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"EXAMINING THE SPATIO-TEMPORAL RAINFALL PATTERNS OVER NORTHEAST AND WEST COAST REGIONS OF INDIA"

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ABSTRACT:

Climate change is not only a major global environmental problem, but is a serious issue to a developing country like India. These global changes will have an impact on the regional and local scales too. An attempt has been made to investigate the spatio-temporal variations of rainfall over two geographical regions of India i.e. the Northeast Region (NER) and West coast region (WCR). These regions are physically different from the rest of the country; they form distinct physiographic units, topographically rugged and receive heavy rainfall. Southwest monsoon rainfall data for the period 1875-2006 and the trends are tested by Mann Kendall test of significance. The analysis reveals that in the NER; Arunachal Pradesh and Assam/Meghalaya meteorological sub-divisions (MS) show significant decrease in rainfall. This decrease can be attributed to the increase in deforestation and decreasing trend in depression over the Bay of Bengal. For the WCR, significant decrease is observed at Kerala while it is reverse for Coastal Karnataka. The significant decrease in rainfall at Kerala can be ascribed to the absence of off shore troughs and cyclones/depressions during the monsoon period (1909-2000). Apart from this, there is an increase in urban and agricultural area, all these factors might have influenced in decreased rainfall over Kerala.

Keywords: Climate Change, Depressions, Deforestation, Mann Kendal test, Off-shore troughs

1. INTRODUCTION

Climate change is not only a major global environmental problem, but is also an issue of great concern to a developing country like India. More than 60% of billion plus population practice agriculture in this country. Indian farmer, in spite of making rapid progress in the irrigation, still depends on the monsoon rains. Climate change is likely to threaten food production, increase water stress and shortage, sea-level rise that could flood the standing crop and coastal settlements, and increase in epidemics.

Analysis of rainfall is the starting point for accurate assessment of water resource which is vital for developmental planning, flood mitigation, and efficient water management. Information about the long term trends of rainfall is also important as it would help in understanding the climate change events. Therefore, a proper trend analysis of monsoon rainfall is required for social and economic planning to assess the impact of global warming.

Increase in global surface temperature is likely to lead to the changes in precipitation, and therefore the analysis of precipitation trends during the 20th Century has attracted the attention of the researchers in different regions of the world. IPCC 2001 noted that global precipitation trends were positive throughout the last century, however, the trends vary regionally and seasonally (Osborn *et al.* 2000). Long term variations in heavy precipitations were also examined over Italy (Brunetti *et al.*

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2001a and 2001b). The study carried out by Groisman and Rankova (2001) indicated that precipitation has increased in the USSR during the warm and cold seasons. While in India, Singh and Sontakke (2002) observed the fluctuations of precipitation amounts during 1829-1999 for the Indo- Gangetic Region. Their study indicated a significant trend from 1939 over the central part, and a significant decreasing trend over eastern parts of the country. The findings of Guhathakurta and Rajeevan (2006) revealed that there is a significant decreasing trend in rainfall over Jharkhand, Chattishgarh and Kerala during the southwest monsoon season. No long-term-trend in the south west monsoon rainfall over the country but significant regional variation was observed by them. Kripalani *et al*. (2007a&b) pointed out an increase in mean monsoon precipitation associated with intensification of land–ocean pressure gradient during the establishment phase of the monsoon.

With the backdrop of trend analysis on global and regional scales, an attempt is made to investigate, the spatio-temporal variations of rainfall over the Northeast Region (NER) and West coast region (WCR) of India as depicted in Figure 1.

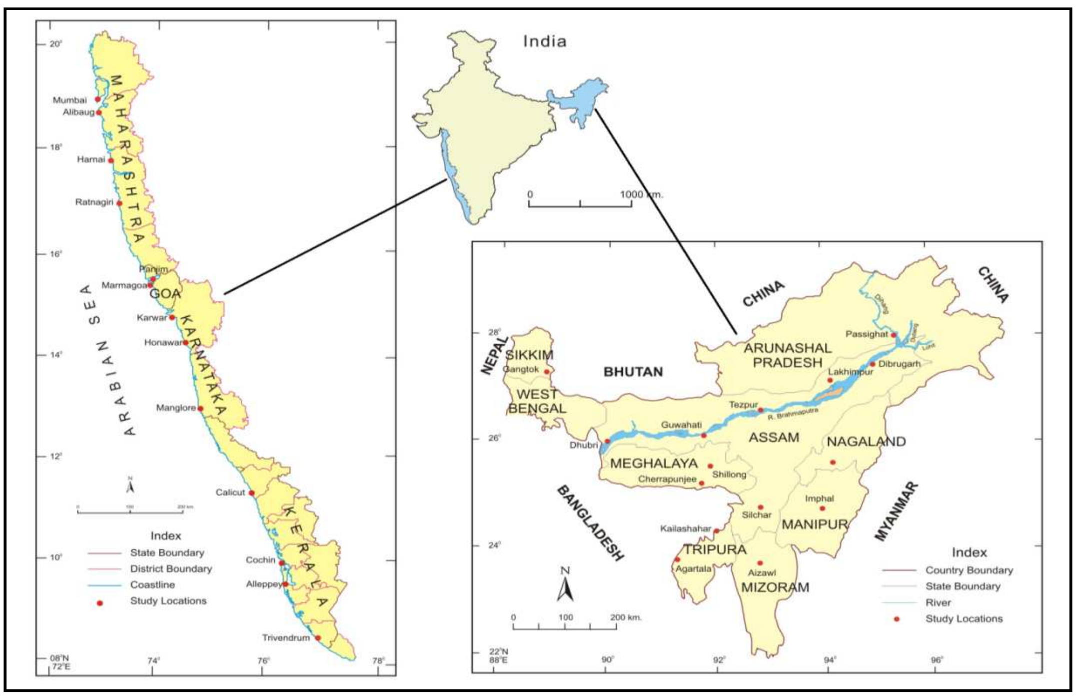

Figure 1. *Study Area of NER and WCR.*

These two regions are physically different from the rest of the country: they form distinct physiographic units, topographically rugged and receive copious rainfall. This has been achieved by the following objectives;

- To study the rainfall trends and determine the rate of changes during monsoon season for 4 Meteorological Sub-divisions (MS) i.e., Arunachal Pradesh, Assam/Meghalaya, Nagaland, Manipur, Mizoram & Tripura and Sub-Himalayan West Bengal in the NER and 3 from the WCR- Konkan/Goa (KG), Coastal Karnataka (CK) and Kerala
- To investigate the epochal variations and examine the relationship between onset date and the rainfall amount.

2. DATA AND METHODOLOGY

Monsoon rainfall (June-September) data for 7 MS from NER and WCR during the period 1875 – 2006 was procured from India Meteorological Department (IMD), Pune. Mann-Kendall and linear regression analyses were employed to detect the trends, and were statistically tested at 0.05 and 0.01 levels of significance. MS rainfall data were also subjected to moving averages of 11 years (in agreement with Pant and Rupa Kumar, 1997).

In order to analyze the onset dates for the study regions, the onset dates for the period 1950-2006 were obtained from various IMD publications. The dates of southwest monsoon arrival at the southernmost tip of the NER and over the Konkan/Goa, Coastal Karnataka and Kerala MS were noted from Indian Daily Weather Reports (IDWR), Climate Diagnostic Bulletin of India and Mausam. The monsoon onset date of the MS has been converted into day (Julian calendar) and standard statistical methods (like mean deviation, standard deviation, Correlation and significant tests) were adopted.

3. RESULTS AND DISCUSSION

3.1 Trends in MS monsoon rainfall

In order to understand the causative factor for significant increase/decrease in monsoon rainfall, Mann-Kendall test was adopted. Since, there was less deviation from the results of Mann-Kendall test to linear regression; the linear trends were used for illustration as reported in Figure 2 (a-b). The rainfall trends and decadal rate of change of 4 MS Arunachal Pradesh, Assam/Meghalaya, Nagaland, Manipur, Mizoram & Tripura and Sub-Himalayan West Bengal in the NER are reported in Table 1 also illustrated in Figure 2 (a-b).

Table 1. *Sub-Divisional Monsoon Rainfall Trends (NER)*

S.N	Met. Sub-divisions	Trend	Decadal Rate (mm)
1	Arunachal Pradesh (AP)	-*	-52.785
2	Assam /Meghalaya	-**	-10.905
3	Nagaland, Manipur Mizoram & Tripura (NMMT)	-	-5.125
4	Sub-Himalayan West Bengal (SHWB)	-	-0.496

(Indicate 0.05 and ** 0.01 levels)*

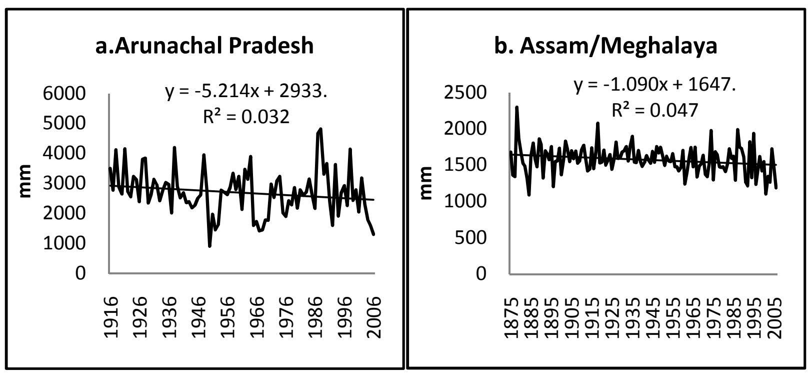

Figure 2 (a & b). *Sub-divisional Monsoon Rainfall (NER)*

It is clear from the above figure that all the four MS denote decreasing trends for monsoon season but significant in AP (95%) and Assam/Meghalaya (99%). The decadal rate of change for these MS reveals that the rate of decrease is highest in AP where rainfall is decreasing at the rate 52.7 mm per decade.

The significant decreasing trend in monsoon rainfall might be attributed to the linearly growing demand of fuel wood consumption in the NER. Consequent deforestations in the mountainous region lead to the decrease in rainfall (Figure 3 a). Along with the deforestation, the synoptic systems - low-pressure areas and depressions - over the Bay of Bengal show decreasing trend which is again responsible for the decrease in rainfall activities over the NER (Figure 3 b).

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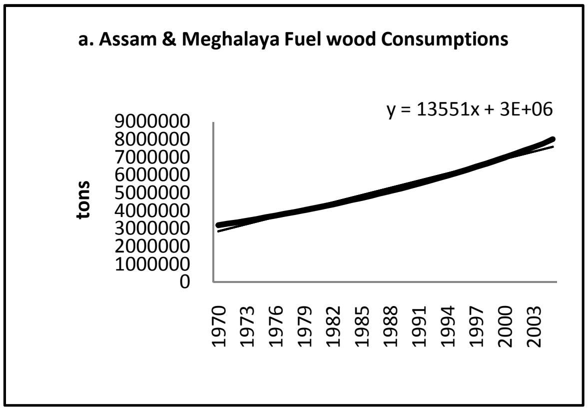

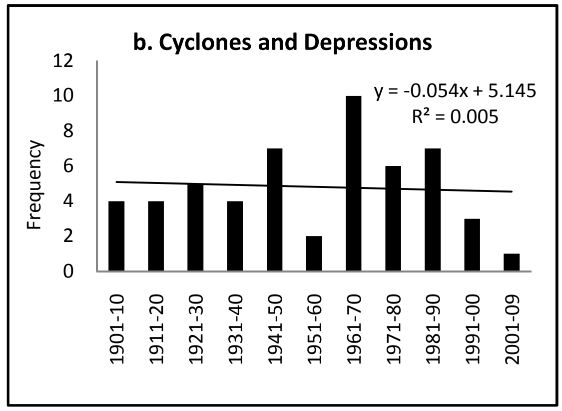

Figure 3 (a). *Fuel wood Consumption* ***(b)***. *Cyclones and Depression during Monsoon season (NER).*

During the last two decades, the years 1991, 1992, 1994, 1996, 2001, 2002, 2003 & 2006 witnessed more drought frequency. This is due to the decrease in rainfall during the month of July and August as no cyclone and depressions were formed during the monsoon season except during the month of June in 1991. The present findings are in conformity with that of Srivastava *et al.* (1992, 1998) and Manjunath *et al.* (2007).

In order to find out the rainfall behavior over the MS in WCR, three MS namely, Konkan/Goa (KG), Coastal Karnataka (CK) and Kerala have been selected. The results obtained are presented in the following Table 2 and illustrated in Figure 4(a & b).

Table 2. *Sub-Divisional Rainfall Trends (WCR).*

S.N	Met. Sub-divisions	Trend	Decadal Rate (mm)
1	Konkan/Goa	-	-8.371
2	Coastal Karnataka	+*	23.054
3	Kerala	-**	-41.823

*(Indicate *0.05% and ** 0.01% Significant Trend).*

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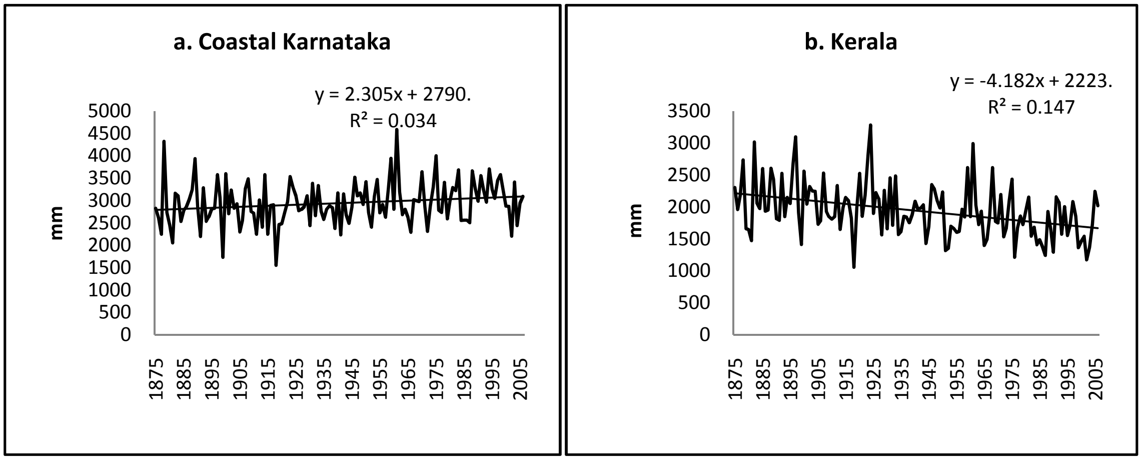

Figure 4 (a & b). *Sub-divisional Monsoon Rainfall (WCR).*

From the Table and figure, it can be inferred that CK reports significant increase in monsoon rainfall at 95% while KG and Kerala sub-divisions exhibit decrease in rainfall which is significant at 99% level for Kerala. The above findings are well supported by the works of Guhathakurta and Rajeevan (2006) which has revealed significant decreasing trend in rainfall over Kerala during the southwest monsoon season.

The decadal rates of increase/decrease for these MS are reported in the following Table 2. The rate of decrease is found to be highest over Kerala where rainfall is decreasing at the rate 41.82 mm per decade while it is increasing at the rate of 23 mm per decade in Coastal Karnataka.

The significant increase in monsoon rainfall is attributed to synoptic feature forming over Coastal Karnataka particularly the west coast trough. The significant decrease in rainfall during monsoon season at Kerala can be ascribed to the absence of off shore troughs and cyclones/depressions during the monsoon period (1909-2000) except during the month of September (1979). As a result, the moist laden air coming from the Arabian Sea might have decreased leading to the low rainfall. Apart from the synoptic system, there is an increase in urban and agricultural area, all these factors might have influenced in decreased rainfall over Kerala (Figure 5 a-c). The present study is in agreement with the result of Srivastava *et al.* (1998).

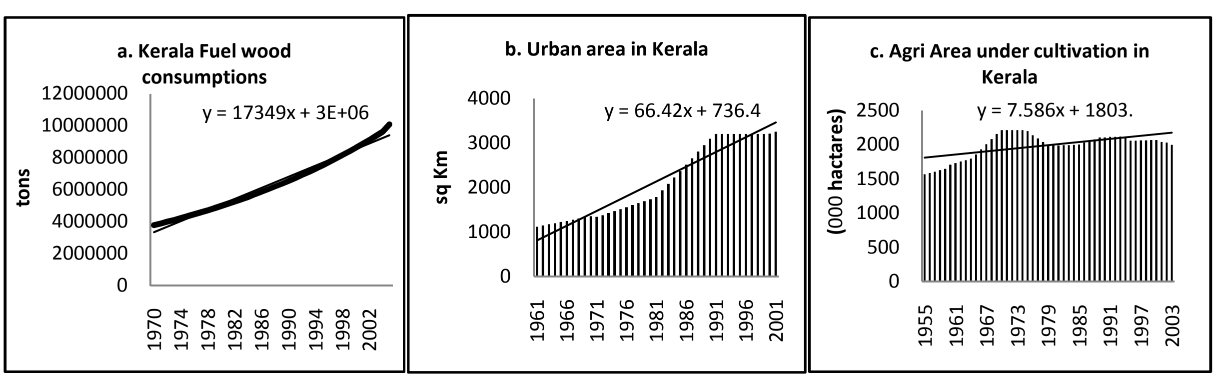

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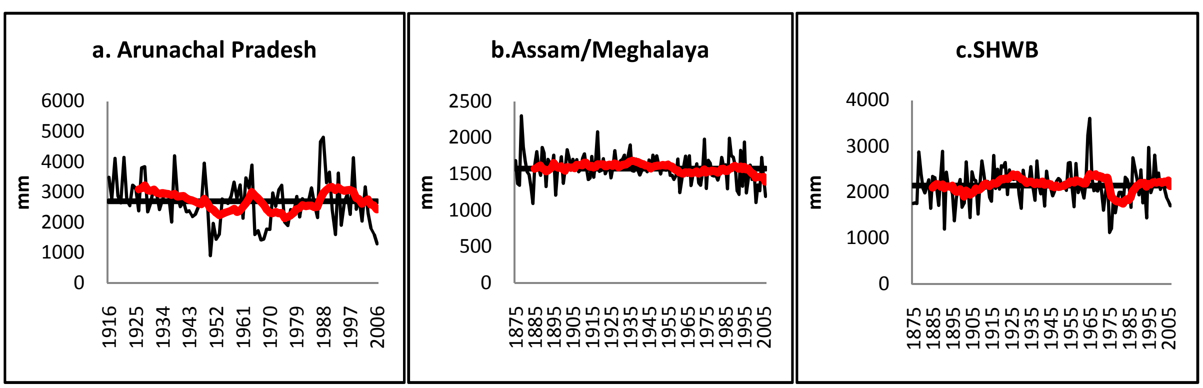
Figure 5 (a-c). *Fuel wood Consumption and Land use Trends*

3.2 Epochal variations of the monsoon rainfall

It is known fact that Indian summer monsoon rainfall values display multi-decadal variations in which there is a clustering of wet and dry anomalies (Pant and Rupa Kumar, 1997). To examine the epochs of wet and dry or the above-normal and below-normal conditions, 11 years moving averages of summer monsoon rainfall were computed and the low frequency events were identified. 11 years moving average is commonly used in the time series data to smoothen out short-term fluctuations and highlight longer-term trends or cycles. The results are presented in Figure 6 (a-d).

The 11 years moving average for AP indicates that the rainfall was above-normal prevailed up to 1947 after which it remained below-normal till 1960's and also during 1965-1985. Again, it stayed above the mean till 2005 and since then it shows a decreasing tendency. For Assam/Meghalaya, the 11 years moving average of rainfall was above the mean during the period 1885 till 1955, and then it was below mean. For SHWB and NMMT, 11 years moving average was on the mean from 1915-1975, from 1975 onwards however it showed decreasing tendency.

In the WCR (Figure 6 e-g), the rainfall patterns with 11 years moving averages for KG indicate that the rainfall remained above the mean till 1900 and thereafter, it is below the mean till 1930's. The period between 1930 and 1990's witnessed above the mean rainfall. During recent decades, however, it shows decreasing trend. For CK, the 11 years moving average rainfall was above the mean from 1945 onwards till 2006. For Kerala, the 11 years mean rainfall was above the average rainfall during the period 1885 to 1940 and from 1940 onwards it is showing decreasing tendency.



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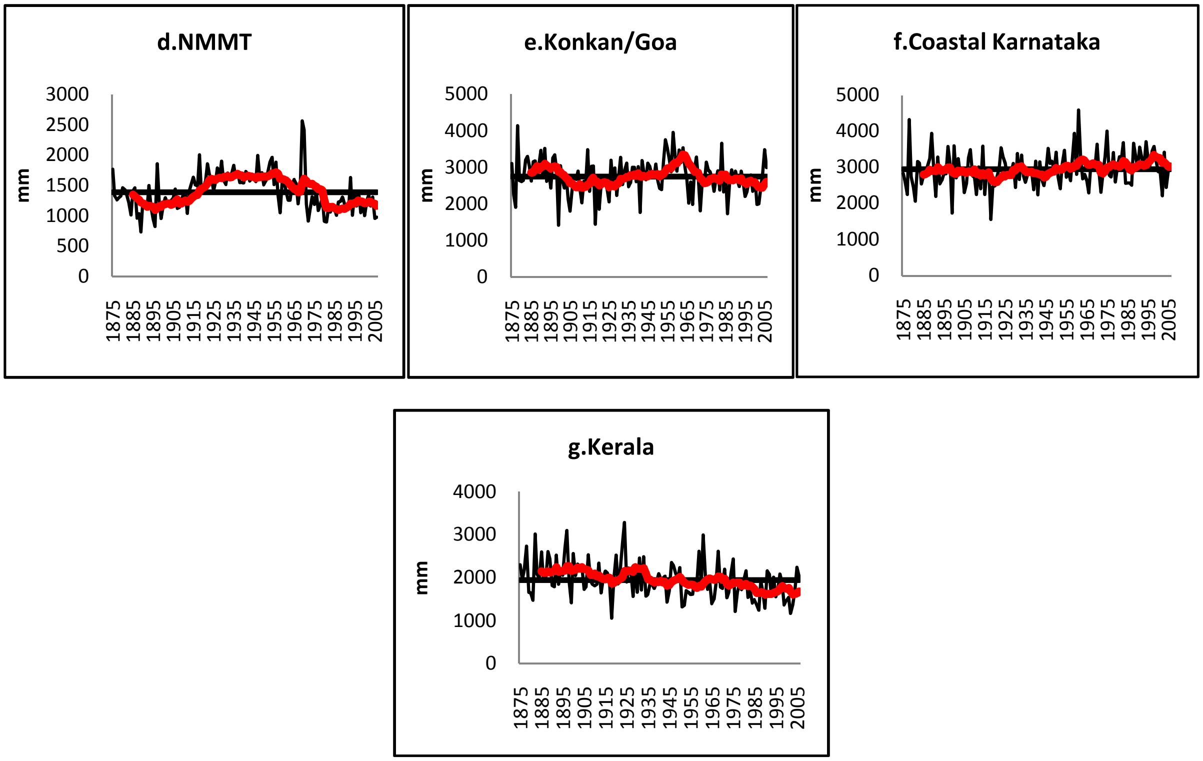

Figure 6 (a-g). *Sub-divisional Monsoon Rainfall 11 Years Moving Averages (NER & WCR)*

3.3 Analysis of monsoon onset date

As mentioned in the earlier section, the summer monsoon over India is the principal rainfall season for India. Onset and withdrawal dates are among the most important parameters of the south west monsoon and play crucial role for the monsoon rainfall variations. However, large year-to-year variations are observed in respect of the dates of monsoon onset over Kerala (MOK). Although, the correlation between the dates MOK and the total seasonal rainfall during summer monsoon season is very weak (Joseph *et al.* 1994; Dhar *et al.* 1980), the timely arrival of the monsoon is of utmost significance. If the date of MOK is delayed, considerably it may affect the crucial agricultural operations like sowing of Kharif crops. The MOK though a regularly occurring one is a very complex phenomena, it is a non-linearly linked with many factors like surface and upper air winds, sea surface temperature etc.

Various researchers have studied the relationship between onset dates and many weather parameters. For instance, Ananthakrishnan and Thiruvengadathan (1968) studied the onset date with winter westerly circulation and the thermal gradient at 200 hPa level. Gupta and Ali (1985) associated the monthly mean wind and temperature data at 300 and 200 hPa levels for the month of April with the onset of the south west monsoon while Kung *et al.,* (1980) developed regression equations for forecasting the onset dates over Kerala. There are few studies related to the onset date and the normal rainfall over the MS with respect to the NER.

With this in background, an attempt is being made to understand the relationship between the onset dates and the rainfall over different MS. In order to analyse the early onset date and late onset over NER and WCR, standard deviation was used to measure the scatter of this data. Hence standard deviations (σ) have been worked out taking into consideration mean+/- 1 SD for the period 1950-2006. The results are presented in Table 3 (a-d).

Table 3. *Monsoon Onset*

a. NER			b. Kerala		c. CK		d. K/G	
	EO	LO	EO	LO	EO	LO	EO	LO
	1950	1956	1953	1952	1953	1955	1956	1961
	1952	1960	1958	1956	1958	1960	1957	1962
	1953	1962	1967	1960	1967	1961	1958	1971
	1957	1975	1968	1961	1968	1962	1965	1990
	1958	1988	1972	1962	1972	1990	1967	2006
	1959	1999	1979	1990	1979	1999	1972	
	1964	2000	1983	2001	1983	2001	1979	
	1972	2004	1995	2004	1995	2004	1983	
	1983	2006	1997		1997		1986	
	1986		2003		2003		1992	
	1992							
	2005							
NOD	3rd June		1st June		5th June		10th June	
SD(σ)	6.3		7.1		6.8		6.5	
EO	12		10		10		10	
LO	9		8		8		5	
(µ)	36		39		39		42	

Normal onset dates (NOD), Early onset (EO), Late onset (LO) & Normal years (µ)

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The above Table 3 (a) indicates that during the last 57 years, 21% of the years were with early monsoon onset while 63% of years were normal whereas 14 % of the years were of late onset. The standard deviation of monsoon onset for the NER is 6 days, this means that it is deviating up to 6 days from the normal.

In case of WCR, the onset dates for the 3 MS were collected from IMD publications and early/late onset were worked out and reported in Table 3 (b-d). The above Table indicates that σ varies between 6.5 at Konkan and Goa to 7.1 at Kerala. The common years when west coast sub divisions had early onset e.g. 1958, 1967, 1972, 1979 and 1983 whereas late onset are 1961, 1962 and 1990.

An attempt was also made to find out the relationship between the onset dates and the rainfall amount over the study regions however the results were not significant.

4. CONCLUSIONS

In a nutshell, the following may be summarized as follows

- All the Meteorological sub-divisions in Northeast region denote decreasing trend but significant in Arunachal Pradesh and Assam/Meghalaya.
- The rate of decrease is highest in Arunachal Pradesh where rainfall is decreasing at the rate 52.7 mm per decade.
- Coastal Karnataka in West coast region reports significant increase in monsoon rainfall while Kerala exhibit significant decrease.
- The rate of decrease is found highest over Kerala where rainfall is decreasing at the rate 41.82 mm per decade while it is increasing at the rate of 23 mm per decade in Coastal Karnataka.

It can be concluded that on the meteorological sub-divisional level, Arunachal Pradesh and Assam/Meghalaya reveals significant decreasing trend in the monsoon rainfall. The results discussed above are so complex that it is very hard to interpret the observed changes in climatic variables in terms of cause and effect relationship precisely. Under the current global warming, it is likely that there have been increase in the number of heavy precipitations events within many land regions (IPCC, 2007). When compared with the IPCC, the results shows different character i.e. there is a decrease in summer monsoon rainfall except for the Coastal Karnataka sub-division. To some extent, the changes in land cover/land use (deforestation) and decrease in cyclones/depressions could have influence the weather parameters particularly precipitation over the Northeast region. It is also with the global climate changes that modify the weather patterns regionally as observed in the study. For the West coast region, the significant increase in monsoon rainfall can be related to synoptic systems forming over Coastal Karnataka particularly the west coast troughs. The significant decrease at Kerala can be attributed to the absence of off-shore troughs and cyclones/depressions during the monsoon season. These changes in rainfall can be attributed partly to regional and local factors which in addition to the overall effect of global warming. The dates of monsoon onset as well the correlation with the rainfall over the study regions do not show any significant trend. Further, detailed and in-depth analyses are required to find the causes for abrupt changes and trends in rainfall over the study regions.

5. ACKNOWLEDGEMENT

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