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Understanding climate change in terms of rainfall fluctuations and status of agricultural productivity in Northeastern States of India

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ABSTRACT

Although several studies have been done to understand climate change in India, state wise analysis on trend of climatic variables particularly of rainfall is lacking in northeast India. The paper analyses the behaviour of annual and seasonal rainfall in Northeaster region of India looking for trends in long historical data series. We have used Sen's coefficient and modified Mann–Kendall test to analyse historical rainfall data monthly, annually and seasonally. The data for the present study were obtained from the Indian Meteorological Department (IMD). Our analysis shows that there is huge variation in monthly rainfall trends from one state to another. Seasonal wise analysis displays a negative trend of rainfall for most seasons and most states. Finally, annual data reveals that Assam, Manipur, Mizoram, Nagaland, Tripura, and Sikkim have experienced decreasing trend of rainfall during the study period. Arunachal Pradesh is the only state where the annual trend of rainfall is on the rise. This decreasing trend of rain fall is really an issue of concern given the fact that the Northeast is agrarian economy which immensely relies on natural rainfall for agricultural activities. Further the infrastructure for assured irrigation facilities has not been developed in the region as of yet. As the agricultural productivity is very low, public policy support for development of irrigation infrastructure is urgently required for diversifying agricultural sector.

Key words: *Climate change, Sen's Coefficient, Mann-Kendall test, Northeast India*

Introduction

Climate change is known as large variations in climate averages that exist for decades or even for longer periods. Although climatic condition has changed in all over the world, its impact is not uniform across regions (Trajakovich and Kolkovic, 2009). Since the rate of increase in temperature and variability in precipitation is significantly higher in Himalayan region, therefore, the potential impacts of climate change on ecology, economy, and society are enormous in this region (Mathison *et al*., 2013). In recent years, various studies have been done for detecting possible climate trends and changes in India. These studies broadly concluded that during last century there is observed increasing trend in surface temperature in India (Hingane *et al*., 1985; Srivastava *et al*., 1992; Arora *et al*., 2005, Dash *et al* ., 2007). Though researchers, in general, have observed that the trend and magnitude of warming in India over the years is broadly consistent with the global trend and magnitude. However, the diurnal temperature range (DTR)[1] trends in India are reasonably different from those observed in other parts of the world because of the comparatively large increase in 'maximum daily temperature' over a major part of India (Srivastava *et al.*, 1992; Rupa Kumar *et al.,* 1994). Similarly, while there is conclusive evidence that the trend of rainfall is decreasing in most part of the world, several studies relating to changing pattern of rainfall over India observed that there is no clear trend of increase or decrease in average rainfall over the country (Mooley and Parthasarathy, 1984; Thapliyal and Kulshrestha, 1991; Kumar *et al.*, 2010). Though the above studies have made important contribution to understand the trend of climatic variables in India, yet these studies have focused on the analysis of climatic data for a single station or a group of stations. State wise analysis on trend of climatic variables particularly of rainfall is lacking in northeast India. Secondly, what limited studies have been done those too did not control for the presence of serial correlation in long time series data. This study aims to study the trends in the monthly, annual, and seasonal rainfall in NER.

Study Area

The NER of India consists of eight states viz; Assam, Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura. The region is spread over 255 168 km^2, which is about 3.85% of the country's area and extends from 21050' to 29^{0}34' northern latitude, and 85^{0}34' to 97^{0}50' eastern longitude. From bio geographical point of view, this region can be divided into the Eastern Himalayas in the north, the Northeast Hills in the south, and the Brahmaputra River Basin in between (Mani, 1974). The region is characterized by high forest cover, rich biodiversity, fragile mountain ecosystems, high seismicity, and heavy precipitation. The region has diverse climate ranging from hot and moist tropical in plains and foot hills to cold and dry alpine of higher mountains due to influence of locations, topography and altitude. The economy of northeast is largely agrarian in nature with over 70% of the population directly or indirectly depends on agriculture for livelihood. Like other parts of India, most of the crop areas in the region is under rainfed agriculture, and so is in areas highly vulnerable to climate variability and climate change.

Methodology

Methods

In order to estimate the magnitude of trend in rainfall, we have used a nonparametric method known as Sen's estimator (Sen, 1968) and statistical significance of the trend in the time series was analysed using Mann–Kendall (MK) test (Mann, 1945; Kendall, 1975).

Sen's method assumes a linear trend in the time series and has been widely used for determining the magnitude of trend in time series data of climatic variables (Lettenmaier *et al.,* 1994; Yue and Hashino, 2003; Partal and Kahya, 2006). In this method, the slopes (Ti) of all data pairs are first calculated by

$$T_i = \frac{x_j - x_k}{j-k} \quad for\ i = 1, 2, \ldots \ldots . N. \qquad \ldots \text{(i)}$$

where xj and xk are data values at time j and k (j>k), respectively. The median of these N values of Ti is Sen's estimator of slope, which is calculated as follows:

$$\beta = \begin{cases} T_{\frac{N+1}{2}} & N\ is\ odd \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & N\ is\ even \end{cases} \qquad \ldots (2)$$

A positive value of â indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

To ascertain if the Sen's estimator of slope is statistically, nonparametric Mann–Kendall (MK) test has been employed. The MK test is a non-parametric rank based test which checks the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend. Test statistic S is defined as follows.

$$S = \sum_{i=2}^{n} \sum_{j=1}^{t-1} sign\ (x_i - x_j)$$

Where n is the length of the data series x_i and x_j are the sequential data in the series and

$$sign\ (x_i - x_j) = \begin{cases} -1\ for\ (x_i - x_j) < 0 \\ \ 0\ for\ (x_i - x_j) = 0 \\ \ 1\ for\ (x_i - x_j) > 0 \end{cases}$$

$$E[S] = 0$$

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{p-1}^{q} t_p(t_p - 1)(2t_p + 5)}{18}$$

Where t_p is the number of ties for the pth value and q is the number of tied values. The second term in the variance formula is for tied censored data. Standardised test statistics Z is computed by

$$z = \begin{cases} \frac{s-1}{\sqrt{Var(s)}} \\ 0 \\ \frac{s+1}{\sqrt{Var(s)}} \end{cases}$$

If the computed value of $|Z|>z_{á/2}$, the null hypothesis (H_0) is rejected at á level of significance in a two – sided test. In this analysis, the null hypothesis was tested at 95% confidence level[2].

The annual compound growth rates for area, production and yield of foodgrains, non-foodgrains both for NER and All India for the period 2000-01 to 2013-14 have been calculated. We have estimated annual compound growth rates using the semi-log trend equation

$$ln\ Y = a + bt \qquad ...(3)$$

where Y is the value of the variable and t is time.

Data

We have used collected state wise monthly data on rainfall from Indian Meteorological Department (IMD) for all the eight states of NER for the period 1901 to 2017. The Indian Meteorological Department (IMD) is an agency of the Ministry of Earth Sciences of the Government of India which solders the responsibility for meteorological observations, weather forecasting and seismology in India. IMD is headquartered in Delhi and operates hundreds of observation stations across India and Antarctica. Meticulous quality checks and pre-processing are done by IMD before releasing data so as to provide error-free data for analysis and design. Therefore, IMD data is regarded as the most reliable long series of data for the study area.

The data on area, production and yield of foodgrains, non-foodgrains and irrigation both for NER and All India level have been collected from the Directorate of Economics and Statistics, Government of India. The data pertains to the period 2000-01 to 2012-13 for irrigation and 2000-01 to 2013-14 for other variables.

Results and Discussion

Trend analysis of monthly rainfall data

As expected, rainfall trends show large variability in magnitude and direction of trend from one state to another. We have estimated 96 values (12 months × 8 states) of Sen's coefficient for all eight states of NER. Our analysis reveals that 61 values of Sen's coefficients were negative, 43 values were positive and one value was zero (Table 1). Out these 61 negative values, 42 values were statistically significant at least at 10 % level of significance. On the other hand, 25 of the positive values were found to be statistically significant. This clearly indicates that the decreasing trend of rainfall is dominating the picture. Nagaland, Manipur and Assam are the three states for which the trend of rainfall is negative for most of the months. Conversely, Arunachal Pradesh and

Table 1. Sen's estimator of slope (mm/year) for monthly rainfall

	AP	AS	MAN	MEGH	MIZ	NAG	TRI	SK
JAN	0.02	-0.01	-0.04	0.00	-0.02	-0.04	0.04	-0.01
FEB	0.09	-0.04	-0.13	-0.05	-0.09	-0.11	-0.02	-0.04
MAR	0.23	-0.02	-0.03	0.06	0.18	-0.10	0.27	0.12
APR	0.36	-0.01	-0.57	0.31	0.06	-0.33	0.61	0.14
MAY	0.28	-0.41	-1.24	-0.38	-0.92	-0.65	0.53	-0.15
JUN	-0.14	-1.47	-3.28	-0.59	-2.04	-1.74	-1.71	-1.31
JUL	0.54	-0.19	-0.88	1.55	-0.39	-0.37	-2.47	-0.09
AUG	-0.05	-0.70	-1.38	0.15	-0.69	-0.64	-1.37	-0.76
SEP	0.61	0.02	-0.41	0.62	0.31	-0.06	-0.50	0.10
OCT	0.12	-0.28	-0.70	0.17	-0.30	-0.30	-0.26	-0.22
NOV	0.00	-0.04	-0.13	0.01	-0.09	-0.10	0.00	-0.08
DEC	0.02	0.02	0.01	0.01	-0.01	0.02	0.00	0.00

Note: 1. Bold values indicate statistical significance at least at 90% confidence level as per the Mann – Kendall test (+for increasing trend and " for decreasing trend).2. AP=Arunachal Pradesh, AS=Assamn, Man=Manipur, Megh= Meghalaya, Miz=Mizoram, Nag=Nagaland, SK=Sikkim, and TR= Tripura.
Source: Computed by authors

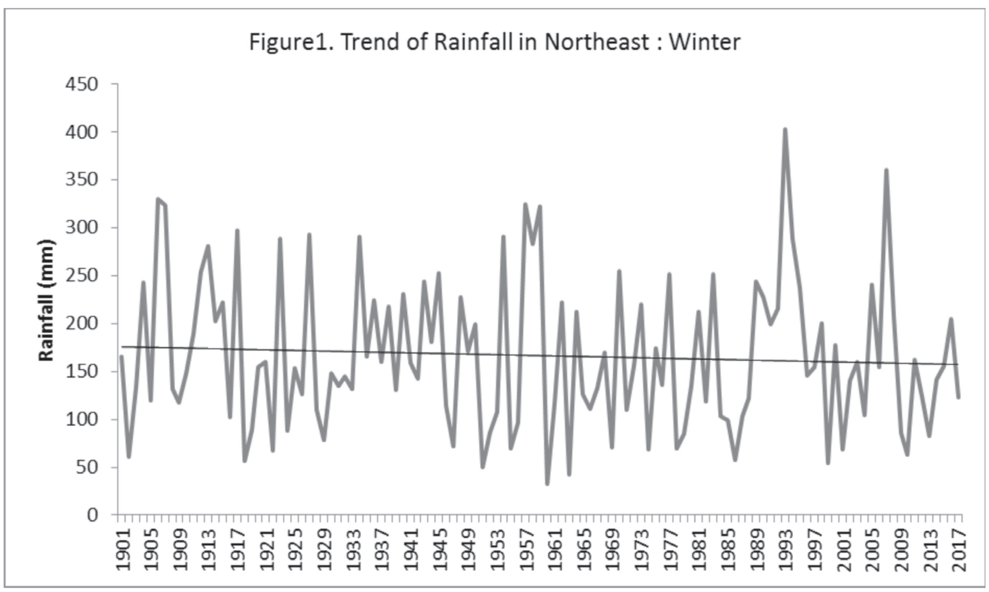
Meghalaya have experienced increasing trend of rain fall for most of the months.

Trend analysis of seasonal rainfall

In order to examine if there are trends in the data at seasonal scale, each year was divided into four climatic seasons (Rao, 1981), namely winter (January – February), pre-monsoon (March – May), southwest monsoon (June – October), and post-monsoon (November – December). It is important to note here that the southwest monsoon season in this region lasts for 5 months (June – October) in contrast to 4 months (June – September) for the whole of India, while the post monsoon season lasts for only 2 months. We begin the trend analysis of seasonal rainfall by drawing scatter plots of seasonal rainfall data (Fig. 1 to 4).

As we can see, apart from pre-monsoon season, the trend of rainfall is roughly negative in northeast India in all other seasons. In pre-monsoon season, the trend line is almost parallel to the horizontal axis which indicates that we do not have any noticeable trend of rainfall in pre-monsoon season. Speaking about the magnitude of rainfall, southwest monsoon is observed to have the highest magnitude of rainfall followed by pre-monsoon and post-monsoon seasons. Finally, year to year variation in rainfall is observed to be the highest in post-monsoon season marginally followed by winter season. Conversely, the year wise variation in rainfall is observed to be the lowest in southwest season.

In order analyse the trend of seasonal rainfall across different states, we have estimated Sen's slope. The estimated results are reported in Table 2.



Source: Compiled from IMD data

Table 2. Sen's estimator of slope (mm/year) for seasonal rainfall

	Winter	Pre-monsoon	Southwest Monsoon	Post-monsoon
AP	0.11	0.85	1.04	0.03
AS	-0.07	-0.38	-2.51	-0.04
MAN	-0.21	-1.76	-5.30	-0.10
MEGH	-0.06	0.07	1.41	0.04
MIZ	-0.10	-0.49	-3.07	-0.08
NAG	-0.15	-1.04	-3.14	-0.09
SK	0.02	1.44	-6.49	0.05
TR	-0.06	0.31	-2.49	-0.06

Bold values indicate statistical significance at least at 90% confidence level as per the Mann – Kendall test (+for increasing trend and " for decreasing trend).

As we can see, for Arunachal Pradesh (AP), the estimated slopes are all positive and statistically significant. This indicates that the trend of rainfall in AP has increased in all seasons over the study period. However, the magnitude of Sen's coefficient is not uniform across seasons: the value of the coefficient is estimated to be highest in southwest monsoon and lowest in post-monsoon seasons. The picture of Sen's coefficient is just opposite in Assam: here all the values are positive and are statistically significant baring the case of post-monsoon season. This reveals that the trend of rainfall has decreased in Assam: the southwest monsoon season being the most suffering season of the lot. Similarly, the Sen's coefficients are estimated to be positive in all seasons for Manipur. Therefore, Manipur also share the same fate that of Assam: falling trend of rainfall in all seasons. Fourthly, the trend of rainfall has exhibited a decreasing trend in winter and increasing trend in post-monsoon seasons for Meghalaya. The trend of rainfall in pre-monsoon and southwest monsoon seasons is found to be statistically insignificant for the state. Fifthly, Mizoram and Nagaland have exhibited an decreasing trend of rainfall in all seasons which are statistically significant. Like Assam, these states also experienced highest fall in rainfall in southwest monsoon and lowest fall in rainfall in post monsoon seasons. In

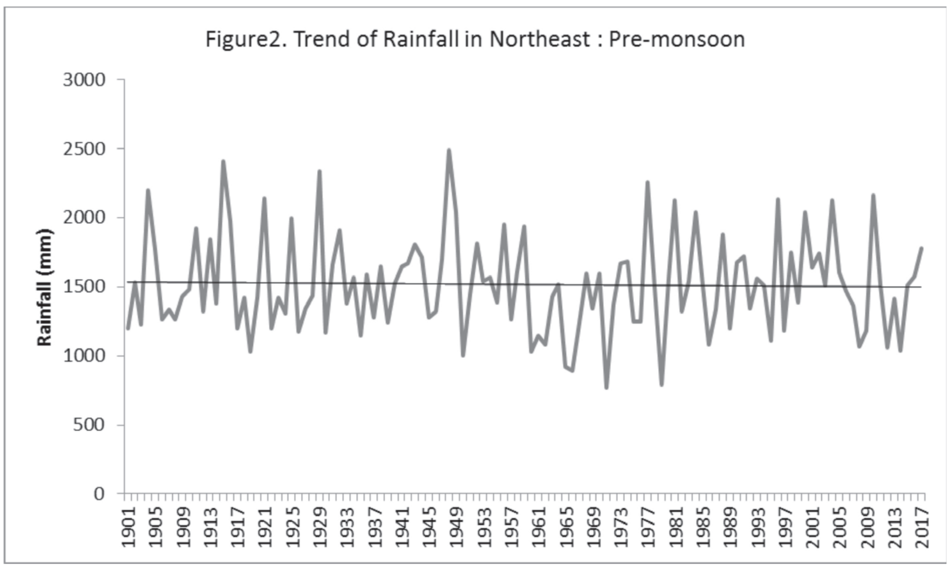


Figure2. Trend of Rainfall in Northeast : Pre-monsoon

Source: Compiled from IMD data

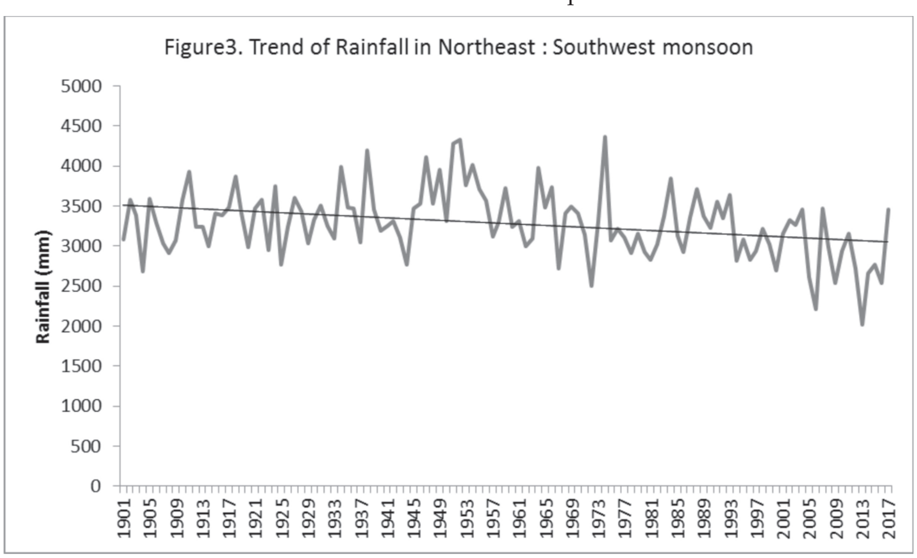


Figure3. Trend of Rainfall in Northeast : Southwest monsoon

Source: Compiled from IMD data

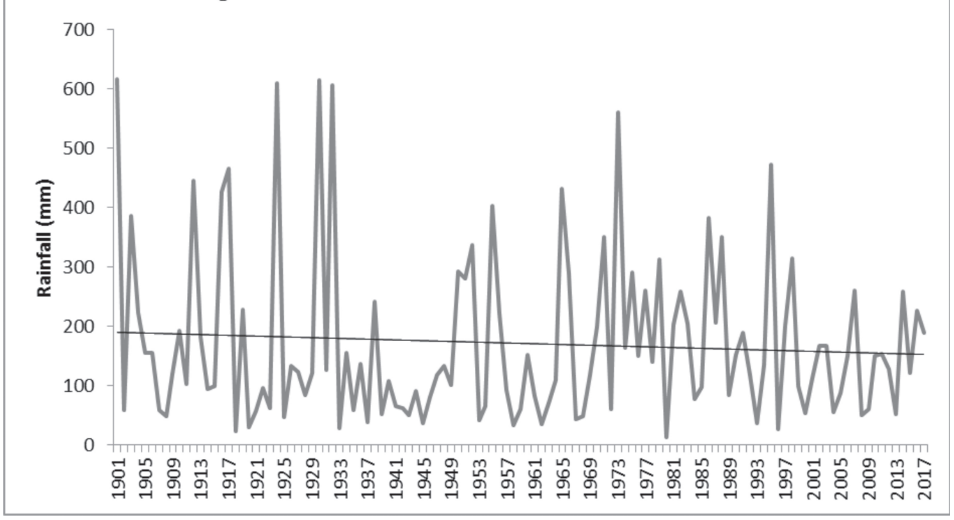


Figure4. Trend of Rainfall in Northeast : Post-monsoon

Source: Compiled from IMD data

Sikkim, the Sen's coefficient is found to be significant only for pre-monsoon and southwest monsoon seasons. In the pre-monsoon seasons, the positive value of the coefficient indicates that the trend of rainfall has an increasing trend for the season, whereas the negative value of the coefficient in southwest monsoon reveals that the trend of rainfall has decreased in this season. Finally, Tripura also have exhibited a decreasing trend of rainfall in all but pre-monsoon season. The Sen's coefficient of rainfall is found to be statistically insignificant in pre-monsoon season.

Trend analysis of annual rainfall

We begin this section with a comparative analysis of annual rainfall data of India and NER. To do this comparison, we have calculated annual average rainfall data of India and NER from 1901 to 2013. The calculated data have been plotted in a trend line figure to make the comparison visually convenient (Figure 5).

Table 3. Sen's estimator of slope (mm/year) for annual rainfall

States	Sen's Coefficient
AP	1.67
AS	-2.78
MAN	-6.51
MEGH	1.20
MIZ	-3.77
NAG	-3.93
TR	-5.12
SK	-2.37

Bold values indicate statistical significance at least at 90% confidence level as per the Mann – Kendall test (+for increasing trend and “ for decreasing trend).
Source: Estimated by authors

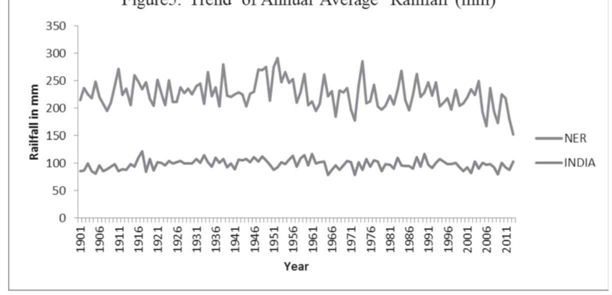


Figure5. Trend of Annual Average Rainfall (mm)

Source: Compiled from IMD data

As we can see, the annual average rainfall is significantly higher for NER than all India average during the entire study period. Secondly, the trend of annual average rainfall has remained almost stable for India while that of NER has shown a gradual decline since 1960. The Sen's coefficient estimated for annual data of NER states are reported in Table 3.

It is evident from the table that the coefficient of Sen's estimator is negative and statistically significant for Assam, Manipur, Mizoram, Nagaland, Tripura, and Sikkim. This indicates that six of the NER states have experienced decreasing trend of

Table 4. Share of area under different crops in total cropped area

Year	States	Cereals	Pulses	Other Food-crops*	Total food-crops	Non-food crops	Net Irrigated Area
			Percentag				
1950-51	NER	85.4	2.7	0.0	88.1	11.9	24.4
	All India	75.3	12.4	1.1	88.8	11.2	15.4
1970-71	NER	85.3	2.9	1.1	89.2	10.8	24.2
	All India	74.5	11.4	1.3	87.2	12.8	16.5
1990-91	NER	83.3	3.6	1.0	87.9	12.1	19.3
	All India	70.0	12.3	1.8	83.7	16.3	31.1
2012-13	NER	59.3	3.9	20.5	83.7	16.4	10.4
	All India	50.	11.3	9.6	71.6	28.4	47.7

* include sugarcane, fruits, vegetables, condiments and spices.

rainfall during the study period. Out of these six states, the negative value of Sen's coefficient is estimated to highest for Manipur marginally followed by Tripura. Therefore, the decreasing trend of rainfall is more in these two states. The two other states where the coefficient turns out to be positive are Arunachal Pradesh and Meghalaya. But the Sen's coefficient for Meghalaya is not statistically significant indicating that there no significant trend of annual rainfall for the state Meghalaya: the annual rainfall has remained almost stable during the study period. Arunachal Pradesh is the only state where the Sen's coefficient is positive and significant. This implies that the annual trend of rainfall is on the rise in Arunachal Pradesh during the study period.

Cropping pattern and agricultural growth

A striking feature of the cropping pattern of NER of India is the predominance of cereals, mainly paddy, which accounted for 59.3 percent of total cropped area in 2012-13 as against 83.3 percent in 1990-91 (Table 4). It has undergone changes since 1990-91.

Table 5. Annual compound growth rate during 2000-01 to 2013-14

States		Area	Production	Yield*
			Percent	
Arunachal Pradesh	Foodgrains	1.2	4.7	4.0
	Non-foodgrains	2.4	5.3	
Assam	Foodgrains	-0.2	2.2	2.6
	Non-foodgrains	0.7	0.6	
Manipur	Foodgrains	3.9	1.9	-1.0
	Non-foodgrains	32.2	27.3	
Meghalaya	Foodgrains	0.0	2.0	2.1
	Non-foodgrains	1.1	0.5	
Mizoram	Foodgrains	-4.9	-7.8	-3.6
	Non-foodgrains	-7.9	-2.5	
Nagaland	Foodgrains	2.0	4.4	2.6
	Non-foodgrains	3.2	7.1	
Sikkim	Foodgrains	-0.7	0.6	1.5
	Non-foodgrains	-1.1	0.7	
Tripura	Foodgrains	0.3	2.5	2.1
	Non-foodgrains	4.1	-3.0	
NER	Foodgrains	0.2	2.3	1.2
	Non-foodgrains	1.7	2.2	
All India	Foodgrains	-1.4	2.5	3.4
	Non-foodgrains	2.2	2.7	

*only foodgrains considered

However total food crops constituted 83.7 percent in the NER as against 71.6 percent for the country as a whole. This indicates slow process of crop diversification in NER as farmers produce less variety of non-food crops. The important reason for slow rate of diversification is the non-availability of irrigated area in NER. While the net irrigated area in the NER declined from 24.4 percent in 1950-51 to 10.37 percent in 2012-13, the same increased from 15.4 percent to 47. 7 percent for the country as a whole. Interestingly, there is a substantial increase in the area of other food crops to 20.5 percent in 2012-13 as against only 1.0 percent in 1990-91 in NER. This is mainly due to the increase in the area under cultivation of fruits and vegetables since 2003-04 onwards.

For India as a whole, a significant breakthrough in agricultural sector occurred during the mid-1960s with the use of seed-water-fertiliser technology. The country switched from a food importer to a net food exporter by the beginning of 1970s. The share of pulses and other non-food crops shows an increasing trend for the country as a whole since 1970-71. But the opposite trend has been observed for the NER. Even during the latest decade 2000-01 to 2012-13 of the availability of irrigation facilities in the NER lags far behind the rest of the country (refer Fig. 6).

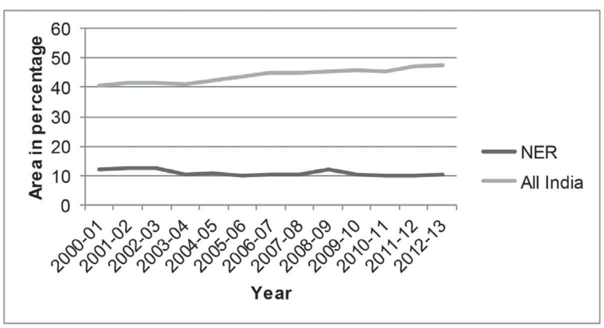


Fig. 6. Percentage share of irrigated area to total cropped area

The annual compound growth rates of area, production and yield estimated for the period 2000-01 to 2013-14 are presented in Table 3. The area growth for both foodgrains and non-foodgrains mainly attributed to growth of CPR area in NER and growth of yield estimated only 1.2 percent. For the country as a whole, negative growth of food grains area was compensated by higher growth of area under non-foodgrains (2.2 percent) and yield growth (3.4 percent).

Conclusion

The paper analyses the behaviour of annual and seasonal rainfall in Northeaster region of India looking for trends in long historical data series. The Variance Correction Approach as prescribed by Yue and Wang (2004) has been used to deal with the serial correlation in long time series. We have applied Sen's coefficient technique to detect the nature of trends of eight rainfall series with more than 100 years of observation. Monthly rainfall trends show large variability in magnitude and direction of trend from one state to another. Nagaland, Manipur and Assam are the three states for which the trend of rainfall is negative for most of the months. Conversely, Arunachal Pradesh and Meghalaya have experienced increasing trend of rain fall for most of the months. Secondly, seasonal data indicates that, apart from pre-monsoon season, the trend of rainfall is roughly negative in northeast India in all other seasons. Year to year variation in rainfall is observed to be the highest in post-monsoon season marginally followed by winter season. Conversely, the year wise variation in rainfall is observed to be the lowest in southwest season. Finally, annual data reveals that Assam, Manipur, Mizoram, Nagaland, Tripura, and Sikkim have experienced decreasing trend of rainfall during the study period. Arunachal Pradesh is the only state where the annual trend of rainfall is on the rise.

The agriculture in Northeastern states is rainfed and only about 10% of total cropped area is under irrigation with wide variation across the states. Despite the importance of irrigation, cultivators in the region hardly use any artificial means to irrigate their land. They mainly rely on rainwater to cultivate their land which is grossly irregular in time and quantity. Thus a suitable public policy towards agricultural development with emphasis on providing irrigation infrastructure to the cultivator is urgently required for the region.

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