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MONSOONAL DROUGHTS IN INDIA – A RECENT ASSESSMENT

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ABSTRACT: Drought frequencies during the years 1901–2010 were investigated over three spatial units – All India, 5 Homogeneous Regions (HR) and 36 Meteorological subdivisions (MSs). The All-India rainfall trend is in fact indicative of no trend, while the Northeast HR (NER) shows a significant decrease. Furthermore, a significant decrease in rainfallis to be observed over Himachal Pradesh, Madhya Pradesh, Maharashtra and the Southern Peninsular region, and a significant increase over West Bengal, Punjab, Haryana, Coastal Karnataka, North Interior Karnataka and Rayalaseema.

There have been 21 All-India drought years during the last century, of which 13 were linked to El Niño. When compared with HRs, the WCR is highly prone to El Niño while the NER is not affected by this global tele-connection. Western Uttar Pradesh, Eastern Rajasthan, Uttarakhand, Vidharbha and Telangana shared 11–10 drought occasions with El Niño.

Maximum frequencies of droughts (21) were reported for East Madhya Pradesh within the WCR and Orissa within the Central Northeast Region (CNER), while Andaman, Nicobar and Rayalaseema experienced minimum drought episodes (12) over the last century.

Sixty percent of the MSs in the West Central Region (WCR) and the Northwest Region (NWR) were coherent with All-India droughts. During the years 1918, 1972 and 2002, the majority of HRs (except NER) witnessed normal or below-normal rainfall. Western Madhya Pradesh within the WCR saw maximum drought events (13). The highest degree of simultaneous occurrence of drought years between the MSs and all-India concern Eastern Rajasthan, Western Madhya Pradesh, East and West Uttar Pradesh. The study also found that the MSs in HRs highly affected are East Rajasthan (NWR), West Madhya Pradesh (WCR), West and East Uttar Pradesh (CNER), NER and Coastal Karnataka (Peninsular Region). Western Uttar Pradesh, Eastern Rajasthan, Vidarbha and Telangana had 10–11 occasions when El Niño and Drought years occurred.

KEY WORDS: drought, homogeneous regions, frequencies, El Niño.

INTRODUCTION

The Indian monsoon is known for its uneven distribution of rainfall in space and time. Some events are associated with a surfeit, while others are coupled with deficient, rainfall. Both are hydrological hazards causing damage and loss as regards crops, property and the generation of hydro-electricity that impose strain on the Indian economy. Certainly, these flood and drought (F/D) events exert an impact on food grain production in India (Preethi *et al.* 2011). While the IPCC's 2012 report states that there is no significant change (increase/decrease) in the magnitude and frequency of floods on the regional scale, the drought scenario reveals a significant change over some parts of the world. This report sustains the view regarding the erratic behavior of F/D events.

A recurrent aspect of the Southwest monsoon is that some areas of the country face the spectra of drought. This is a large-scale phenomenon and one of greater duration. It is also a slow process, such that it can be very difficult to determine inception and timing. This feature can be exemplified by the droughts of 1987 and 2002 with which the entire country witnessed severe drought conditions. Similarly, the monsoon of 2010 was associated with drought over the eastern and NE regions. In the Indian context, every drought year exhibits variations in spatio-temporal distribution. The critical significance of the monsoon has made it necessary to gain insights into the morphology of these extreme events. This comes as no surprise, given that this subject has been of interest to researchers since time immemorial.

Much research work has been devoted to the understanding of the characteristics of F/D events. One example might be Parathasarthy *et al.* (1984). Singh (2001) studied probabilities of F/D years over India during the SW monsoon period and noted that areas prone to such years are nearly the same. Nandargi *et al.* (2003) studied the floods associated with the severe drought of 2002 and concluded that Bihar experienced severe floods due to the excessive volume of water released from the northern tributaries

of the Ganga. Mall *et al.* (2006) studied the probability of drought occurrence with maximum probability in West Rajasthan (25%), Saurashtra and Kutch (23%), Jammu and Kashmir (21%) and Gujarat (20%). Sen and Sinha Ray (1997) observed a down ward trend for the area affected by all-India droughts over NW India, as well as central and southern parts of the Peninsula. Gore *et al.* 2010 and Sinha Ray, Shewale (2001) analyzed the spatial cohesion to drought occurrence between India and Maharashtra, and concluded that the probability of simultaneous occurrence of drought was between 30 to 40%.

Several studies (Sinha Ray and Shewale (2001), Shewale and ShravanKumar (2005) link La Niña /El Niño with F/D, and indicate that there is no one-to-one relationship between them. Singh (2001) studied the variability of monsoon rainfall during normal, flood and drought years and found an increase in countrywide rainfall, but decreases over the Central and Western Coastal regions of India. Sikka and Kulshrestha (2002) studied the droughts for the period 1877–2002 and categorized drought years as mild, moderate, severe and phenomenal. Tyalagadi *et al.* (2007) and Jenamani *et al.* (2005) analyzed the drought years 2002 and 2004, and found that July was the critical month contributing to seasonal water deficiency. Dutta *et al.* (2011) investigated the drought years 2002 and 2009 and concluded that the prolonged dry spell and weak monsoon circulation were the main causal factors under pinning deficit monsoons. Akre *et al.* (2012) studied the effect of El Niño years over Central India and found that rainfall was greater in La Niña years than during the El Niño.

The aforementioned studies are based on either the all-India or regional levels. Some have focused particularly on F/D year, while others have compared severe drought years. Sikka D.R. (2002) analysed F/D conditions from 1875–2000, considering different homogeneous regions (HR) of the country. However, no attempt was made to find consistency among drought incidences observed over the HRs. This paper, therefore, attempts not only to elucidate spatio–temporal variation to drought phenomena, but also to seek consistency in drought incidences between the three spatial units of all-India, five HRs, and 36 meteorological subdivisions (MSs). The work described here has thus aimed to identify whether there is any relationship between the above-mentioned spatial units and spatio-temporal variation in drought incidences across these three regions. With a view to these goals being accomplished, the sub-objectives outlined entailed:

- identification of drought years and their successive occurrences for the 3 different spatial units referred to,
- evaluation of the spatial cohesion between the three spatial units,
- assessment of the association between El Niño events and drought years.

DATA AND METHODOLOGY

Actual **D**aily **R**ainfall data (ADR) from 1350 rain-gauge stations spread across the whole of India were employed in the computation of monthly rainfall data by reference to the formula:

$$\text{ADR} = \frac{\sum rf}{N} \tag{1}$$

Where: rf – is actual daily rainfall,
N – is the total number of rain-gauge stations.

By using monthly rainfall data for the given MS, monsoon seasonal rainfall data are obtained. The computation of all-India rainfall was achieved using an **A**rea **W**eighted **R**ainfall (**AWR**) index given by:

$$\text{AWR} = \frac{\sum A_i r_i}{\sum A_i} \tag{2}$$

Where: A_i – is the area of the given MS,
r_i – is monthly rainfall.

Monthly rainfall data for 36 MSs during the period 1901–2010 were acquired from the National Data Centre, Indian Meteorological Department (IMD), Pune (Fig. 1). El Niño years and indices were procured from the *Climate Diagnostic Bulletin of India* (2004–2010), which is prepared by the IMD (Srivastava and Guhathakurta 2004–2010). The same was also obtained from www.cpc.ncep.noaa.gov. The rainfall data for the five HRs were obtained from the website www.iitm.res.in of the Indian Institute of Tropical Meteorology (IITM), Pune (Fig. 2). The India Meteorological Department categories F/D years by reference to percentage departures from normal rainfall. However, for the present analysis, the criteria adopted in singling out F/D years (Parathasarthy 1984) were as described below.

Criterion adopted: The above criteria is used to list the drought years over the period 1901–2010 (110 years) when

$r < (\mu - \sigma)$ = drought year,
$r < (\mu - 1.5\ \sigma)$ = moderate drought year,
$r < (\mu - 2\ \sigma)$ = severe drought year,

where: r is rainfall, μ = the mean μ, σ – standard deviation.

This study makes reference to standard statistical criteria like frequency, mean and standard deviation, as well as to simple linear regressions. Trend lines were utilized to

Figure 1. Meteorological Subdivisions (MSs)

Figure 2. Homogeneous Regions (HRs)

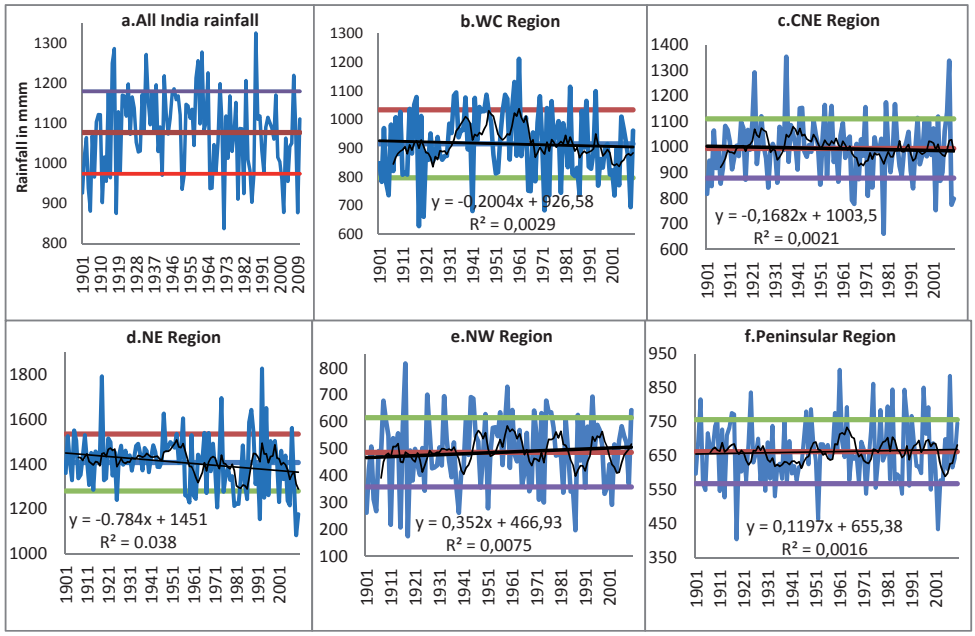
Legend for the MSs:

1 – Andaman and Nicobar Islands, 2 – Arunachal Pradesh, 3 – Assam and Meghalaya, 4 – Nagaland, Manipur, Mizoram and Tripura, 5 – Sub-Himalayan, West Bengal and Sikkim, 6 – Gangetic West Bengal, 7 – Orissa, 8 – Jharkhand, 9 – Bihar, 10 – East Uttar Pradesh, 11 – West Uttar Pradesh, 12 – Uttaranchal, 13 – Haryana, Chandigarh and Delhi, 14 – Punjab, 15 – Himachal Pradesh, 16 – Jammu and Kashmir, 17 – West Rajasthan, 18 – East Rajasthan, 19 – West Madhya Pradesh, 20 – East Madhya Pradesh, 21 – Gujarat region 22 – Saurashtra and Kutch, 23 – Konkan and Goa, 24 – Madhya Maharashtra, 25 – Marathawada, 26 – Vidarbha, 27 – Chhattisgarh, 28 – Coastal Andhra Pradesh, 29 – Telangana, 30 – Rayalaseema, 31 – Tamil Nadu and Pondicherry, 32 – Coastal Karnataka, 33 – North Interior Karnataka, 34 – South Interior Karnataka, 35 – Kerala, 36 – Lakshadweep.

detect increase/decrease in rainfall during the last 110 years**.** These procedures have been adopted for the study region. Amongst the 36 MSs, Arunachal Pradesh was not referred to, as there were gaps in the data range.

RESULTS AND DISCUSSIONS

The rainfall data for India as a whole and for five HRs were made subject to the calculation of seven-year moving averages, as illustrated in Figures 3a–e. Figure 3a indicates that all-India rainfall shows a slight decrease not achieving statistical significance, while the Northwest Region (NWR) – Figure 3e and the Peninsular Region (PEN) – Figure 3f show a non-significant upward trend. In contrast, the West Central Region (WCR) – Figure 3b, Central Northeast Region (CNER) – Figure 3c and Northeast Region (NER) – Figure 3d all show a downward trend which does achieve significance in the case of the NER.



Figures 3 (a–f). Rainfall linear trends over All India and the Homogeneous Regions

IDENTIFICATION OF DROUGHT YEARS – ALL INDIA LEVEL

It is clear from Table 1 that, over the span of 110 years, only one year has been identified as a severe drought year (1972). This means that probability of such a year arising is very negligible – at 0.9%. According to Shewale and ShravanKumar (2005) the occurrence of successive drought years for the country as a whole should be a rare event. This is because macro-level synoptic situations leading to large-scale monsoon failures are generally not likely to repeat in consecutive years.

Table 1. Categories of drought years over All India

Type of DY	**Drought years over All India**												
Drought yr $\mu - \sigma$	1901	1904	1907	1913	1915	1941	1951	1952	1965	1966	1982	1987	2004
Moderate drought yr $\mu - 1.5\ \sigma$	1905	1911	1918	1979	1986	2002	2009						
Severe drought yr $\mu - 2\ \sigma$	1972												

Note: DY – drought years, red underlined years are El Niño years.

However, in the 110 years of the data analyzed, there were only 4 episodes of uninterrupted droughts, i.e. 1904–1905, 1951–1952, 1965–1966 and 1986–1987. Also, successive drought years are greater in number than successive flood years on the macro level.

IDENTIFICATION OF DROUGHT YEARS – HOMOGENEOUS REGIONS

The above classification of drought years was also adopted for the 5 HRs, and is reported on in Table 2. The **NWR** experienced 21 drought years, of which four were severe and five moderate. There were three consecutive drought years (1985–1987) of which 1987 was a severe drought year. Other consecutive drought years were 1904–1905 and 1999–2000. About 50 percent of the drought years of this region are consonant with the identified all-India drought years.

WCR – in all there were 17 drought years, of which 6 and 2 (1918, 1920) were moderate and severe respectively. The successive drought years were 1965–1966. This regional so shared half of its drought years with India as a whole. Similar behavior was observed in the **CNER**. It is interesting to note a lack of successive drought years for the **CNER** across the whole span of 110 years. The **NER** witnessed the most drought events of any of the five HRs (21). Of these, 5 and 1 (2008) were moderate and severe respectively. There were three and two occasions respectively of successive drought years, i.e. 1957–1959, 1961–1962 and 1981–1982. The contribution of this region to all-India F/D years is only 18%. The **PEN** region saw 13 drought years, of which 3 (1918, 1952 and 2002) were severe. No successive drought years were observed in this region.

To sum up, it is seen that the NW, WC and CNE regions share 50% of drought years with India as a whole. The NER is observed to be least affected by El Niño (2 droughts only), while the WCR is characterized by the highest coincidence with El Niño (involving 9 droughts).

THE EFFECT OF EL NIÑO ON DROUGHT EPISODES

The effect of El Niño in modulating and modifying weather in different parts of the world is well recognized. The widespread droughts the world experienced in 1972, 1982 and 1987 is attributed to the presence of El Niño.

Many studies have tried to establish linkages between drought and El Niño (Shewale and Rase 2000). Negative correlation of El Niño with Indian monsoon rainfall is established fact. This relationship shows the ISMR to be below normal when a strong El Niño occurs over the east of the Pacific, while the opposite situation applies to La Niña events. The drought years 1987, 2002, 2004 and 2009 have been credited to the presence of El Niño. This section, therefore, attempts to elucidate the relationship, if any, between El Niño and the drought All-India droughts and those noted in the 5 HRs.

Table 2. Categories of drought years over the Homogeneous Regions (HRs)

Type of DY	Drought years over the HRs															Total
	NWR															**21**
DY	1904	1925	1948	1968	1972	1974	1982	1985	1986	1991	1999	2000				12
Moderate DY	1901	1905	1939	1951	2002											5
Severe DY	1911	1915	1918	1987												4
	WCR															**17**
DY	1902	1904	1965	1966	1968	1979	1987	1995	2004							9
Moderate DY	1905	1941	1972	1974	2002	2009										6
Severe DY	1918	1920														2
	CNER															**19**
DY	1903	1907	1918	1928	1932	1951	1959	1968	1974	1992	2004					11
Moderate DY	1901	1965	1966	1972	2009	2010										6
Severe DY	1979	2002														2
	NER															**21**
DY	1925	1957	1958	1959	1961	1962	1967	1975	1981	1982	1986	1994	1996	2001	2005	15
Moderate DY	1972	1980	1992	2006	2010											5
Severe DY	2008															1
	PEN															**13**
DY	1905	1911	1913	1930	1934	1972	1976	1987	1990	1999						10
Moderate DY																0
Severe DY	1918	1952	2002													3

Note: DY – drought years, red underlined years are those featuring El Niño events.

The data relating to El Niño years were procured from the NOAA for the period 1901–2010. In all there were 25 El Niño years in the last century. Out of 21 all-India drought years, 13 took place when El Niño was occurring in the Pacific Ocean. This gives a 62% probability of droughts occurring as a consequence of El Niño. El Niño years along with drought years for India as a whole and for the five HRs are as tabulated in Table 3.

Table 3. El Niño episodes and the occurrence of droughts in All India and the Homogeneous Regions

El Niño years	**All-India**	**NWR**	**WCR**	**CNER**	**NER**	**PEN**
1902			1			
1905	1	1	1			1
1911	1	1				1
1914						
1918	1	1	1	1		1
1923						
1925		1			1	
1929						
1930						1
1932				1		
1939		1				
1941	1		1			
1951	1	1		1		
1952	1					
1957					1	
1965	1		1	1		
1969						
1972	1		1	1	1	1
1976						1
1982	1	1			1	
1987	1	1	1			1
1997						
2002	1	1	1			1
2004	1		1	1		
2009	1		1	1		
Total = 25	13	9	10	7	4	8

In contrast, 12 years of El Niño were not associated with all-India droughts, this showing that the presence or absence of an El Niño does not necessarily have an over riding influence on the occurrence or absence of drought in India. There were 10 and

9 drought years for the WCR and NWR respectively that coincided with El Niño years while the NER witnessed 4 drought years in connection with El Niño years, indicating only a very weak relationship. The WCR is highly prone to the El Niño phenomenon, while the NER is not affected by this global tele-connection. Interestingly, when the rest of the country and the other HRs were experiencing moderate drought years (in 1918 and 2002), the NER was afflicted by above-normal rainfall. This can be attributed to the well-marked lows over the Bay of Bengal, and the presence of a monsoon trough.

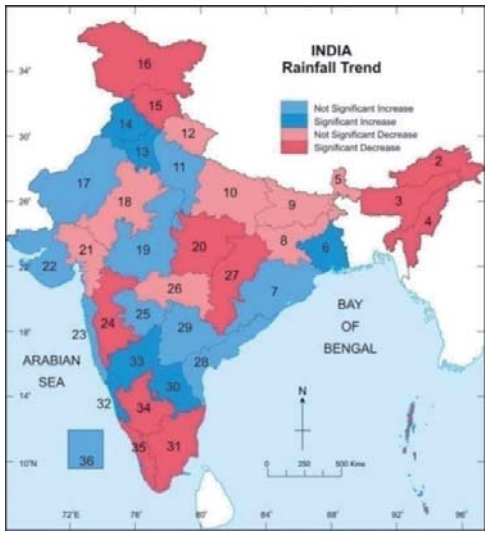


Figure 4. Rainfall trends over the MSs

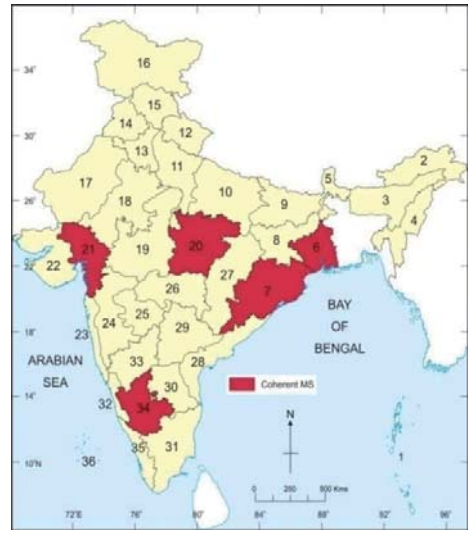


Figure 5. Frequently drought-affected MSs (≥ 20)

It is also noticeable that, during 1972, all-India and four of the HRs other than the NW region experienced moderate drought. The rainfall for the NW region was above normal because of a high frequency of westerly disturbances. This again makes it clear that there is no one-to-one relationship between El Niño and monsoon rainfall.

RAINFALL ANALYSIS FOR METEOROLOGICAL SUBDIVISIONS

Rainfall data for the 36 MSs were analyzed to identify trends. The analysis reveals that 16 MSs show an upward trend, with 6 of these achieving significance. There are in turn 20 MSs indicating decrease, and of these the data for 12 MSs prove to be significant. Figure 4 shows how rainfall has decreased significantly over the NE region,

Himachal Pradesh, Madhya Maharashtra and the Southern Peninsular region. Equally, rainfall increased significantly over West Bengal, Punjab, Haryana, Coastal Karnataka, North Interior Karnataka and Rayalaseema.

IDENTIFICATION OF DROUGHT YEARS FOR MSs

An attempt is made to identify drought events for all the MSs over the span of 110 years. During the drought years of 1939, 1972, 1982, 2002 and 2004, all MSs experienced either below or normal drought. The maximum frequency of occurrence of droughts (21) was reported for East Madhya Pradesh (MS 20) in the WCR and for Orissa (MS 7) in the CNER, as followed by Gangetic West Bengal in the NER, Gujarat (MS 21) and South Interior Karnataka (MS 34), each having a frequency of 20. Andaman and Nicobar and Rayalaseema experienced the minimum occurrence of drought episodes, with just 12 over the period of 110 years (Fig. 5). It is to be noted that not a single MS witnessed drought during the years 1906, 1909, 1910, 1914, 1916, 1917, 1931, 1942, 1943, 1946, 1960, 1961, 1963, 1964 and 1988 – the majority of these being all-India flood years.

COMPARISION OF DROUGHT YEARS BETWEEN ALL-INDIA AND THE MSs

In order to find out which MSs contribute to the all-India drought, data as reported on in Table 4 were scrutinized. The year 1918 was conspicuous given that more than 25 of the 36 MSs experienced drought. Around 60% of the MSs were affected during the drought years of 1972, 1987 and 2002, which were phenomenal. Amongst the MSs, Western Madhya Pradesh (MS 19) in the WCR saw a maximum for drought events (14), followed by Eastern Rajasthan (MS 18) in the NWR, Eastern Madhya Pradesh (MS 20) again in the WCR, followed by Eastern UP (MS 10) and Western UP (MS 11), both belonging to the CNER. These MSs are adjacent and have a minimum of 12–14 episodes in common with all-India drought.

COHESIVE MSs AFFECTED BY DROUGHT

The simultaneous occurrences of drought between the MSs and all-India were determined and the results tabulated in a matrix. A map (Fig. 6) was generated on the basis of this matrix.

As is shown in this Figure, Eastern Rajasthan (MS 18) and Western Madhya Pradesh (MS 19) along with East and West Uttar Pradesh (MS 10 and 11) and Uttarakhand (MS 12) shared 9 drought years common to all-India. Interestingly, these MSs are all adjacent.

Table 4. Drought years for the MSs

Drought	Meteorological subdivisions																																	Total	Percent
Years	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36		
1901					1		1		1								1	1			1	1						1	1	1						1	11	31
1904					1									1			1		1		1	1	1			1		1	1	1						11	31
1905											1	1	1	1			1	1		1			1	1	1						1	1	1			13	36
1907	1			1						1	1	1	1		1				1	1					1											10	28
1911											1			1			1	1	1		1	1	1	1		1			1	1		1	1				14	39
1913										1	1	1	1					1		1							1	1	1			1	1			11	31
1915						1	1	1					1	1			1	1	1		1	1										1					11	31
1918										1	1	1	1	1	1	1	1	1	1		1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	25	69
1941											1	1	1							1			1		1		1		1			1				1	10	28
1951						1	1	1	1	1	1	1	1			1	1	1	1		1									1					1		15	42
1952																									1		1	1	1	1	1			1	1		9	25
1965		1				1	1		1	1	1	1	1	1	1	1		1	1	1					1	1								1	1		17	47
1966	1	1			1		1	1	1									1	1	1			1			1					1						12	33
1972			1	1	1		1	1	1	1	1				1	1					1	1	1	1	1	1		1	1	1		1	1				21	58
1979	1					1	1		1	1	1	1	1	1	1	1		1	1	1							1										14	39
1982				1		1		1	1						1	1					1			1		1		1			1			1			13	36
1986			1	1	1			1												1	1		1	1						1			1	1		11	31
1987	1						1			1	1	1	1	1	1		1	1	1	1	1	1		1		1	1	1			1	1		1	1		22	61
2002			1				1	1	1	1	1				1		1	1	1	1	1		1	1			1	1	1		1	1		1	1	1	22	61
2004			1						1	1							1		1	1						1			1					1	1		10	28
2009			1	1	1			1	1	1	1	1	1		1		1	1	1	1						1	1	1	1								18	50
Total	4	2	5	5	4	4	6	10	7	12	13	11	11	7	9	6	9	12	12	12	9	5	8	8	5	9	9	8	9	5	6	11	6	7	8	5		
Percent	19	10	24	24	19	19	29	48	33	57	62	52	52	33	43	29	43	57	57	57	43	24	38	38	24	43	43	38	43	24	29	52	29	33	38	24		

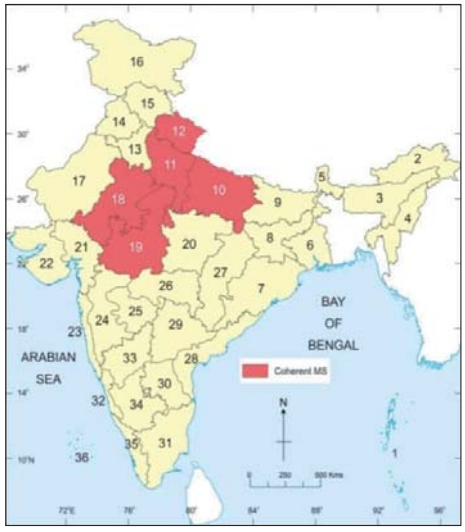


Figure 6. Coherent MS during the drought years

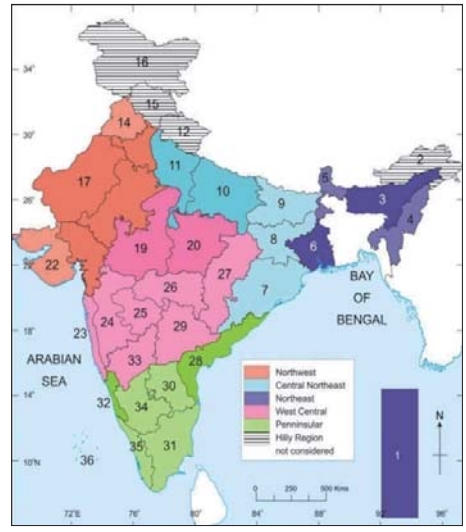


Figure 7. Drought: frequently affected MS

THE RELATIONSHIP BEWTEEN THE THREE SPATIAL UNITS

The study aimed to identify which MS in an HR contribute to all-India droughts. Drought frequencies were therefore tabulated (Tab. 5) and a map prepared (Fig. 7).

Table 5. All India drought years with corresponding HRs and their MSs

North East Region (NER)							
Drought	Meteorological subdivisions						
Years	1	3	4	5	6	36	total
1901				1		1	2
1904				1			1
1905							0
1907	1		1				2
1911							0
1913							0
1915					1		1
1918						1	1
1941							0
1951					1		1
1952						1	1
1965						1	1
1966	1				1		2
1972		1	1	1			3
1979	1						1
1982			1		1		2
1986		1	1	1			3
1987	1						1
2002		1			1		2
2004		1					1
2009		1	1	1			3
Frequencis	4	5	5	5	5	4	

Central Northeast Region(CNER)						
Drought	Meteorological subdivisions					
Years	7	8	9	10	11	total
1901	1		1			2
1904						0
1905					1	1
1907				1	1	2
1911					1	1
1913				1	1	2
1915	1		1			2
1918				1	1	2
1941					1	1
1951	1	1	1	1	1	5
1952						0
1965	1	1		1	1	4
1966		1	1	1		3
1972		1	1	1	1	4
1979	1	1		1	1	4
1982		1	1			2
1986		1				1
1987	1			1	1	3
2002	1	1	1	1	1	5
2004			1	1		2
2009		1	1	1	1	4
Frequencis	7	9	9	12	13	

North West Region (NWR)							
Drought	Meteorological subdivisions						
Years	13	14	17	18	21	22	total
1901			1	1	1	1	4
1904		1	1		1	1	4
1905	1	1	1	1			4
1907	1						1
1911		1	1	1	1	1	5
1913	1			1			2
1915	1	1	1	1	1	1	6
1918	1	1	1	1	1	1	6
1941	1						1
1951	1		1	1		1	4
1952							0
1965	1	1		1			3
1966				1			1
1972					1	1	2
1979	1	1		1			3
1982					1		1
1986					1		1
1987	1	1	1	1	1	1	6
2002			1	1	1		3
2004			1				1
2009	1		1	1			3
Frequencis	11	8	11	13	10	8	

West Central Region (WCR)										
Drought	Meteorological subdivisions									
Years	19	20	23	24	25	26	27	29	33	total
1901								1		1
1904	1		1			1		1		4
1905		1	1	1	1				1	5
1907	1	1			1					3
1911	1		1	1		1		1	1	6
1913		1					1	1	1	4
1915	1									1
1918	1		1	1	1	1		1	1	7
1941		1	1		1		1	1		5
1951	1									1
1952						1		1	1	3
1965	1	1				1	1			4
1966	1	1	1				1			4
1972			1	1	1	1		1	1	6
1979	1	1					1			3
1982				1		1	1			3
1986		1	1	1						3
1987	1	1		1		1	1			5
2002	1	1	1	1			1	1		6
2004	1	1				1		1		4
2009	1	1				1	1	1		5
Frequencis	13	12	9	8	5	10	9	11	6	

Peninsular Region (PEN)						
Drought	Meteorological subdivisions					
Years	28	30	31	32	35	total
1901	1	1				2
1904	1	1				2
1905				1		1
1907						0
1911		1		1		2
1913	1			1		2
1915				1		1
1918	1	1	1	1	1	5
1941				1		1
1951		1			1	2
1952	1	1	1	1	1	5
1965					1	1
1966				1		1
1972	1	1		1		3
1979						0
1982	1		1			2
1986			1		1	2
1987	1		1	1	1	4
2002	1		1	1	1	4
2004					1	1
2009	1					1
Frequencis	10	7	6	11	8	

The table indicates that East Rajasthan (MS 18), followed by Haryana (MS 13) and West Rajasthan (MS 17) – all in the **NWR HR –** witnessed 13 and 11 drought years in common with all-India drought years. In contrast, Western Madhya Pradesh (MS 19), Eastern Madhya Pradesh (MS 20), Telangana (MS 29) and Vidarbha (MS 26) from the **WCR HR** contribute 13, 12, 11 and 10 drought events respectively to all-India drought years. In the **CNER** it is Western and Eastern Uttar Pradesh (MS 11 and MS 10) that account for the highest frequency of occurrence of droughts. Almost all the MSs from the **NER** share common drought incidences with all-India drought years. In the **PEN** Region, Coastal Karnataka (MS 32) and Coastal Andhra Pradesh (MS 28) share 11–9 years in common with all-India drought years. In Figure 7, the darker shading of an MS points to a higher frequency of occurrence of drought.

THE RELATIONSHIP BETWEEN MSs AND EL NIÑO

The details of the observed impact of El Niño in various MSs are as given in Table 6, which shows in terms of the sub-divisions the drought years occurring over the last 110 years. However, only those MSs with highest levels of occurrence of droughts in common with El Niño are shown. Out of 19 drought years for Western Uttar Pradesh (MS 11), only 11 coincided with El Niño, while Uttarakhand had a total of 17 drought years, of which 10 were consonant with El Niño. These two MSs are thus highly influenced by El Niño phenomenon. On the other hand, Eastern Rajasthan (MS 18), Vidarbha (MS 26) and Telangana (MS 29) saw 19 drought years, of which 10 were related to El Niño.

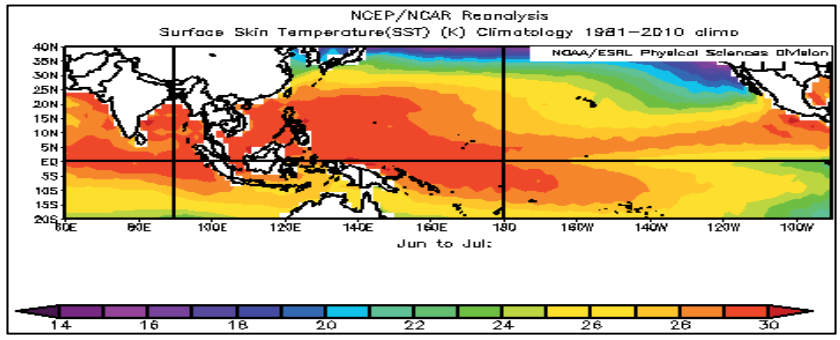
Table 6. MS drought years along with El Niño years

MS	Drought year	Drought years		
		total	with El Niño	%
11	1905, 07, 11, 13, 18, 28, 29, 37, 41, 44, 51, 65, 72, 79, 87, 91, 2002, 06, 09	19	11	58
12	1905, 07, 13, 18, 41, 44, 51, 65, 72, 76, 79, 87, 91, 92, 97, 2006, 09	17	10	59
18	1901, 05, 11, 13, 15, 18, 25, 28, 39, 51, 65, 66, 79, 87, 91, 2000, 02, 03, 09	19	10	53
26	1902, 04, 11, 18, 20, 50, 52, 65, 71, 72, 74, 82, 84, 85, 87, 96, 97, 2004, 09	19	10	53
29	1901, 04, 11, 13, 18, 20, 26, 29, 39, 41, 52, 68, 71, 72, 85, 97, 2002, 04, 09	19	10	53

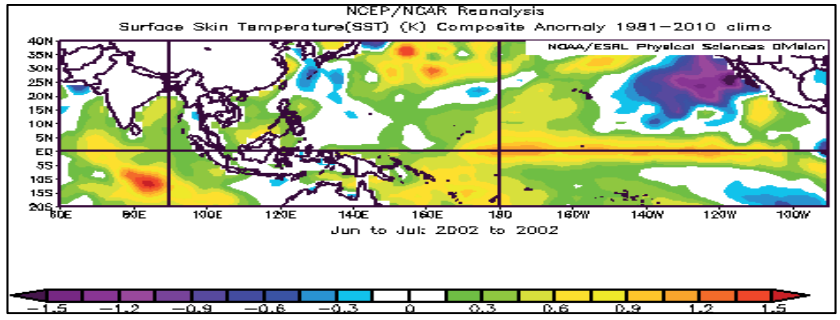
Note: Red underlined years are those featuring El Niño events.

The effect of high/low sea-surface temperature during the El Niño years 2002 and 2009 is compared with the average value of years 1981–2010 (Fig. 8). The two years in question were special, given that the Ganga Plains and Central India experienced drought. This could be attributed to a cooling of the Indian Ocean and adjoining seas that subdued rainfall over the said regions.

1981–2010



June–July 2002



June–July 2009

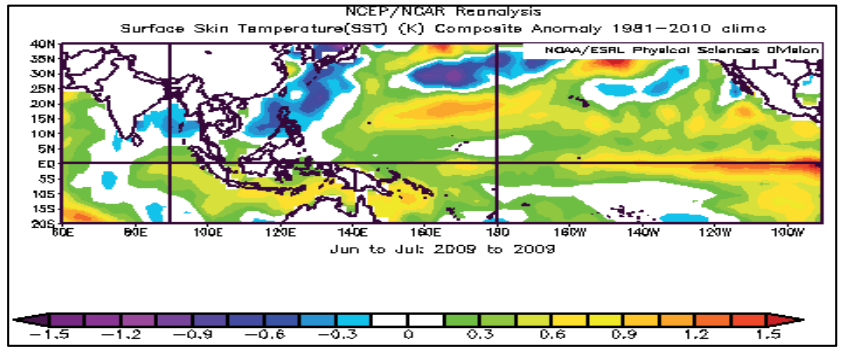


Figure 8. The Surface Skin Temperature (SST) anomaly of June–July 2002 and 2009 in relation to average value of years 1981–2010, (after The NCEP/NCAR Reanalysis…)

CONCLUSIONS

The study sustains conclusions as described below.

All-India rainfall indicates no trend, while that for the NER shows a significant decrease. Out of the 36 MSs, 12 were characterized by rainfall decreasing significantly, with these comprising the NER, Himachal Pradesh, Madhya Maharashtra and the Southern Peninsular region. Equally, 6 MSs show a significant increase, i.e. West Bengal, Punjab, Haryana, Coastal Karnataka, North Interior Karnataka and Rayalaseema.

There were 21 all-India drought years during the last century, of which 13 were linked to El Niño. When compared with the HRs, the WCR is seen to be highly prone to El Niño events, while the NER is not affected by this global tele-connection. Western Uttar Pradesh, Eastern Rajasthan, Uttarakhand, Vidharbha and Telangana shared 11–10 drought occasions with El Niño.

Maximum frequencies of drought (21) were reported for East Madhya Pradesh in the WCR and Orissa in the Central Northeast Region (CNER). Andaman and Nicobar and Rayalaseema in turn experienced a minimum for drought episodes (12) over the whole 110-year period.

MSs of the West Central and Northwest Regions (WCR, NWR) show 60% coincidence with all-India droughts. During the years 1918, 1972 and 2002, a majority of the HRs (except in the NER) witnessed normal or below-normal rainfall. During the all-India drought years, Western Madhya Pradesh within the WCR saw a maximum occurrence of drought events (14). This was followed by Eastern Rajasthan in the NWR, Eastern Madhya Pradesh (WCR), and Eastern and Western Uttar Pradesh (in the CNER), which are also adjacent. These have about 12–14 episodes in common with all-India. The highest frequency of simultaneous occurrence of drought years between the MSs and all-India characterize Eastern Rajasthan and Western Madhya Pradesh along with East and West Uttar Pradesh. The contributory role of a particular MS within an HR to the all-India drought years is particularly clear in the cases of East Rajasthan (in the NWR), West Madhya Pradesh (WCR), West and East Uttar Pradesh (CNER), all the MSs of the NER, and Coastal Karnataka within the PEN region.

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