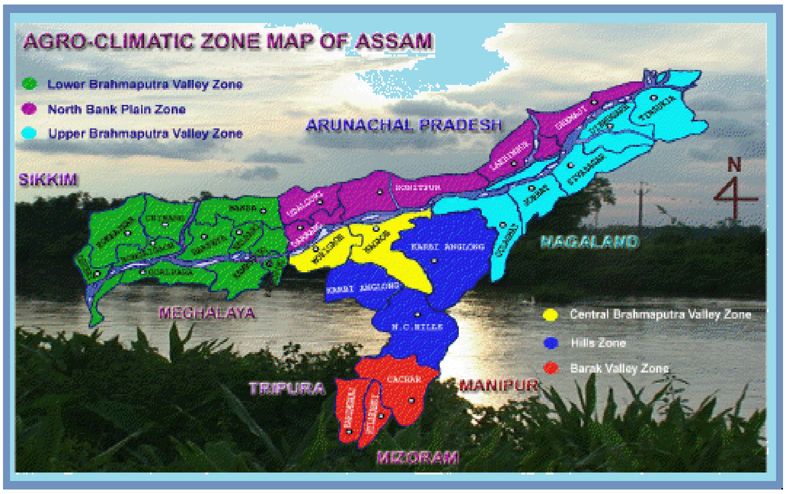
Materials and Methods:

Data on maximum and minimum temperature, morning and evening humidity and rainfall for last 40 years have been taken from the meteorological department of India. To start with, we have computed the quinquennial (five year) moving average of maximum and minimum temperature of bi-monthly average and that of rainfall from 1971-75 to 2006-10 and then plotted to have an approximate idea about the temporal change of these climatic attributes. The seasonal variations in the movement have also been noticed. We tried to check the stationarity of time series processes and compare the trend coefficients of various individual months of the year. It is done by using Augmented Dickey-Fuller (ADF) method and AIC with intercept and time trend and for both level and first difference form as per the requirement (Dickey and Fuller, 1979). Also, to have a better idea about the extremity of the climatic characters, the movement of the gap between the maximum and the minimum temperatures has been observed. Thereafter, the causality between temperature and rainfall is examined by Granger test (Granger, 1969) for all the regions (as mentioned below), for which the data were available. Finally, the vector auto-regression (Watson, 1994) and cointegrating relationship among the three relevant climate variables have been examined and presented. Cointegration vectors are estimated by Johansen (1988) method and the single cointegrating relation is presented here.

Construction of Zones:

The whole of Assam is broadly divided into six agro-climatic zones as shown in Figure 1.

Figure-1: Agro-Climatic Zone Map of Assam



However, the meteorological data generated from various stations do not represent exactly the agro-climatic zones used for analysing agricultural issues. In case of Karbi-Anglong, N. C. Hills zone the series of data is incomplete and partly available in case of Goalpara sub-regions. Hence, looking at the meteorological stations and for the sake of analysis (inter-zonal comparison) the following six zones have been constituted here that represent various agro-climatic and socio-economic activity areas of Assam. This is so done because of the fact that over time climatic parameters changes not only because of the geological or ocean movements, but also because of the long term human intervention at the regional or local level like various socio economic activities including major destruction and alteration of vast forest areas for agriculture, industry or urbanisation, embankments of major rivers, mining activities etc. The geographical position with respect to river and hills that affects the wind flow and moisture content in various seasons also matters for the climatic condition and its change over time.

The zones constituted for the purpose of present analysis are as follows.

1. Upper Brahmaputra Valley Zone (UBVZ) consists of Tinsukia, Dibrugarh, Sibsagar, Jorhat and Golaghat, on the southern side of the upper Brahmaputra region bordering Nagaland. We refer this zone by Dibrugarh zone or Zone-1. The region is primarily dominated by the oil, coal and natural gas mining activities along with oil refinery and coal based industries. Also there is the largest tea garden in the world and its processing units.

2. North Brahmaputra Plain Zone (NBPZ) consists of Lakhimpur and Dhemaji. This is the Lakhimpur zone or Zone-2. It has flood prone areas of low-lying northern Brahmaputra plain areas of upper Assam dominated by backward agricultural (crop and sericulture) activities.

3. Lower Brahmaputra Valley Zone (LBVZ) consists of Kamrup, Nalbari, Barpeta and Baksa. This zone is referred here as Kamrup zone or zone-3 having both city industrial area and vast agricultural activities.

4. Barak Valley Zone (BVZ) consists of Cachar, Hailakandi and Karimganj and is known as Cachar zone or zone-4. The entire Barak Valley area, bounded by Manipur, Mizoram on the east and south and Tripura and Bangladesh on the west, fall in this zone. It is primarily known for its basic agricultural activities and virtually no major industry.

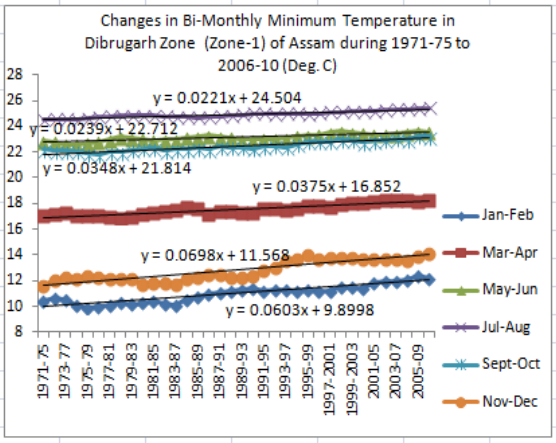
5. Central Brahmaputra Valley Zone (CBVZ) consists of Darrang, Sonitpur, Udalguri, Nagaon and Morigaon of Central Brahmaputra Valley in between Himalaya on the north and Karbi-Anglong, N. C. Hills on the south. As no systematic data is available for Nagaon and Morigaon, the meteorological data collected from Tezpur station is used to represent zone-5, here named as Darrang zone. As data is collected in Tezpur station, the neighbouring areas of Darrang, Sonitpur and Udalguri are included here carving out of conventional North Brahmaputra Plain Agricultural Zone. It also partly represents the Hills Zone (HZ) of Karbi-Anglong and N.C. Hills.

6. Goalpara zone (zone-6 here), consists of Goalpara, Dhubri, Kokrajhar, Bongaigaon and Chirang in the western most part of Assam and Lower Brahmaputra Valley with some oil industries and major agricultural activities and bordering Meghalaya hills and plain Bangladesh as well as West Bengal.

Observations and Analysis:

A linear regression on time shows that across the zones of Assam minimum temperature recorded a gradual increase consistently over the years during 1971-75 to 2006-10, which is accompanied with significant inter-month variation. Across various zones the minimum temperature increased consistently and at relatively rapid rate than that of maximum temperature and that is clear from figure 2. Within each zone the over time growth of maximum as well as minimum temperatures in winter months is relatively faster than that of summer months. Yearly average minimum temperature has a positive trend in Dibrugarh, Kamrup, Cachar and Darrang zones. Maximum temperature is more erratic in Goalpara and Darrang zones of Assam. The temperature range, however, becomes the lowest in the hot summer and rainy months and it is much higher in pre-summer and post monsoon periods across the zones. Rainfall also shows some erratic movement and peak rainfall month shifted towards the normal post-monsoon months. Also in most of the zones the rainfall in March or April reaches very high level over the years (fig. 3). Humidity level does not show significant variation as compared to the temperature and rainfall though it is supposed be related to these factors. Moreover, the trend and stationarity analysis show no significant difference between morning and evening humidity. So, only evening humidity is considered in the present analysis and henceforth will be named as humidity only.

Fig.2: Variation in Seasonal Temperature (Maximum and Minimum) across the Regions of Assam during 1971-75 to 2006-10



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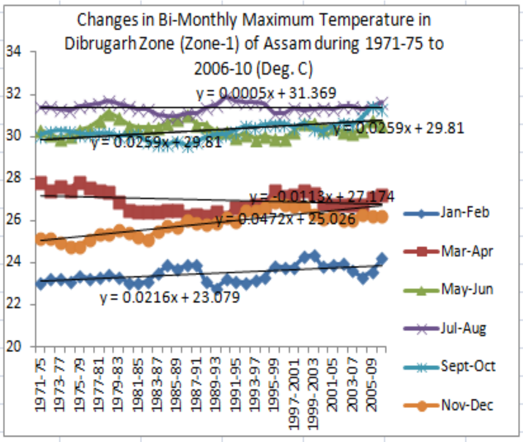

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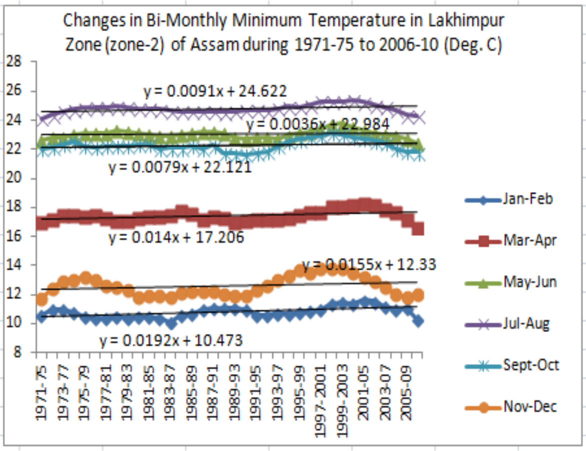

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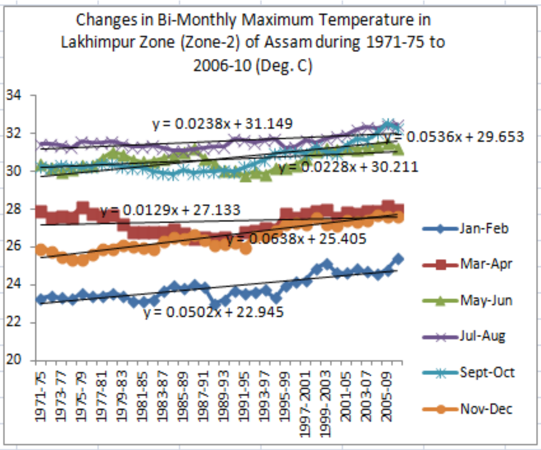

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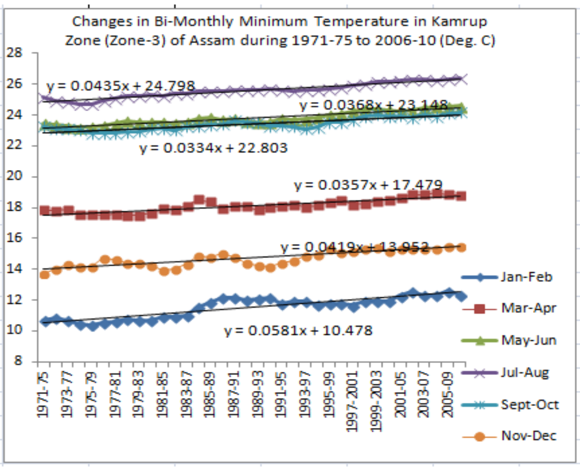

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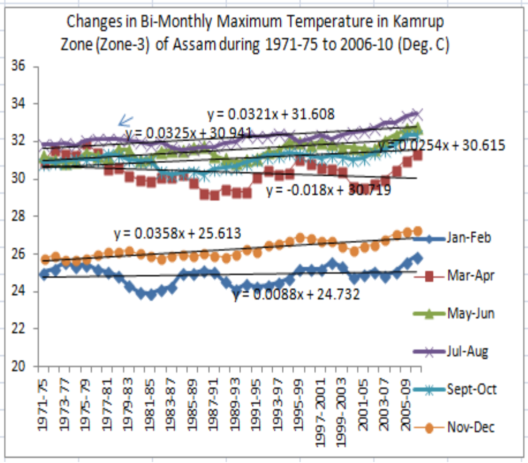

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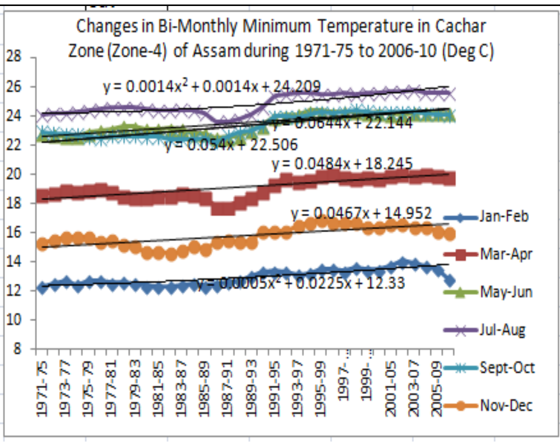

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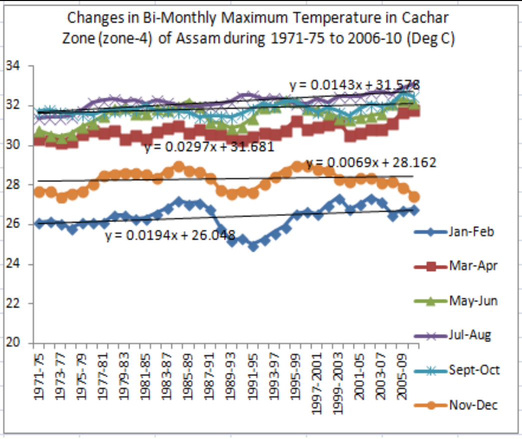

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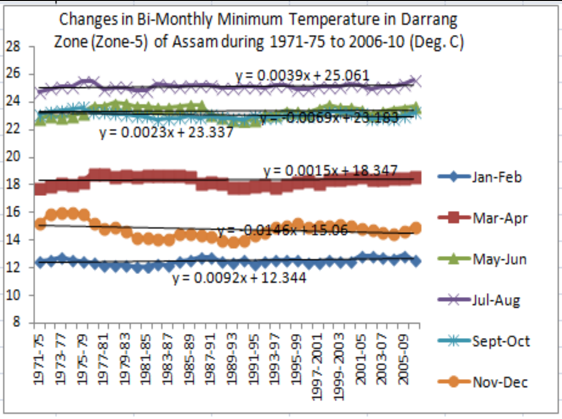

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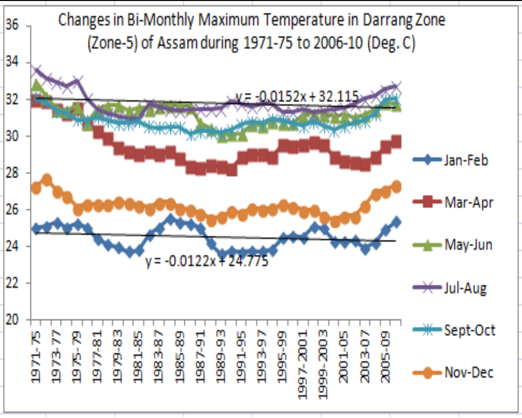

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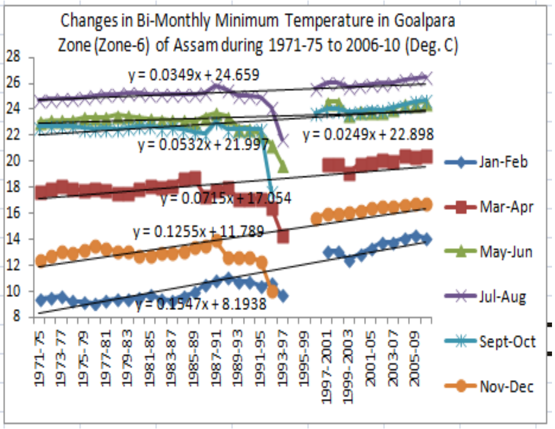

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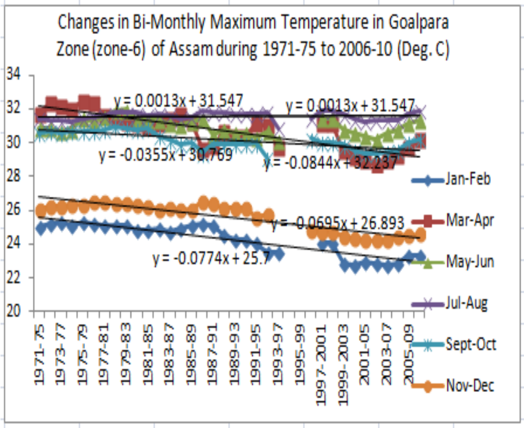

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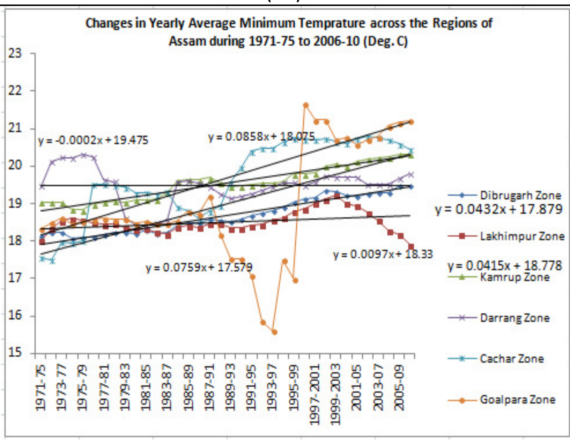

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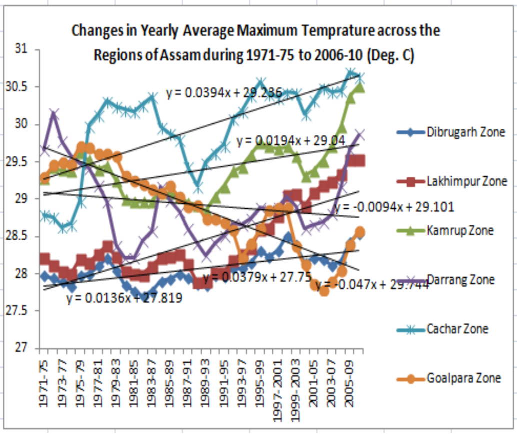


(2n)

Fig. 3: Variation in Seasonal Rainfall across the Regions of Assam during 1971-75 to 2006-10

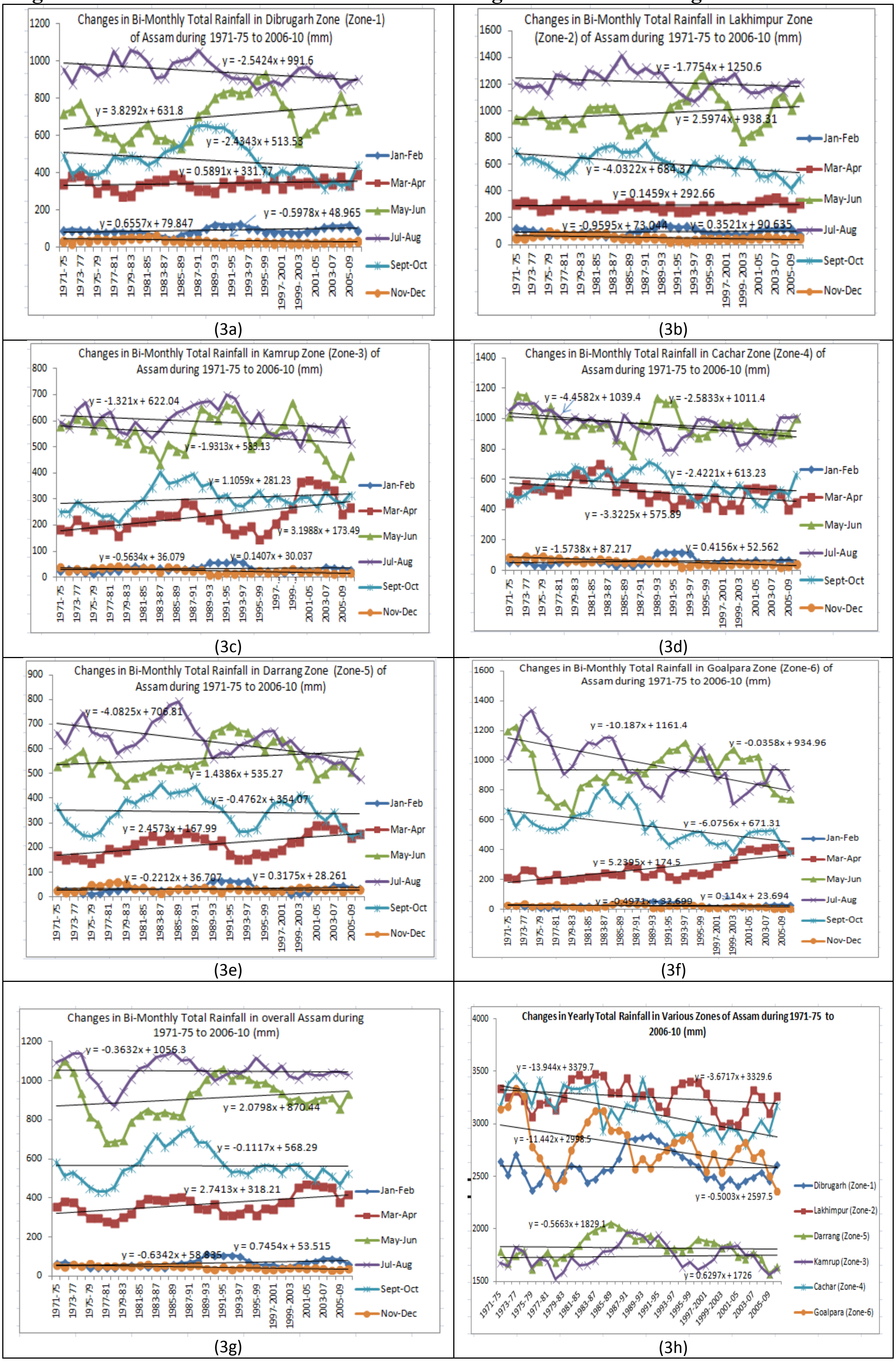


Table-1: Unit Root Test for Stationarity of Climatic Components of Zone-1 (Dibrugarh Zone) and the Trend Across the Months of the Year

	Rainfall					Min. Temp.					Max. Temp.					Humidity				
	Level		Ist. Diff.		Com-	Level		Ist. Diff.		Com-	Level		Ist. Diff.		Com-	Level		Ist. Diff.		Com-
Month	Coeff.	Trend	Coeff.	Trend	ment	Coeff.	Trend	Coeff	Tr.	ment	Coeff.	ment	Coeff	Tr.	ment	Coeff.	Trend	Coeff.	Trend	ment
Jan	-1.089**	-.182			I(0)	-1.052**	.068**			I(0), +ve trend	-1.67**	.037*			I(0), +ve trend	-1.54**	-.211**			I(0), -ve trend
Feb	-.755*	-.270			I(0)	-1.38**	.070**			I(0), +ve trend	-1.616**	.044#			I(0), +ve trend	-1.18**	-.104			I(0)
Mar	-1.017**	1.121			I(0)	-1.35**	.056**			I(0), +ve trend	-1.16**	-.0156			I(0)	-1.117**	.0698			I(0)
Apr	-1.153**	-.297			I(0)	-1.384**	.044**			I(0), +ve trend	-1.075**	.0021			I(0)	-.748	.055	-1.506**	.0596	I(1)
May	-1.018**	2.85			I(0)	-0.955*	.028**			I(0), +ve trend	-1.316**	.0165			I(0)	-1.39**	.182			I(0)
Jun	-.949**	.1084			I(0)	-0.794*	.0117**			I(0), +ve trend	-.944**	-.015			I(0)	-.98*	.0685			I(0)
Jul	-1.24**	-1.12			I(0)	-1.035**	.023**			I(0), +ve trend	-1.20**	.0112			I(0)	-.937**	.0115			I(0)
Aug	-2.628**	-4.80*			I(0), -ve trend	-3.890*	.070**			I(0), +ve trend	-1.115**	-.013			I(0)	-.917**	.082			I(0)
Sep	-.711*	-0.45			I(0)	-1.277**	.0394**			I(0), +ve trend	-1.002**	.032*			I(0), +ve trend	-.415	-.069#	-2.61**	-.039	I(1), -ve trend
Oct	-1.23**	-0.474			I(0)	-1.017**	.0416**			I(0), +ve trend	-.984**	.025#			I(0), +ve trend	-.836**	-.162**			I(0), -ve trend
Nov	1.60**	0.185			I(0)	-0.792**	.0666*			I(0), +ve trend	-1.078**	.0295*			I(0), +ve trend	-.594*	-.178**			I(0), -ve trend
Dec	-1.224**	-.729**			I(0), -ve trend	-1.410**	.105**			I(0), +ve trend	-1.014**	.0569**			I(0), +ve trend	-.938**	-.270**			I(0), -ve trend

Note: #, * and ** indicates that the coefficients are significant at ten, five and one per cent level of significance.

In the Dibrugarh zone (zone-1) in upper Assam of South Brahmaputra, rainfall has shown a stationary pattern with significant negative trend in August and also in December, while minimum temperature has recorded stationarity and significant positive growth throughout the years. Trend growth of minimum temperature has been very high during the winter months, especially during November to February as compared to the summer months of the year. The monthly average maximum temperature is also stationary across the months and has a significant positive trend only during colder months from September to February. Comparison of every months figure reveals that the growth of minimum temperature has always been significantly higher than that of maximum temperature. The relative humidity level across the months is more or less stationary (except in the month of September and April) and shows no significant change during summer months but from September to January, humidity has recorded a declining trend. Because of the presence of Himalaya on the north, the north-east wind during winter cannot pass across the Brahmaputra and that is true for all the years. But the economic activities like coalmining, petroleum mining, oil refineries etc. have been increasing over the years and coal mining activities gain momentum in dry winter in the absence of rain and that led to further increase in temperature. Also there are rising tea industries functioning throughout the year and more intensely during summer and monsoon seasons.

In the Lakhimpur zone of North-Brahmaputra of upper Assam, rainfall shows some erratic movement across the months. Though over time rainfall in the months of March and August increases, but it declines significantly during the months of July, October and December. However, the minimum temperature does not show any significant trend except in the month of July, and in most of the months it shows a gradual upward trend. The monthly average maximum temperature however exhibits a significant upward trend throughout the year and this rate is comparatively much higher in the winter months than that of the summer and rainy months. The relative humidity however shows more erratic pattern and non-stationary in the months of April, July and October. It has a significant positive trend during December, March, June and August; while humidity in the evening also has an increasing trend over the years in the months of January and May.

Kamrup zone, which includes urban Guwahati, Kamrup rural, Barpeta, Nalbari and Baksa areas, has recorded a significant declining trend in rainfall during winter (December, January) and in July. But, rainfall follows a significantly rising trend in March, August and October. Minimum temperature across all the months of the year shows a significant positive trend. Here also, trend coefficients in winter months and May are comparatively greater than those of other summer months. Except in the first four months of the year, maximum temperature in the other months has also increased over time and the rate is much higher in the last two months. Despite rising trend of humidity during January to April, rainfall has recorded a significant rising trend only in March along with minimum temperature. But rainfall in February and April has been highly erratic, which happens due to the variation in occurrence of depression caused by the complex interplay of temperature, humidity, and wind in this part.

Table-2: Unit Root Test for Stationarity of Climatic Components of Zone-2 (Lakhimpur Zone) and the Trend Across the Months of the Year

	Rainfall					Min. Temp.					Max. Temp.					Humidity				
	Level		Ist. Diff.		Com-ment	Level		Ist. Diff.		Com-ment	Level		Ist. Diff.		Com-ment	Level		Ist. Diff.		Com-ment
Month	Coeff.	Trend	Coeff.	Trend		Coeff.	Trend	Coeff.	Tr		Coeff.	Trend	Coff.	Tr.		Coeff.	Trend	Coeff.	Trend	
Jan	-1.316**	-.276			I(0)	-1.05**	.0047			I(0)	-2.213**	.102**			I(0), +ve trend	-.93**	.136*			I(0), +ve trend
Feb	-.8805**	.091			I(0)	-.774**	.0023			I(0)	-1.09**	.067*			I(0), +ve trend	-.957**	.055			I(0)
Mar	-2.78**	4.292**			I(0), +ve trend	-.914**	.011			I(0)	-.39	.0276	-2.516**	.0221	I(1)	-1.28**	.1501#			I(0), +ve trend
Apr	-.894	.126	-4.434**	1.465	I(1)	-.658*	-.0037			I(0)	-1.062**	.0115			I(0)	-.259	.091	-2.73	.092	Non-Sty
May	-1.077**	.0903			I(0)	-0.832**	-.00035			I(0)	-1.132**	.0466*			I(0), +ve trend	-1.30**	.105#			I(0), +ve trend
Jun	-2.90*	5.447			I(0)	-0.569**	-.0097			I(0)	-.89**	.00069			I(0)	-.910**	.132*			I(0), +ve trend
Jul	-1.116**	-5.99*			I(0), -ve trend	-.431	.0014	-1.292**	.081#	I(1), +ve trend	-1.254**	.0372*			I(0), +ve trend	-1.37#	.073	-7.034*	-.0105	I(1)
Aug	-2.596**	11.28**			I(0), +ve trend	-.693**	.0034			I(0)	-.974**	.011			I(0)	-.98**	.167**			I(0), +ve trend
Sep	-1.0046**	-3.265			I(0)	-.764**	.0070			I(0)	-.934**	.0571**			I(0), +ve trend	-1.186**	.039			I(0)
Oct	-1.368**	-.758#			I(0), -ve trend	-.888**	.0002			I(0)	-.775**	.0409**			I(0), +ve trend	-.781	.026	-2.5196	.0406	Non-Sty
Nov	-.962*	.122			I(0)	-.521*	.0021			I(0)	-1.339**	.0615**			I(0), +ve trend	-.572*	.0526			I(0)
Dec	-.921**	-.795*			I(0), -ve trend	-1.11**	.0137			I(0)	-1.48**	.1183**			I(0), +ve trend	-.307#	.089	-2.21**	.101#	I(1), +ve trend

Note: #, * and ** indicates that the coefficients are significant at ten, five and one per cent level of significance.

Table-3: Unit Root Test for Stationarity of Climatic Components of Zone-3 (Kamrup Zone) and the Trend Across the Months of the Year																				
	Rainfall					Min. Temp.					Max. Temp.					Humidity				
	Level		Ist. Diff.		Com-ment	Level		Ist. Diff.		Com-ment	Level		Ist. Diff.		Com-ment	Level		Ist. Diff.		Com-ment
Month	Coeff.	Trend	Coeff.	Trend		Coeff.	Trend	Coeff.	Trend		Coeff.	Trend	Coeff.	Trend		Coeff.	Trend	Coeff.	Trend	
Jan	-1.037**	-.025#			I(0), -ve trend	-.894**	.042**			I(0), +ve trend	-.967**	-.0055			I(0)	-.980**	.0528			I(0)
Feb	-1.813**	.212			I(0)	-1.458**	.083**			I(0), +ve trend	-1.201**	.0412#			I(0)	-1.297**	.2193*			I(0),+ve trend
Mar	-1.82**	1.62**			I(0),+ve trend	-.995**	.038*			I(0), +ve trend	-1.005**	-.0026			I(0)	-1.283**	.198#			I(0), +ve trend
Apr	-1.006**	2.205			I(0)	-.981**	.0322*			I(0), +ve trend	-1.199**	-.0207			I(0)	-1.01**	.247*			I(0), +ve trend
May	-1.15	-.518	-4.47**	-.552	I(1)	-2.55#	.102**	-5.54**	.0086	I(1), +ve trend	-2.2185	.122**	-7.997*	.0493	I(1), +ve trend	-1.264**	-.0299			I(0)
Jun	-1.99*	-2.60			I(0)	-.9397**	.0325**			I(0), +ve trend	-.8644#	.0197	-2.683**	.0033	I(1)	-1.103**	.043			I(0)
Jul	-1.18**	-3.24#			I(0), -ve trend	-1.201**	.461**			I(0), +ve trend	-.951**	.0331*			I(0), +ve trend	-1.661**	.0342			I(0)
Aug	-4.31	9.85*	-6.46**	-.339	I(0), +ve trend	-1.336	.0556*	-2.22	.0002	Non-sty, +ve trend	-.931**	.0323**			I(0), +ve trend	-2.785*	.1352#			I(0), +ve trend
Sep	-1.095	-1.37	-3.64*	-.902	I(1)	-.804#	.031**	-2.15**	.006	I(1), +ve trend	-.7607**	.027#			I(0), +ve trend	-1.138**	-.0029			I(0)
Oct	-1.214**	2.50*			I(0), +ve trend	-1.01**	.034**			I(0), +ve trend	-.844**	.0214#			I(0), +ve trend	-1.105**	.027#			I(0), +ve trend
Nov	-1.163**	-.40			I(0)	-.905**	.0254#			I(0), +ve trend	-2.632	.0789**	-6.704*	.0167	I(1), +ve trend	-.657**	-.035			I(0)
Dec	-1.37**	-.346*			I(0), -ve trend	-1.117**	.062**			I(0), +ve trend	-1.602**	.0659**			I(0), +ve trend	-.105	.1407	-10.29**	.1509*	I(1), +ve trend
Note: #, * and ** indicates that the coefficients are significant at ten, five and one per cent level of significance.																				

Table-4: Unit Root Test for Stationarity of Climatic Components of Zone-4 (Cachar Zone) and the Trend Across the Months of the Year

	Rainfall					Min. Temp.					Max. Temp.					Humidity				
	Level		Ist. Diff.		Com-ment	Level		Ist. Diff.		Com-ment	Level		Ist. Diff.		Com-ment	Level		Ist. Diff.		Com-ment
Month	Coeff.	Trend	Coeff.	Trend		Coeff.	Trend	Coeff.	Trend		Coeff.	Trend	Coeff	Trend		Coeff.	Trend	Coeff	Trend	
Jan	-2.265#	-.137	-12.09**	-.845*	I(1), -ve trend	-1.704**	.0503**			I(0), +ve trend	-1.019**	.0038			I(0)	-.870**	.263**			I(0), +ve trend
Feb	-1.01**	-.054			I(0)	-.695**	.0133			I(0)	-1.274*	.040			I(0)	-1.086	.305#	-3.611*	-.107	I(1), +ve trend
Mar	-2.60*	1.238			I(0)	-.811**	.032*			I(0), +ve trend	-1.272**	.0312			I(0)	-1.317**	.387**			I(0), +ve trend
Apr	-1.06**	-3.20			I(0)	-.857**	.053**			I(0), +ve trend	-1.036**	.0248			I(0)	-3.507*	.802**			I(0), +ve trend
May	-.995**	.956			I(0)	-.836**	.0474**			I(0), +ve trend	-.8635**	.025			I(0)	-1.138**	.2278**			I(0), +ve trend
Jun	-1.398**	-5.76#			I(0), -ve trend	-.585*	.025*			I(0), +ve trend	-.7935**	.0168			I(0)	-1.097**	.1578**			I(0), +ve trend
Jul	-.988**	-3.51#			I(0), -ve trend	-7.81**	.042**			I(0), +ve trend	-.929**	.0362*			I(0), +ve trend	-1.124**	.136**			I(0), +ve trend
Aug	-1.098**	.73			I(0)	-.562*	.028*			I(0), +ve trend	-1.268**	.0254*			I(0), +ve trend	-.8784	.1775#	-6.263*	.1314#	I(1), +ve trend
Sep	-1.025**	1.38			I(0)	-.738**	.036**			I(0), +ve trend	-1.116**	.0298**			I(0), +ve trend	-1.002	.21*	-3.841#	.1006	I(1), +ve trend
Oct	-1.187**	-1.25			I(0)	-.601**	.0389*			I(0), +ve trend	-2.30**	.0173			I(0)	-.8284**	.2109**			I(0), +ve trend
Nov	-1.76**	-1.91**			I(0), -ve trend	-1.665#	.088*	-2.147*	.0104	I(1), +ve trend	-.7623**	-.0109			I(0)	-.34	.1101	-1.80**	.0918	I(1)
Dec	-2.417**	-1.086#			I(0), -ve trend	-1.268**	.0696*			I(0), +ve trend	-1.134*	.010			I(0)	-.6702*	.2076*			I(0), +ve trend

Note: #, * and ** indicates that the coefficients are significant at ten, five and one per cent level of significance.

Table-5: Unit Root Test for Stationarity of Climatic Components of Zone-5 (Darrang Zone) and the Trend Across the Months of the Year																				
	Rainfall					Min. Temp.					Max. Temp.					Humidity				
	Level		Ist. Diff.		Com-	Level		Ist. Diff.		Com-	Level		Ist. Diff.		Com-	Level		Ist. Diff.		Com-
Month	Coeff.	Trend	Coeff.	Trend	ment	Coeff.	Trend	Coeff.	Trend	ment	Coeff.	Trend	Coeff.	Tr.	ment	Coeff.	Trend	Coeff.	Tr.	ment
Jan	-1.028**	-.098			I(0)	-2.51	.016	-7.29**	-.0054	I(1)	-.869**	-.0164			I(0)	-1.189**	.1301#			I(0), +ve trend
Feb	-.913**	.164			I(0)	-4.736#	.115**	-4.355*	-.0002	I(1), +ve trend	-2.174#	.0724#	-1.942**	.0261	I(1), +ve trend	-.971**	.1401			I(0)
Mar	-3.73**	2.73**			I(0), +ve trend	-1.056**	.0062			I(0)	-.853**	-.0516			I(0)	-1.0617**	.2553*			I(0), +ve trend
Apr	-1.17**	1.78#			I(0), +ve trend	-1.022**	.0113			I(0)	-.668**	-.037			I(0)	-.897**	.1311			I(0)
May	-1.714	3.064#	-2.142**	.184	I(1), +ve trend	-1.18**	.032			I(0)	-.845**	-.0009			I(0)	-1.745	-.1132	-4.863	-.0706	Non-Sty
Jun	-1.29**	1.32			I(0)	-.812**	-.01			I(0)	-1.1613	-.0411	-2.69	.0103	Non-Sty	-1.222**	.1243#			I(0), +ve trend
Jul	-1.131	-5.064*	-4.643	-1.85	Non-Sty, -ve trend	-.834**	.0062			I(0)	-.796**	-.004			I(0)	-.7707**	-.016			I(0)
Aug	-1.29	-.66	-3.137**	-1.164	I(1)	-2.79*	.0281			I(0)	-1.302	.0265	-4.542**	.045	I(1)	-1.045**	.0632			I(0)
Sep	-.871**	-.262			I(0)	-.918**	.001			I(0)	-.708**	.0062			I(0)	-.710*	.0444			I(0)
Oct	-1.05**	-.591			I(0)	-1.077**	-.0013			I(0)	-.6006*	-.0064			I(0)	-.8536**	-.014			I(0)
Nov	-.93**	.173			I(0)	-.50**	-.0094			I(0)	-1.032**	-.0367			I(0)	-.866**	.0124			I(0)
Dec	-1.00**	-.324			I(0)	-1.006**	-.003			I(0)	-1.087#	.0086	-3.417**	.0243	I(1)	-.5431*	-.030			I(0)

Note: #, * and ** indicates that the coefficients are significant at ten, five and one per cent level of significance.

During the dry winter months November to January when there remains very less moisture in the air with cold North-East wind and in June-July rainfall has been declining in the Barrack Valley zone of Cachar over the years when the minimum temperature also exhibits a rapidly rising trend with stationarity leading to the situation of more dry. The minimum temperature however recorded rising trend throughout the year in tune with the global warming and the maximum temperature also moving upward over the years during the prime rainy season, July to September. Thus despite rising trend of relative humidity across the months, the zone has been experiencing consistently stagnant rainfall in the major months and declining trend in winter as well as prime rainy season June-July, which is the major period of paddy cultivation under monsoon. Even in the other monsoon months there has been a minor decline in rainfall and the major rainfall period has also been shortened over the years.

The rising intensity of floods in the recent past thus cannot be fully associated with the rainfall pattern in the zone. The floods in this downstream area have been mostly due to heavy rainfall within a shorter period in the high hill upstream areas. However, the sudden landslides and draught at times can be related to the shortened and low rainfall in the zone.

In the Darrang zone representing both sides of Brahmaputra of Middle Assam, rainfall has recorded a rising trend during March to May in the pre-monsoon season and a negative trend in July, the peak rainfall month of the year in normal years. The zone also recorded no trend in minimum as well as maximum temperature across the months except in some early months of the year like February to May having a positive trend in minimum temperature of low or high intensity. Humidity in the zone also follows a similar pattern except in January, March and June. The zone is blocked on both sides, by N. C. Hills on South and the Himalaya range on the North with the mighty Brahmaputra cutting across. The rising pre-monsoon minimum temperature is appeared to be associated with depression and rising early rainfall or advancement of rainfall season and low rainfall in the prime rainy month.

In almost all the areas monsoon rainfall has become erratic and is significantly declining over the years in prime monsoon time of July, except in Dibrugarh, where the declining trend is also continued for the month August. Also the low rainfall season of winter months has recorded a further decline despite some rising trend of humidity in one or more winter months in all the zones except the mining dominated, industrial and fast growing urban areas of Dibrugarh zone. In the North, Central and Lower Brahmaputra plain and valleys, we noticed a gradual shift of rainfall either towards early months or sometimes towards later months, which calls for preparedness for the unforeseen floods as the case is also true for the upstream high hill Arunachal and other adjoining areas. High concentration of rainfall in pre-monsoon months of March, April or May and decline in the prime season many a times cause sudden floods in those areas and more loss of property and crops due to its unpredictable nature. The severe flood in Nalbari and Barpeta areas in 2004 in the month of April however was due to heavy untimely rainfall in the upstream Arunachal that flowed through rivers passing through these parts of Assam. Sharp decline in the proportion of annual rainfall in the primary monsoon months of June-July and continuous rise in rainfall in the pre-monsoon months of April-May and post-monsoon months of September-October in overall Assam can easily be revealed from figure 4. Percentage of annual rainfall in June-July has declined at an annual exponential rate of 0.292 per cent and the proportion of annual rainfall during April-May and August-September has increased at an annual exponential rate of 0.142 per cent. The coefficients are significant at 1 per cent level in both the cases.

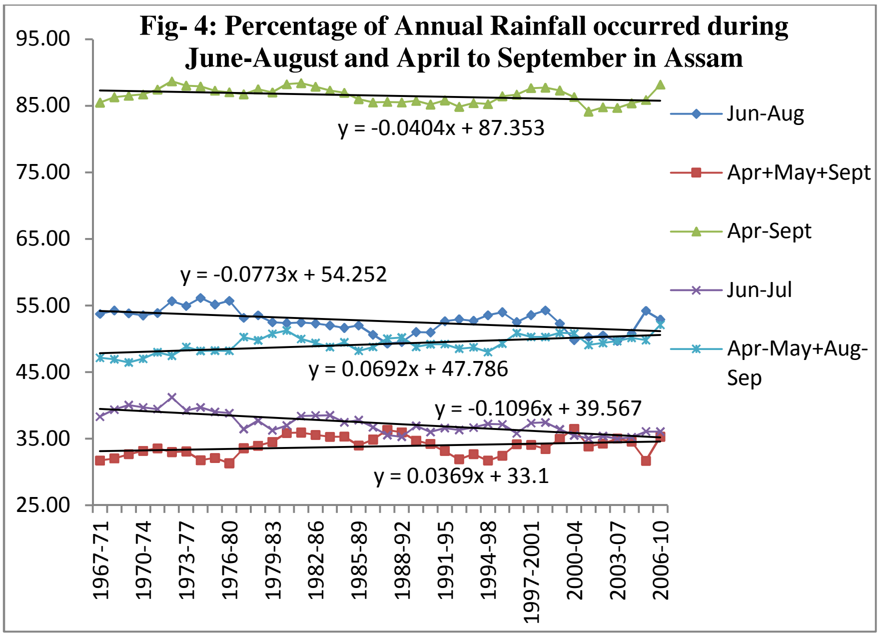
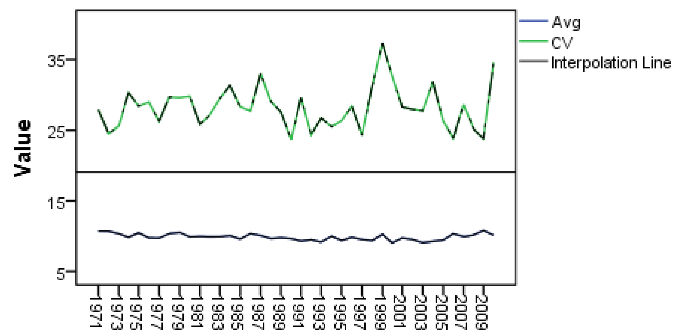


Table-6: Summary of Major Indications of Spatio-Temporal Change in Climatic Factors in Assam				
	Rainfall	Min Temp	Max Temp	Humidity
Dibrugarh+ (Zone-1)	Negative trend in rainy season especially in August and also in winter	Rising all through and highly during winter. Every month more than max. temperature	Increasing significantly during September to February	Negative trend during September to January
Lakhimpur + (Zone-2)	Upward trend in pre & post (March & August) monsoon months. Significant negative trend in July, October & December	Rising trend in July and insignificant rise in other months	Significant rise throughout the time space of the year	Erratic and non-stationary during April, July & October. Most of the other time it has rising trend
Kamrup+ (Zone-3)	Declining in winter and monsoon month, July. Rising in pre & post monsoon months (March, August & October)	Rising throughout the year. Increase is more during winter months	Except first four months, upward trend with more intensity during winter months	Rising trend of December to April, August and October
Cachar+ (Zone-4)	Declining in winter and monsoon months of June & July	Has been rising in all seasons	Rising trend during monsoon months (July to September)	Increasing trend almost in every season
Darrang+ (Zone-5)	Rising trend in pre-monsoon months (March to May), declining trend in July (main monsoon month)	Upward trend in early months and no trend in other months	Rising in February and insignificant temporal change in other months	Positive trend in January, March, June and no trend in other months

Maximum temperature shows more erratic pattern than that of minimum temperature, which has been increasing systematically in almost all the areas except in north Brahmaputra flood plains where it is growing in the early months of the years or in monsoon months with low rainfall. Everywhere, the rising trend of minimum temperature has been more intense in the winter months than that of other seasons. In the industrial and mineral based activities of urban Dibrugarh and Kamrup maximum temperature has also been rising significantly in the latter half of the year and in Cachar zone during monsoon period which is shrinking over the years. In Lakhimpur zone however it has increased throughout the seasons. Relative humidity across the zones however has recorded more inconsistency as compared to temperature and rainfall that may be due to the changing wind direction along with the rising temperature or divergence of maximum minimum temperature.

Data reveal that the gap between the maximum and the minimum temperature has always been much higher in the winter months as compared to that of summer months across all the regions. Also on an average the minimum temperature has been rising at faster rates than that of maximum temperate except a few erratic areas and thus the maximum minimum gap shows a marginal decline across the seasons. But the coefficient of variation in month-wise maximum minimum temperate gap shows more variability over the years, as shown in figure 5.

Fig. 5: Changes in Average Yearly Max-Min Temperature Gap and its Monthwise Coeff. of Variation in Assam



The inter-zonal variation in temperature, humidity and rainfall (which is also dependent upon the temperature, sunshine, evaporation, and wind direction from the source like Bay of Bengal, Arabian Sea, Indian Ocean and flow from African forest zones) depends, apart from the geographical position with respect to the Himalayas and Brahmaputra, also on the local economic activities over the years. The more erratic rainfall and consistent rise in temperature on both sides of Brahmaputra can be associated with the pattern of forest degradation for the expansion of agriculture, mining activities and population concentration or relocation despite being relatively low average density in the state as compared to the national average. The satellite imagery (fig. 6) shows the degraded picture of forest on northern part and in the Dibrugarh zone and parts of Cachar zone of Assam.

Fig. 6

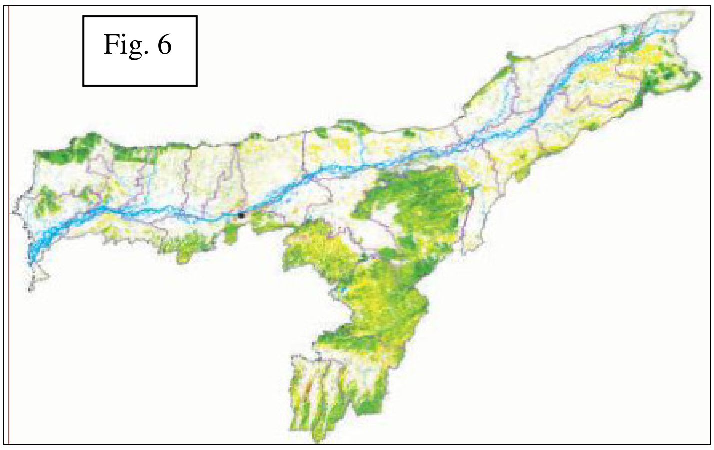


Fig.-7: Changes in Forest Area over time in Various Zones of Assam (Hectare)

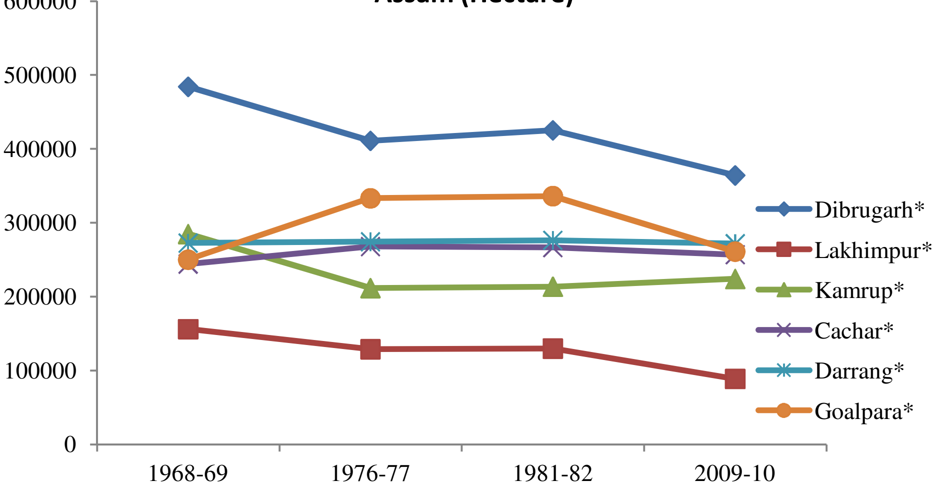


Table-7: Changes in Forest Area across the Zones of Assam during 1968-69 to 2009-10								
	Area in Hectare				Annual Compound Rate of Growth (%)			
Year	1968-69	1976-77	1981-82	2009-10	1968-9 to 1976-7	1976-7 to 1981-2	1981-2 to 2009-10	1968-9 to 2009-10
Dibrugarh+	484239	411040	425176	364210	-2.03	0.68	-0.55	-0.69
Lakhimpur+	155989	128778	129778	88734	-2.37	0.15	-1.35	-1.37
Kamrup+	284722	211560	213560	224057	-3.64	0.19	0.17	-0.58
Cachar+	244130	267807	266565	256824	1.16	-0.09	-0.13	0.12
Darrang+	272578	274350	276350	271750	0.08	0.15	-0.06	-0.01
Goalpara+	250085	333167	336167	261114	3.65	0.18	-0.90	0.11
Assam	2080241	1963555	1984449	1853260	-0.72	0.21	-0.24	-0.28

From the figures 7 along with the table 7, it seems that the faster rise in temperature in Dibrugarh, Lakhimpur and Kamrup zone can be explained by rapid decline in forest covers, which gets momentum after 1980. Among other factors, decrease in forest cover also appears to contribute towards decline in rainfall and its rising erratic nature.

Another contributing factor towards rising temperature across the countries is the changing industrial, mining and other economic activities. Despite slow growth of industries in the whole

North-East region, the zone-wise variation in warming pattern in Assam also partly dependent upon the industrial and mining activities. Fig. 8 and table 8 reveal rapid rise in concentration of industries in the Kamrup zone, which is followed by Dibrugarh and then by Lakhimpur and Darrang zone. Along with this there is high concentration of tea garden and its processing units and coal mining in Dibrugarh Zone, mining of oil along with tea gardens in Lakhimpur and Darrang zones. Though emission of gases and other hazards depend on the size and pattern of industry (which is not considered here), the concentration of industries, population density and urbanization pattern can explain the high rate of warming in Dibrugarh, Kamrup and Lakhimpur zone compared to others.

Fig.- 8: Growth of Industrial Establishment per Thousand Hectare in Different Zones of Assam during 1974-2010

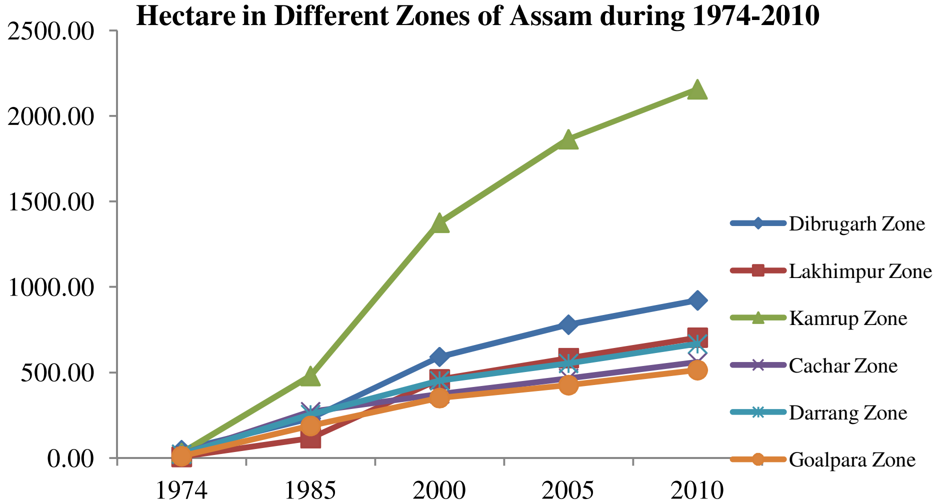


Table-8: Growth of Industries per 1000 Hectare in different Zones of Assam during 1974-2010

	Number per Thousand Hectares					Annual Compound Growth Rate (%)		
Zone\Year	1974	1985	2000	2005	2010	1974-85	2000-10	1974-2010
Dibrugarh Zone	45.76	231.90	591.40	779.34	921.94	15.90	4.54	8.70
Lakhimpur Zone	6.89	115.89	460.65	584.33	703.84	29.25	4.33	13.71
Kamrup Zone	29.07	480.55	1376.49	1864.49	2156.68	29.05	4.59	12.71
Cachar Zone	22.54	270.88	374.46	466.34	561.25	25.36	4.13	9.34
Darrang Zone	22.26	254.45	452.51	553.35	667.03	24.79	3.96	9.90
Goalpara Zone	10.72	187.66	350.79	426.03	514.22	29.72	3.90	11.35
ASSAM	21.38	216.59	498.07	646.29	763.99	23.43	4.37	10.44

Relation among the Three Important Climate Indicators:

It is true that rainfall depends on the moisture flow from its source which is far away from the place of precipitation. Rainfall, temperature and glacial movement in the upstream affect the level of humidity in an area. On the other hand, humidity and rainfall affect the temperature in the short time. Looking at the trend and stationarity pattern as described in tables 1 to 5 it appears that there is a close relation among the rainfall, humidity and temperature. The bivariate causality has been examined by Granger Causality test. The result reveals that there is both-way causality between any two weather variables except humidity in the morning to minimum temperature in zones 1 and 2; humidity in the morning to that of evening and vice versa in zones 1, 3, 4 and 5; maximum temperature to minimum temperature in zones 4 and 5 and minimum temperature to that of maximum in zone 3 (Table 9).

Table-9: Testing of Pairwise Granger Causality between various Components of Weather across the Zones of Assam

N= 478	Zone-1		Zone-2		Zone-3		Zone-4		Zone-5	
Null Hypothesis:	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.	F-Stat.	Prob.
MinTemp does not Granger Cause Rainfall	93.59	6.E-35	92.57	1.E-34	107.74	3.E-39	87.01	7.E-33	105.44	1.E-38
Rainfall does not Granger Cause MinTemp	64.82	1.E-25	61.53	2.E-24	48.97	5.E-20	43.96	3.E-18	66.17	5.E-26
MaxTemp does not Granger Cause Rainfall	98.69	2.E-36	86.23	1.E-32	66.09	5.E-26	46.70	3.E-19	47.32	2.E-19
Rainfall does not Granger Cause MaxTemp	158.57	2.E-53	122.84	1.E-43	95.65	1.E-35	99.95	6.E-37	72.75	3.E-28
Humidity does not Granger Cause Rainfall	64.36	2.E-25	38.59	3.E-16	87.73	4.E-33	39.18	2.E-16	41.42	3.E-17
Rainfall does not Granger Cause Humidity	96.48	7.E-36	51.08	8.E-21	77.21	1.E-29	40.72	5.E-17	57.11	6.E-23
MaxTemp does not Granger Cause MinTemp	1.74	0.1759	1.15	0.3165	0.53	0.5934	6.86	0.0012	7.61	0.0006
MinTemp does not Granger Cause MaxTemp	238.31	3.E-72	223.23	5.E-69	162.90	2.E-54	137.09	1.E-47	115.86	1.E-41
Humidity does not Granger Cause MinTemp	16.99	8.E-08	13.34	2.E-06	0.68	0.5072	1.87	0.1548	4.44	0.0123
MinTemp does not Granger Cause Humidity	139.07	3.E-48	87.61	4.E-33	284.31	8.E-82	144.19	1.E-49	142.13	5.E-49
Humidity does not Granger Cause MaxTemp	99.39	9.E-37	86.52	1.E-32	26.57	1.E-11	36.91	1.E-15	26.92	9.E-12
MaxTemp does not Granger Cause Humidity	152.45	8.E-52	110.04	6.E-40	220.68	2.E-68	135.44	3.E-47	140.50	1.E-48

Vector auto-regression with two period lag yields the following results for zone-1.

Rain = -757.04* +0.084 Rain(-1)* -.296 Rain(-2)* + 28.705MinTemp* + 6.318Hum*,
(-9.458) (1.775) (-7.037) (18.09) (6.22)

$R(bar)^2$ = 0.640, F= 213.12, Log-Likelihood = -2954.78, AIC = 12.384

MinTemp= -18.28* +.536 MinTemp(-1)* -.422 MinTemp(-2)* +.0057Rain* +.972MaxTemp* +.0825Hum*
(-9.201) (11.613) (-14.903) (12.30) (17.34) (4.69)

$R(bar)^2$ = 0.944, F = 1615.203, Log-likelihood = -805.062, AIC = 3.394

MaxTemp = 17.21* +.243MaxTemp(-1)* +.163MaxTemp(-2)* -.0022Rain* +.495MinTemp* -.122Hum*
(35.02) (8.10) (6.76) (-6.44) (32.93) (-14.19)

$R(bar)^2$ = 0.922, F = 1120.976, Log-likelihood = -613.55, AIC = 2.592

Hum = 34.459* +.635Hum(-1)* +.134Hum(-2)* + .0053Rain* +1.056MinTemp* -1.34MaxTemp*
(8.29) (16.39) (3.136) (2.99) (8.192) (-7.34)

$R(bar)^2$ = 0.584, F = 134.86, Log-likelihood = -1387.526, AIC = 5.831

(Figures in the parentheses represent the t-values of the corresponding coefficients and * indicates that the coefficient is significant at 1% level.)

The vector auto-regression reflects the significant positive both-way relation of minimum temperature and rainfall in the region. Though humidity has significant inverse impact on maximum temperature, it has positive effect on the minimum temperature level. The coefficients of various weather variables of linear regressions in case of zone-1 on other relevant variables having significant impact on them are presented in table 10. It also describes similar relationships among those weather variables as noted earlier.

Table-10: Results of Linear Regression of Different Endogenous Variables on Various Explanatory Variables

	Endo. Variables	MinTemp	MaxTemp	Rainfall	Humidity
Coefficients of Variables	Constant	5.839	18.946	121.258	46.186
	Rainfall	.005	-.001	--	.005
	MinTemp	--	.403	35.029	.684
	Max Temp	.895	--	-20.62	-2.16
	Humidity	.123	-.176	6.955	--
	Rainfall(-1)	.005	--	.218	-.006
	MinTemp(-1)	.413	.145	-7.407	.538
	MaxTemp(-1)	-.51	.265	--	1.085
	Humidity(-1)	-.225	.069	-5.501	.495
	$R(bar)^2$, F	0.946, 1194.85	0.924, 971.486	0.671, 163.347	0.803, 279.054

Note: all the coefficients are significant at 1% level of significance.

The normalised co-integrating relation among those variables in case of Zone 1 can be written as

Rainfall = 79.139MinTemp* + 66.234MaxTemp* + 15.96Humidity*, Log likelihood = -5555.628
(5.79) (3.244) (3.352)

(Here * indicates that the coefficient is significant at 1% level. Figures in the parentheses represent t-value of the corresponding coefficient.)

Concluding Remarks:

The whole analysis shows the sustained rise in temperature accompanied by the inter-regional variations, which appears to be due to the geographical position of the respective region with respect to the Himalayas and Major River and altitude that controls the wind flow, precipitation etc. The zonal variation in the trend of temperature is also associated with the variation in anthropogenic human activities.

Though minimum temperature recorded a faster upward trend than that of maximum temperature, the month-wise variability of extremeness of temperature in Assam shows rising but erratic pattern over the years.

Rainfall follows a declining trend and that also varies across the seasons of the year and across the regions. During the prime monsoon season of June-July, a significant declining trend of rainfall has been observed, whereas there has been a rising trend in the proportion of annual rainfall occurring during May-June and August-September. In recent years, the highest level of precipitation of the year is observed either in the pre-normal monsoon months of April-May or in August-October. The result is untimely and unexpected devastating floods. Also the untimely heavy rainfall in a short span of time in the mountain region causes flash flood and damage to life and property in lower and plain Assam.

The study also reveals high degree of causal relation among the three important weather factors. The results of Granger Causality, vector auto-regression and co-integrating relation suggest high degree of inter-relations among these weather variables. If a change occurs in any of these variables either due to socio-economic activities or natural phenomenon, it is reflected in other factors as well. Therefore, the rising uncertainty in monsoon and rising temperature call for more preparedness and continuous adaptation in the crop and non-crop activities for the reduction in the risk and the best possible livelihood practice in the region. Adaptation and disaster mitigation require adequate knowledge, access to suitable technology and appropriate policy measures. A failure in adaptation with the changing climatic uncertainty may lead to socio-economic disaster and jeopardise the livelihood security.

References:

Ananthapadmanabhan, G., Srinivas, K., Gopal, V., 2007. Hiding behind the Poor: A Report by Greenpeace on Climate Injustice. Greenpeace India Society, Bangalore, India.

Barry, R., Chorley, R., 2003. *Atmosphere, Weather, and Climate* (6th edn). London, Routledge.

TERI (The Energy and Resources Institute), 2003. Coping with Global Change: Vulnerability and Adaptation in Indian Agriculture. The Energy and Resources Institute, New Delhi, India.

CESPR, RGVN and INECC, 2012. Impact of Climate Change on the Marginalized Women: An Exploratory Study across Six Districts in Assam. A Research Report.

Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X., Held, I., Jones, R., Kolli, R.K., Kwon, W-T., Laprise, R., Magaña, Rueda V., Mearns, L., Menéndez, C.G., Räisänen, J., Rinke, A., Sarr, A., Whetton, P. 2007. Regional Climate Projections. In Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, USA.

Clemens, S.; Prell, W; Murray, D.; Shimmield, G; Weedon, G (1991), "Forcing mechanisms of the Indian Ocean monsoon", *Nature* 353 (6346): 720-725.

Cruz, R.V., H. Harasawa, M. Lal, S. Wu, Y. Anokhin, B. Punsalmaa, Y. Honda, M. Jafari, C. Li and N. Huu Ninh, 2007. Asia - *Climate Change 2007:* Impacts, Adaptation and Vulnerability. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., Van der Linden, P.J., Hanson, C.E. (Eds.), Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, 469-506.

Deka, J., Baruah, C., Bhuyan, S.K., 2011. Impact of Climate Change on Sustainable Livelihood in Deepor Beel: A Case Study of Keotpara, Azara. NeBIO 2 (3), 6-8, September.

Dev, S. M. 2011. Climate Change, Rural Livelihoods and Agriculture (focus on Food Security) in Asia-Pacific Region. Working Paper-14, IGIDR Mumbai, downloaded from http://www.igidr.ac.in/pdf/publication/WP-2011-014.pdf (accessed on 20-01-2013).

Dickey, D.A., Fuller, W.A., 1979. Distribution of the Estimators for Autoregressive Time Series with a Unit Root. Journal of the American Statistical Association. 74, 427-431.

Granger, C.W. J., 1969. Investigating Causal Relations by Econometric Models and Cross-Spectral Methods. Econometrica. 37, 424-438.

Howitt R., Azuara, J.M., MacEwan, D., 2010, Climate Change, Markets and Technology. Choices. 25 (3).

IPCC, 2007. Climate Change 2007: The Physical Science Basis – Contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change, summary for policymakers. Cambridge, Cambridge University Press.

Johnson, R.H., Houze, R.A., 1987. Precipitating cloud systems of the Asian monsoon. in Chang, C.P. and Krishnamurti, T.N. (Eds.), Monsoon Meteorology. Oxford: Oxford University Press, pp. 298-353.

Karma, A., Ageta, Y., Naito, N., Iwata, S., Yabuki, H., 2003. Glacier Distribution in the Himalayas and Glacier Shrinkage from 1963 to 1993 in the Bhutan Himalayas. Bulletin of Glaciological Research. 20, 29-40.

Johansen, S., 1988. Statistical Analysis of Cointegration Vectors. Journal of Economic Dynamics and Control. 12, 231-254.

Liggins, F., 2008. Impacts of Climate Change India, Met Office Report.

Metz, B.O., Davidson, R., Swart, J. Pan (Eds.), 2001. Climate Change 2001: Mitigation – Contribution of Working Group III to the Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge: Cambridge University Press.

Pathak, D., Gajurel, A.P., Mool, P.K., 2010. Climate Change Impacts on Hazards in the Eastern Himalayas; Climate Change Impact and Vulnerability in the Eastern Himalayas – Technical Report 5. Kathmandu: ICIMOD.

Shrestha, A.B., Wake, C.P., Mayewski, P.A., Dibb, J.E., 1999. Maximum Temperature Trends in the Himalaya and Its Vicinity: An Analysis Based on Temperature Records from Nepal for the Period 1971-94. Journal of Climate.12 (9), 2775-2787.

UNESCO, 2012. Education Sector Responses to Climate Change - Background Paper, TH/ESD/12/OS/009-E, Bangkok.

Watson, M., 1994. Vector Autoregressions and Cointegration. in Engle, R. and McFadden, D. (Eds), Handbook of Econometrics, Vol. 4., Amsterdam: North Holland.

Weitzman, Martin L., 2009. Additive Damages, Fat-Tailed Climate Dynamics, and Uncertain Discounting. Economics, The Open-Access, Open-Assessment E-Journal, Vol. 3, 2009-26 (May 7, 2009), downloaded from http://www.economics-ejournal.org/economics/journalarticles/2009-26H (Accessed on 20-1-2013).

Whiteman, D., 2000. Mountain Meteorology, Oxford: Oxford University Press.

World Bank, 2008. Climate Change Impacts in Drought and Flood Affected Areas: Case Studies in India, *Report No: 43946-IN.*

Ye, L., Tang, H., Wu, W., Yang, P., Nelson, G.C., D'Croz, D.M., Palazzo, A., 2013. Chinese Food Security and Climate Change: Agriculture Futures, Economics, The Open-Access, Open-Assessment E-Journal, No. 2013-2, January 07, 2013, downloaded from http://www.economics-ejournal.org/economics/discussionpapers/2013-2 (Accessed on 20-1-2013).