



Analysis of trend and temporal variability in rainfall over Northeast India

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सार – भारत में वर्षा की प्रवृत्ति का अध्ययन बहुत महत्वपूर्ण है जहां खाद्य सुरक्षा और फलस्वरूप अर्थव्यवस्था मुख्य रूप से वर्षा पर निर्भर है। पूर्वोत्तर भारत की वर्षा में कालिक विविधता का विस्तृत विश्लेषण करने के लिए वर्तमान कार्य किया जाता है। पूर्वोत्तर भारत (एनईआई) में मासिक, मौसमी और वार्षिक वर्षा में कालिक विविधता का अध्ययन 150 वर्षों (1857-2006) के मासिक आंकड़ों का उपयोग करके किया गया है। समय श्रृंखला डेटा में प्रवृत्ति का परिमाण प्राचलिक और गैर-प्राचलिक परीक्षण यानी रैखिक समाश्रयण और मैन-केंडल परीक्षण दोनों का उपयोग करके निर्धारित किया जाता है। आंकड़ों के विश्लेषण से मॉनसून की वर्षा में उल्लेखनीय कमी और मॉनसून के बाद की वर्षा में वृद्धि का पता चलता है। एनईआई वर्षा पर उत्तरी अटलांटिक दोलन (एनएओ) और दक्षिणी दोलन (एसओ) जैसे वैश्विक टेलीकनेक्शन के प्रभाव का भी कालिक विविधता का समाधान करने के लिए अध्ययन किया जाता है। विस्तृत विश्लेषण करने के लिए, समय श्रृंखला वर्षा आंकड़ों को आगे 30 वर्ष की पांच सामान्य अवधियों में विभाजित किया गया है: 1857-1886 (P1), 1887-1916 (P2), 1917-1946 (P3), 1947-1976 (P4) और 1977-2006 (P5) और उपर्युक्त अवधियों के लिए मौसमी वर्षा का प्रवृत्ति विश्लेषण किया गया। जिसमें मॉनसून वर्षा के लिए पांच वर्गीकृत अवधियों में से चार के लिए कमी की प्रवृत्ति और मॉनसून के बाद की वर्षा के लिए प्राप्त तीन अवधियों में उल्लेखनीय वृद्धि को दर्शाया गया है। वर्षा के पैटर्न में परिवर्तन देखने के लिए वार्षिक और साथ ही मौसमी वर्षा के लिए 11 साल के रनिंग मीन की गणना भी की गई।

ABSTRACT. Study of rainfall trend is of great importance in India where food security and economy primarily dependent on rainfall. Present work is carried out to perform the detailed analysis of temporal variability in North East India rainfall. Temporal variation in monthly, seasonal and annual rainfall over northeast India (NEI) is studied using monthly data for 150 years (1857-2006). Magnitude of trend in time series data is determined by using both parametric and non-parametric test, *i.e.*, linear regression and Man-Kendall test. Analysis of data suggests a significant decrease in monsoon rainfall and increase in post monsoon rainfall. Influence of global teleconnection like North Atlantic Oscillation (NAO) and Southern Oscillation (SO) on NEI rainfall is also studied to address the temporal variation. To carry out detail analysis, time series rainfall data is further divided into five normal periods of 30 year each: 1857-1886 (P1), 1887-1916 (P2), 1917-1946 (P3), 1947-1976 (P4) and 1977-2006 (P5) and trend analysis on seasonal rainfall performed for above mentioned periods. Decreasing trend for four out of the five classified periods for monsoon rainfall and significant increase in three periods obtained for post monsoon rainfall. 11 year running mean also calculated for annual as well as seasonal rainfall to see the changes in rainfall pattern.

Key words – Parametric test, Non parametric test, NAO, SO.

1. Introduction

Trend analysis of meteorological variables (Rainfall, Temperature, humidity etc.) helps in understanding the climate change of any region. Among all the variables, rainfall received in an area is one of the key variables to study climatic variability and further for planning socio economic development strategies accordingly. According to the third assessment report of the Intergovernmental Panel on Climate Change (IPCC, 2001) general impacts of climate change on water resource indicates an

intensification of the global hydrological cycle affecting both ground and surface water availability. Hence understanding the dynamic nature of climate is vital for planning and management of the available water resources.

Many researchers have studied the variability and trends in weather parameters across the world (Abaje *et al.*, 2012; Tabari *et al.*, 2011; Deka *et al.*, 2009; Klein Tank and Können, 2003; Kadiolgu, 1997). In India also, several studies carried out to investigate the trends in

annual and seasonal rainfall (Parthasarathy and Dhar, 1975; Mooley and Parthasarathy, 1984; Soman *et al.*, 1988; Thapliyal and Kulshrestha, 1991; Guhathakurta and Rajeevan, 2008; Kumar *et al.*, 2010). Rainfall trend of Northeast India region is also studied by many researchers Lairenjam *et al.*, 2017; Markand and Kishtwal, 2014. Study of Lairenjam *et al.*, 2017 shows nonsignificant negative trend for monsoon and positive trend for pre and post monsoon season among the 30 stations selected for the study. Study carried out by Kumar and Jaswal, 2016 for Western Himalayan Region indicates significant decreasing trend in monsoon rainfall and significant increase in post monsoon rainfall.

Since the rainfall performs crucial role in agriculture, water resource, hydroelectric power generation and consequently economy of the region hence along with annual and seasonal variation monthly rainfall variation also plays an important role in planning purpose. In view of recent increase in extreme weather events like drought, flood, heavy rainfall etc in the Northeast India, need of monthly or weekly rainfall analysis of long term time series data is very important. Therefore present study focus on monthly, seasonal and annual rainfall analysis for the period 1857-2006 to assess the long term trends in precipitation with detail analysis of 5 normal periods of 30 years each. The influence of NAO and SO have influence on Indian region monsoon is studied by various researchers (Sen Roy, 2011; Afzal *et al.*, 2013), statistically significant relationship of global indexes are depicted by the Kakade and Dugam, 2006, hence influence of global teleconnection on NEI rainfall is also carried out in present study.

2. Data and methodology

2.1. Study area

Northeast Indian (NEI) is the part of the country extending north of 21° N and east of 88° E. It is the land of magnificent picturesque beauty, possessing undulating hills, rolling grasslands, cascading waterfalls, rivers, terraced slopes to thrilling flora and fauna thus the physiography of the region ranging from Himalayan Hill to low lands. This geographical contrast reflects very well in the spatial distribution of rainfall as well, eg. annual mean of Assam & Meghalaya together is 2356 mm whereas for Manipur, Meghalaya, Nagaland, Sikkim and Tripura together the annual mean is 1993.3 mm (Kumar *et al.*, 2010).

2.2. Meteorological data

Monthly precipitation data series of Indian Institute of Tropical Meteorology (IITM), Pune

(<http://www.tropmet.res.in/>) for period 1857-2006 was used in the study. Where, longest possible instrumental area-averaged monthly, seasonal and annual rainfall series of seven homogeneous zones and the whole India have been developed using quality-controlled data from well spread network of 316 rain gauge stations. For the period 1901-2006, the area-averaged series has been prepared using simple arithmetic mean of the gauges in the particular area and for the period prior to 1901 (sometimes going back to 1813) with lesser available observations the series is constructed by applying theoretically vindicated objective method. Details of the dataset used for construction of rainfall data series available in Sontakke *et al.* (2008), it is mentioned by the author that number of observation station increases over the time in NEI region form 1829-2005. Number of observation station was consistently more than 25 after 1871 onwards whereas during the period 1857-1870 observation station number varies between 2 to 18. Monthly NAO (1886-2006) and SOI (1876-2006) indices used in the study was downloaded from <http://www.cru.uea.ac.uk> and <http://www.bom.gov.au> respectively.

2.3. Methodology used for determination of trend in rainfall

As per WMO (1989), mean of 30 years precipitation values are considered as normal, in the present study monthly and annual normal were calculated accordingly. Following WMO (1989) and Subash *et al.* (2011), monthly precipitation data of NEI was divided into five normal periods: 1857-1886 (P1), 1887-1916 (P2), 1917-1946 (P3), 1947-1976 (P4) and 1977-2006 (P5). In order to find the variation in five normal periods following statistical analysis were performed - Mean, standard deviation (SD), coefficient of variance (CV) for monthly, seasonal, *i.e.*, Winter (January and February), Pre-monsoon (March to May), Monsoon (June to September), Post-monsoon (October to December) and annual (January to December) precipitation. 11 year moving average also calculated for annual and seasonal precipitation to understand the change in rainfall pattern. Also to evaluate the trends in monthly, seasonal and annual precipitation linear regression analysis (Parthasarathy and Dhar, 1975; Pant and Rupa Kumar, 1997; Bhutiyan *et al.*, 2009) and Mann Kendall test (Yu *et al.*, 1993; Burn *et al.*, 2004; Bhutiyan *et al.*, 2009; Kumar and Jain, 2010; Subash *et al.*, 2011 and Hu *et al.*, 2012) were performed.

3. Results and discussion

3.1. Precipitation characteristics

The Mean, SD, CV (%) and % contribution of monthly, seasonal and annual precipitation during the

TABLE 1

Monthly, Seasonal and Annual rainfall over Himalayan region during 1857-2006

Month / Season	Mean (in mm)	SD	CV (%)	% Contribution in annual rainfall
Jan	14	13	90	0.6
Feb	27	18	64	1.3
Mar	58	33	57	2.7
Apr	133	44	33	6.1
May	243	57	24	11.3
June	401	69	17	18.6
July	432	71	16	20.0
Aug	377	68	18	17.5
Sep	302	64	21	14.0
Oct	142	68	48	6.6
Nov	25	26	105	1.1
Dec	8	10	132	0.4
Winter	41	22	54	1.9
Pre-Monsoon	433	80	19	20.1
Monsoon	1512	138	9	70.1
Post-Monsoon	175	73	42	8.1
Annual	2162	183	8	100.0

period 1857 to 2006 are given in Table 1. The annual mean precipitation over NEI is 2162 mm with SD of 183 mm and CV of 8% indicate that annual precipitation was consistent. Monsoon contributes 70.1% of the annual precipitation. The contributions of winter, pre-monsoon and post-monsoon to annual precipitation were 1.9%, 20.1% and 8.1% respectively. CV in case of winter was highest (54%) indicating inconsistency followed by 42, 19 and 9% for post monsoon pre monsoon and monsoon respectively. Statewise rainfall and variability change study carried out by India Meteorological Department using 1989-2018 data shows monsoon CV 19.0, 12.9, 24.9, 24.5, 19.1 & 17.6 respectively for Mizoram, Assam, Meghalaya, Nagaland, Tripura and Sikkim whereas the annual CV for north east states ranges from 12.1 to 21.9. Increased CV with the recent data indicates increasing variability in the rainfall with time. As per the desertification and land degradation map of SAC, ISRO 2021 (Using 2003-2018 data) 6 states of North East India, viz., Mizoram, Arunachal Pradesh, Assam, Tripura, Nagaland & Meghalaya shows high rate of desertification whereas Mizoram shows highest rate of desertification where shifting of rainfall pattern plays a significant role.

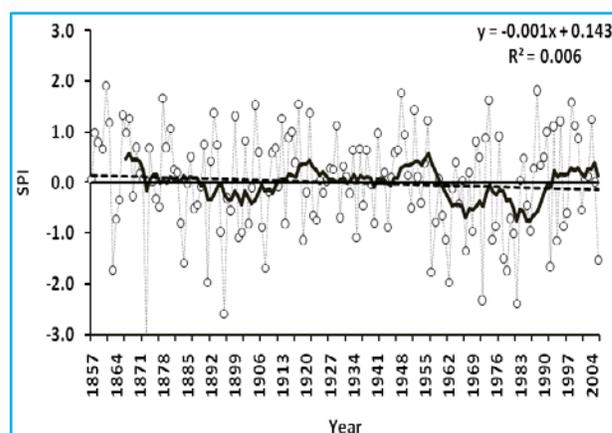


Fig. 1. Annual precipitation trends over NEI during 1857-2006

In monthly analysis, maximum precipitation over NEI occurs during July (431 mm) followed by August (377 mm), which contributes more than 37% of annual precipitation whereas least precipitation occurs in December (8 mm) followed by January (14 mm). Low variation in rainfall over North East India leads it to the potential area for hydroelectric projects but inter seasonal shifting impacts negatively on agriculture. The changing rainfall pattern affects the flow of river and health of monsoon spring.

The percentage contribution of monthly and seasonal precipitation to total annual precipitation for all the five normal periods was shown in Table 2. Among all the five normal periods (P1 to P5), P1 period had the highest mean annual precipitation (2198 mm) and P4 had the least (2142 mm) over the region, contribution of monsoon to annual precipitation varies between 69% to 72%. Contribution of winter precipitation is 2%, pre-monsoon is between 20 to 21% and post-monsoon was between 7 to 9% to annual precipitation for all the normal periods. In general the contribution of July precipitation is highest and varies between 19 to 21% and the contribution of December was least between 0 to 1%.

3.2. Annual precipitation trends

Annual precipitation trends over NEI were shown in Fig. 1. the annual precipitation had two main decline periods, one from 1889-1910 corresponding to P2 and another from 1960-1992 which lies in P4, the significant decrease in mean rainfall of June month was observed in the normal of P2 & P4. The increase in June and September rainfall also indicated in the overall increase of P3. Monsoon normal of all the years shows decrease except for the month of July where mean had increased from 431 in the P1 to 449 mm in the P5 period.

TABLE 2

Monthly and Seasonal precipitation for all the five normal periods and their % contribution to annual precipitation

Month / Season	P1 (1857-1886)		P2 (1887-1916)		P3 (1917-1946)		P4 (1947-1976)		P5 (1977-2006)	
	Mean	% cont								
	Jan	13	1	14	1	15	1	15	1	11
Feb	28	1	30	1	29	1	21	1	29	1
Mar	63	3	64	3	52	2	53	2	58	3
Apr	127	6	142	7	128	6	123	6	144	7
May	240	11	237	11	249	11	247	12	241	11
Jun	416	19	399	19	422	19	410	19	359	17
July	431	20	423	20	419	19	441	21	449	21
Aug	397	18	383	18	378	17	366	17	359	17
Sep	319	14	298	14	308	14	280	13	305	14
Oct	139	6	127	6	142	7	153	7	152	7
Nov	17	1	24	1	27	1	28	1	27	1
Dec	9	0	6	0	6	0	7	0	12	1
Winter	41	2	45	2	45	2	36	2	40	2
Pre-Mon	429	20	443	21	429	20	422	20	444	21
Monsoon	1562	71	1503	70	1527	70	1497	70	1472	69
Post-Monsoon	165	8	157	7	174	8	187	9	191	9
Annual	2198	100	2148	100	2175	100	2142	100	2147	100

TABLE 3

Mann Kendall test ‘Z’ values for seasonal and annual precipitation

Season / Annual	P1	P2	P3	P4	P5	1857 - 2006
Winter	0.71	-0.50	1.07	0.75	1.30	0.01
Pre-Monsoon	0.00	-0.18	1.11	-1.03	1.36	0.28
Monsoon	-1.00	0.57	-1.21	-0.64	-0.29	-2.39*
Post-Monsoon	-1.03	1.75	0.32	-1.07	1.50	2.12*
Annual	-1.32	1.28	0.07	-1.39	1.57	-1.13

* Significant at 95% confidence level

Mann Kendall test ‘Z’ values (Table 3), shows non-significant annual decreasing trend observed over NEI during 1857-2006 and significant decrease in monsoon

rainfall whereas the trend observed for post monsoon rainfall shows increase in trend.

3.3. Seasonal precipitation trends

3.3.1. Winter

While performing the parametric trend analysis for the same data though the observed trends were non-significant but there were significant decline during some period observed in seasonal analysis. For winter rainfall there were two decline periods from 1951-1961 and another from 1968-1991 [Fig. 2(a)]. According to Guhathakurta and Rajeevan (2006) a decrease in winter rainfall was observed in Nagaland, Manipur, Mizoram and Tripura.

3.3.2. Pre-monsoon

In pre-monsoon precipitation, non-significant increasing trends observed over NEI for the period 1857-

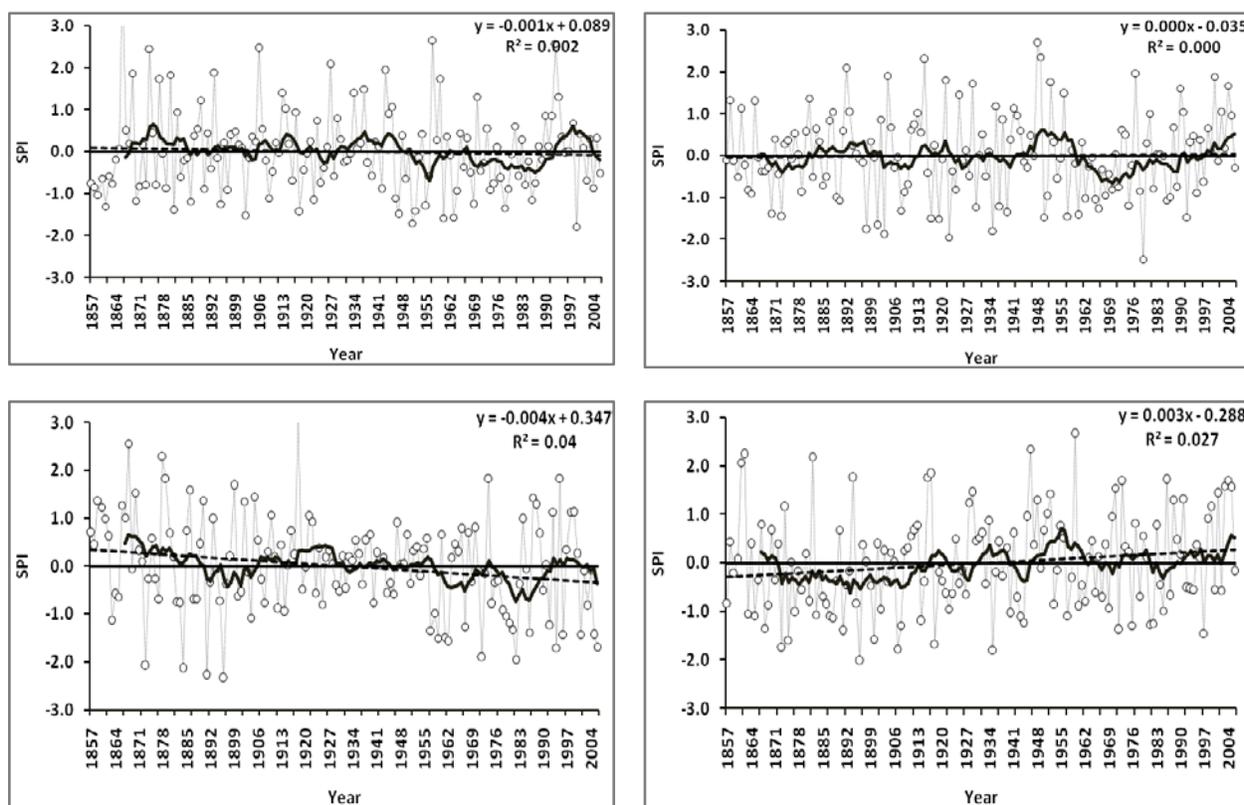


Fig. 2. Seasonal precipitation trends over NEI during 1857-2006 (a) Winter (b) Pre-monsoon (c) Monsoon and (d) Post-monsoon

2006 [Fig. 2(b)]. There three decline period during (1869-1880, 1903-1913 and 1960-1989) observed over NEI [Fig. 2(b)].

3.3.3. Monsoon

In monsoon precipitation, significant decreasing trends were observed over the regions (Table 3). Markand and Kishtwal (2014) also reported the significant decreasing trend for monsoon in NEI. Larenjam *et al.* (2017) also observed significant decrease in 6 stations for July and August rainfall in their study over 30 stations of Northeast India. Decreasing trend in NMMT subdivision monsoon rainfall was also reported by Jain *et al.* (2012). There were two decline periods 1958-1973 & 1976-1992 over NEI [Fig. 2(c)]. The monsoon precipitation decreased by 2.4% over NEI during last decade (1997-2006). In normal periods, decreasing trends are observed for all normal periods except P2 over NEI.

3.3.4. Post-monsoon

In post-monsoon precipitation, a significant increasing trend is observed over NEI (Table 3). There

were mainly two enhance precipitation periods from 1946-1962 & 1991-2006 over NEI [Fig. 2(d)]. A sharp increasing trend is observed in 1944-1956. The post-monsoon rainfall was high by 23.4% during last decade. In normal periods increasing trends are observed P2, P3 and P5. Jain *et al.* (2012) reported large variation from one year to another but a significant trend is reported for post monsoon rainfall during 1871-2008.

3.4. Monthly precipitation trends

Monthly precipitation trends were studied for entire period (1857-2006) as well as for all the five normal periods by using Mann Kendall test (Table 4). In NEI, significant decreasing trends were observed in June and August with 26 mm and 21 mm from their respective monthly mean precipitation during the period 1857-2006. Percentage-wise, these were 6% each from their respective mean precipitation. Non-significant decreasing trends were observed in February, March and September. Non-significant increasing trends were observed in October and November.

TABLE 4
Mann Kendall test 'Z' values for monthly precipitation

Month	P1	P2	P3	P4	P5	1857 -2006
Jan	1.45	-1.34	0.39	0.55	0.93	0.18
Feb	0.43	0.52	0.73	0.57	1.05	-0.07
Mar	1.96*	-0.55	0.50	-0.25	0.59	-1.16
Apr	-0.96	1.11	-0.07	0.66	0.89	0.24
May	0.52	-0.62	1.59	-2.85**	0.75	0.58
June	-1.03	0.14	-0.79	-0.27	0.68	-2.60**
July	-2.09*	0.52	-1.68	0.00	-0.07	0.62
Aug	0.00	0.71	-0.04	-0.18	0.32	-2.20*
Sep	1.14	0.00	-0.18	-0.21	-0.32	-1.16
Oct	-1.25	1.50	0.36	-1.25	1.68	1.52
Nov	-0.43	0.21	-0.21	0.64	-0.34	1.46
Dec	0.84	1.37	0.71	-0.98	-2.27*	0.40

* Significant at 95% confidence level

** Significant at 99% confidence level

TABLE 5
Percentage (%) departure of decadal mean from normal, Excess (E), Deficient (D) precipitation years over NEI from 1857-2006

Decade	Annual			Winter			Pre-monsoon			Monsoon			Post-monsoon		
	% Dep.	E	D	% Dep.	E	D	% Dep.	E	D	% Dep.	E	D	% Dep.	E	D
1857-1866	3.5	3	1	-10.1	1	2	1.8	3	0	3.9	3	1	7.1	2	2
1867-1876	0.2	1	1	10.9	2	1	-6.3	0	2	3.2	3	1	-11.8	1	3
1877-1886	1.3	2	1	0.2	2	2	1.6	1	0	2.8	3	1	-12.3	2	1
1887-1896	-2.8	1	2	11.0	2	1	6.9	3	1	-3.9	1	2	-20.9	1	4
1897-1906	0.3	2	1	8.8	1	1	-3.7	1	3	2.3	3	1	-8.8	0	1
1907-1916	0.6	2	1	4.4	1	1	3.5	2	1	-0.1	1	0	-1.2	1	3
1917-1926	0.3	2	1	-11.9	0	2	-5.3	2	3	3.6	2	0	-11.3	1	1
1927-1936	1.2	1	1	20.3	2	0	-0.7	2	2	0.3	0	0	8.9	2	1
1937-1946	0.3	0	0	15.5	3	1	2.6	1	2	-0.9	0	0	1.3	1	3
1947-1956	4.9	3	0	-35.2	0	4	10.3	4	1	2.5	0	0	21.0	3	0
1957-1966	-5.4	0	3	5.1	2	2	-11.7	0	5	-4.1	0	4	-3.2	1	1
1967-1976	-2.2	1	3	-10.5	1	1	-6.5	0	1	-1.4	1	2	3.7	2	2
1977-1986	-6.3	0	3	-26.0	0	2	-3.4	2	2	-6.9	0	5	-2.7	1	2
1987-1996	2.2	4	2	28.3	2	0	0.7	2	1	1.4	4	3	6.4	2	1
1997-2006	2.0	3	1	-11.0	0	1	10.1	3	0	-2.5	2	3	23.6	5	1

TABLE 6

Correlation coefficients between seasonal and annual precipitation over NEI and NAO and SOI indices

	Index	Annual	Winter	Pre-Monsoon	Monsoon	Post-Monsoon
1857-2006	NAO	-0.113	0.310	-0.062	-0.164	0.046
1876-2006	SOI	0.255	-0.139	-0.102	0.307	0.307

3.5. Decadal annual and seasonal precipitation analysis

Decade wise percentage departure of annual & seasonal mean from normal, excess, deficient precipitation years over NEI from 1857-2006 are shown in Table 5. Annual/seasonal excess and deficient precipitation years are calculated by following methodology:

Seasonal/Annual Excess precipitation = Seasonal/Annual mean precipitation + SD

Seasonal/Annual Deficient precipitation = Seasonal/Annual mean precipitation - SD

In NEI, during the decade 1947-1956, annual percentage departure of decadal mean from normal was maximum (4.9% more than its annual normal) with 3 excess annual precipitation years and no deficient year. During the same decade, pre-monsoon precipitation was maximum with 10.3% more than its normal precipitation and 21% during post monsoon. The monsoon precipitation was maximum in 1857-1866 decade with 3.9% more precipitation from its respective mean. Further, during the decade 1987-1996, there were maximum numbers (4) of excess annual as well as monsoon precipitation years. During decade 1977-1986, annual percentage departure of decadal mean from normal was minimum (6.3% less than its annual normal) with 0 excess annual precipitation years and 3 deficient year. Also during the same decade, decadal monsoon precipitation was less by 6.9% than normal monsoon precipitation with 0 excess years and 5 deficient years. It was also observed that number of deficit shows increased in recent decades for monsoon and decrease for post monsoon in recent decades.

3.6. Impact of global teleconnection on precipitation

Correlation coefficients between seasonal and annual precipitation over NEI and NAO and SO indices were calculated and depicted in Table 6

Impact of NAO on NEI rainfall was negative with annual, pre monsoon and monsoon rainfall over the region and significant positive relation with winter rainfall during

1857-2006. Whereas significantly positive relationship between the annual, monsoon and post monsoon rainfall with SOI during 1876-2006. Decadal analysis of rainfall in connection with the global oscillation depicts the consistently positive relation with the NAO except 1907-1926 and strengthening during recent decades in post monsoon. Study carried out by Sarkar *et al.*, 2004 also suggests decreasing impact of SOI on Indian monsoon including Northeast India.

4. Conclusions

An understanding of the spatial and temporal distribution and changing patterns in rainfall is a basic and important requirement for the planning and management of water resources. This study has examined trends in monthly, seasonal, and annual rainfall over NEI. Study shows a non significant decreasing trend in annual, significant decrease in monsoon rainfall and significant increase in post monsoon rainfall over NEI region. Results also support the inter-seasonal shifting of rainfall without much change in the annual total rainfall of the region. Decadal analysis of the data indicates that the inter-seasonal shifting of the rainfall during recent decades (1947-2006) increased where, monsoon total is decreasing significantly and post monsoon is increasing. Strong positive correlation observed between SOI and monsoon as well as post monsoon rainfall with decreasing trend during recent decades for monsoon rainfall.

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