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INVESTIGATION OF METEOROLOGICAL DROUGHT IN AGRO-CLIMATIC ZONES OF ASSAM IN HUMID NORTHEASTERN REGION OF INDIA

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ABSTRACT

Effective drought index (EDI) which allows determination of onset, duration and severity of drought is applied to investigate meteorological drought in six agro-climatic zones of Assam in the humid north eastern region of India. The daily gridded rainfall data from India Meteorological Department is used over a period of 113 from 1901 to 2013. The analysis revealed that Hills Zone is the most affected zone during monsoon season. The analysis further revealed that dry days are more concentrated since 1992 indicating an increase in frequency of drought occurrence. Drought duration in the agro-climatic zones ranged from nearly a month to more than six years. The MK trend test analysis of the EDI series shows a significant decreasing trend in most of the zones revealing poorer condition for the future. Power spectrum analysis of the yearly minimum EDI series indicated that NBPZ has the periodicity of 2.3 and 2.2 years whereas, for rest of the zones the periodicity ranged from 4.9 years to 8.2 years. No significant periodicities were observed in UBVZ. The results of the study will give valuable insights regarding the drought occurrence and its severity in the north eastern part of India. Such insights will be very much useful for the policymakers, agricultural and water use planners.

Keywords: *Meteorological drought, Effective drought index, Trend analysis, Power spectrum*

INTRODUCTION

Meteorological drought, which is caused by the occurrence of rainfall below its normal value, may affect various water related activities. In a place of high rainfall region, drought can also be expected if the rainfall goes below its normal, and as a result, the planning of agricultural activities in the area will be disturbed. Hence, it is important to assess and characterize the drought for future management. Drought can be considered as one of the hazardous natural calamities for which its onset is so gradual and duration may last for many days. It brought environmental stress which limits the rainfed agriculture (Singh and Kumar, 2009).

Drought is defined as the period of abnormal dry days long enough to cause serious hydrological imbalance. Based on its nature, it is classified as meteorological, hydrological, agricultural, socio-economic and ecological droughts (Parida and Oinam, 2015). Meteorological drought is related to the shortage of rainfall and its propagation led to hydrological drought. Droughts are characterized by onset, duration, severity, and geographical areal extent. Depending on these factors, the impact of droughts varies from mild to severe. Its impact is of utmost importance especially in the agricultural sector in which it directly affects the food production.Unlike flood, drought builds up rather very slowly and yet no systematic method has been developed for its prediction (Salas, 1986) and it's remedial and management strategies were adopted after the incidence of drought.

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Over the years, several indices have been developed to characterize drought severity. One of the commonly used indices is the effective drought index (EDI) developed by Byunand Wilhite, (1999). Recent studies which have used EDI for drought studies are (Oh et al., 2010; Kim et al., 2011; Deo et al., 2015; Byun and Kim, 2010; Park et al., 2014; Lee et al., 2012; Oh et al., 2013).Unlike other indices, EDI can calculate drought severity on daily basis which allows determination of onset and withdrawal of drought. Some studies agreed that drought quantified by EDI is superior than the SPI (Morid et al., 2006; Pandey et al., 2007; Byun and Kim, 2010).

In India occurrence of drought is a common phenomenon. This aspect of climate extremes was reported by many studies mainly for western and central part of the country. In thesestudies, either percentage departure of rainfall from its normal or drought indices such as SPI, PDSI and PNP were used. Of late, few drought studies have taken up in north-eastern India on a districts or city level such asJhajharia et al. (2007), Shrivastava et al. (2008),Ray et al. (2012), Kusre et al. (2014) and Parida and Oinam (2015). Jhajharia et al., (2007) studied the drought proneness at Guwahati and observed six drought events in between 1995 to 2003 and the worst drought was observed in the year 1952. Shrivastava et al. (2008) analysed the meteorological droughts at North Lakhimpur district of Assam using rainfall data for eighteen years (1981-1998). The year 1981, 1986, 1992 were found to be deficit years. The intensity of drought was moderate/mild and no severe drought was noticed. Kusre et al. (2014) attempted to characterize the droughts in the East District of Sikkim during winter by using the reconnaissance drought index (RDI) for the period 1985–2012 and found that the drought was experienced for 66.7 and 59.3% during Oct–Dec and Jan–Mar, respectively. Parida and Oinam (2015) reported that in northeast India,

Assam and Meghalaya experienced drought consecutively during 2005 and 2006 and about 10–14 districts were affected in three consecutive years during 2009–2011 which suggests that droughts were frequent in the recent decade. Taggu and Shrivastava (2018) studied the drought conditions in Imphal and Shillong of northeast India using standardized precipitation index (SPI) and found that there may be water scarcity problems in the coming years.

Another aspect of the drought studies is the periodicity of drought or drought cycle. Many researchers have investigated drought periodicity (Byun et al. 2008; Santos et al., 2010; Kim et al., 2011; Oh et al., 2013; Haroon and Jiahua, 2016). Assam being a north-eastern state of India usually received high amount of rainfall. Rainfall being unpredictable, it is required to investigate its deficiency since a shortage of rainfall is the major cause of meteorological drought.In view of these findings, the research interestof this investigation is to search for the occurrences of drought, trend and periodicity of drought in the agro-climatic zones of Assam by using EDI over the period 1901-2013.

STUDY AREA

For the present study, six agro-climatic zones of Assam of humid north-eastern region were selected. Assam is situated at the foothills of the eastern Himalayas covering an area of 78, 523 km^2 extending from 24°08′ N to 27°09′ N latitudes and 89°42′ E to 96°10′ E longitudes (Mandal, 2014). The major economy of the state is agricultural sector and tea gardens, which provide livelihood to about 70% of the population. The state is bestowed with high potential of water resources and fertile lands beside the plains of Brahmaputra River. The state endured tropical monsoon rainforest climate, with heavy rainfalls during monsoon, high humidity and temperature ranges from 6 to 38°C. Based on factors such as climate, topography and soil types, the state of Assam has been divided into six agro-climatic zones (Mandal, 2014) as shown in Fig. 1.

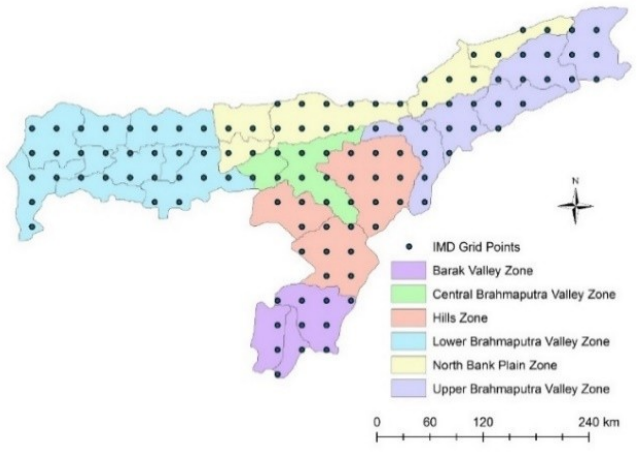

Fig. 1 Agro-climatic zones of Assam

DATA USED

Gridded (0.25° longitude by 0.25° latitude) daily rainfall data for the period from 1901 to 2013 acquired from India Meteorological Department (IMD), Pune is used. Total 115 numbers of grids cover the six agro-climatic zones of Assam as shown in Fig 1. The areal precipitation of each zone is determined using simple arithmetic average method.

4. METHODOLOGY

Characterization of drought

Effective Drought Index (EDI) has gained the popularity among the researchers because it uses only rainfall data. The computation of EDI is done using the following relationship as proposed by Byun and Whilhite (1999).

$$EP_i = \sum_{n=1}^{i} \left[{\left(\sum_{m=1}^{n} P_m\right)}/{n} \right]$$

$$= P_1 + \frac{P_1 + P_2}{2} + \frac{P_1 + P_2 + P_3}{3} + \cdots + \frac{P_1 + P_2 + \cdots + P_{365}}{365}$$

$$= P_1 \left(1 + \frac{1}{2} + \frac{1}{3} + \cdots + \frac{1}{365}\right) + P_2 \left(\frac{1}{2} + \frac{1}{3} + \cdots + \frac{1}{365}\right) + \cdots + P_{365} \left(\frac{1}{365}\right) \quad (1)$$

$$DEP = EP - MEP \quad (2)$$

$$EDI = DEP/ST_{(EP)} \quad (3)$$

Where EP_i is the effective rainfall accumulation in millimetres (mm) of rainfall; P_m is the rainfall on m previous days (mm); n is the duration of the preceding period (day(s)); DEP denotes the deviation of EP from mean effective rainfall (MEP) and $ST_{(EP)}$ represents the standard deviation of EP time series. In equation (1) $i$is the duration of summation which is made equal to 365. Leap years makes the calculation of EDI more complex and therefore precipitation values falling on the 29th February of all the leap years were excluded from the analysis. More elaborated details about the theory and process can be found in Byun and Wilhite (1999), Oh et al. (2013) and Deo et al. (2015). The scheme of classification of drought based on EDI values is given in Table 1.The daily EDI values obtained from Eq. 3 were averaged to form annual and seasonal EDI series. For seasonal analysis two seasons i.e., monsoon (June to October; 5 months) and pre-monsoon (March to May; 3 months) are chosen.

Table 1 Scheme of EDI classification(after Byun and Wilhite, 1999)

EDI values	Classification
EDI > -0.7	No drought
-0.7 ≥ EDI > -1.5	Moderate drought
-1.5 ≥ EDI > -2.5	Severe drought
EDI ≤ -2.5	Extreme drought

Determination of trend in the EDI series

A non-parametric Mann-Kendall trend test (Mann, 1945; Kendall, 1975) was performed for annual, monsoon and pre-monsoon EDI series as per the procedure adopted by Jain et al. (2012).

Determination of periodic cycles

Periodicities of climatic variables are usually due to astronomical cycles such as the earth's rotation around the sun. Several approaches viz., Maximum Entropy method (MEM), Multi-Taper method (MTM), Wavelet Transform and; Blackman & Tukey method have been developed in the past to examine presence of periodicity in the time-series. In this study, for each zone, power spectrum analysis is carried out on yearly minimum EDI values using the method given in WMO (1966). The details of the methodology may be found in Turkes et al. (2002).

RESULTS AND DISCUSSION

The statistical properties of rainfall of the six agro-climatic zones of Assam are given in Table 2. The average annual rainfall in all the agro-climatic zones is well above the average annual rainfall of India (1190 mm). The average annual rainfall was the highest in BVZ while it was lowest in HZ. The deviation of individual rainfall from its mean (standard deviation) in the study area is also found to be very high and varies in the range of 547 (LBVZ) to 266 (HZ). The rainfalls in the LBVZ and UBVZ agro climatic zonesispositively skewed while rest of the zones exhibited negatively skewed distribution.

Table 2. Statistical properties of rainfall of agro-climatic zones of Assam (1901-2013)

Zone	LBVZ	NBVZ	UBVZ	CBVZ	HZ	BVZ
Annual Average (mm)	2457.7	2348.2	2419.0	1747.0	1607.2	2781.8
Standard Deviation	547.2	304.6	511.9	347.0	266.1	491.7
Coefficient of skewness	4.2	-0.01	3.2	-0.6	-0.8	-1.2

Characterization of drought

EDI calculation requires first 365 days of rainfall records which will be utilized to give EDI value on the next day i.e., 366th day from the start. Thus, in this study, EDI time series started on the first day of 1902 using rainfall records of the year 1901. Daily EDI time series for the period 1902 to 2013 for the six different agro-climatic zones are illustrated in Fig. 2. As evident from Fig. 2, all the zones were affected by occasional droughts and floods throughout the time period. For LBVZ, the driest condition was observed from June to August of 1962 reaching peak drought on 23rd July 1962. On 17th December 2012, peak drought occurred in NBPZ while in the zones of UBVZ and CBVZ the peak droughts occurred respectively on 24th June (2013) and 17th January (1976). The date of peak drought was found to be same for HZ and BVZ which is on 5thMarch 1976.Cases of extreme drought condition were not observed in LBVZ and UBVZ. Based on the minimum EDI, the drought severity followed in the order- HZ, BVZ, CBVZ, NBVZ, LBVZ and UBVZ.

The seasonal number of drought days in which EDI is ≤ -0.7 was counted for the whole period to investigate the seasonal distribution of dry period and is given in Table 3. The total number of drought days (in percent) with moderate to extreme drought conditions were almost similar in both the seasons. About 20% days of the monsoon season were dried in CBVZ, HZ and BVZ while only about 13 to 15% days were dried in LBVZ, NBPZ and UBVZ. Dried days during monsoon season is very crucial while deciding proper water resource management plan as this season received more than 70% of the total annual rainfall. Nearly 15% days in UBVZ and CBVZ; 14% in LBVZ and BVZ and 17% in NBPZ and HZ of the total pre-monsoon days were found to be dried. The total number of dry days under different drought classes for each season is given in Table 3. It is clear from Table 3 that LBVZ and UBVZ experienced no extreme drought cases in both the seasons. In the monsoon season, 66 days in NBPZ, 86 days in CBVZ, 97 days in HZ and 38 days in BVZ were observed as extreme drought condition. The most affected zone during monsoon was HZ and the least affected zone was LBVZ. In the pre-monsoon season, the highest number of extreme drought days (92 days) was observed in all the zones except LBVZ and UBVZ. However, the number of days fulfilling the criteria of both severe and extreme drought conditions were very less as compared to moderate drought. It signifies that the drought condition in the state is mild. The yearly variation of number of drought days (EDI ≤ -0.7) for the six zones is shown in Fig. 3. As evident from the figure, except for LBVZ, dry days were more concentrated after 1992 indicating an increase in dryness level in the last two decades. During the year 2012 the NBPZ, UVBZ, CBVZ and HZ have experienced drought as all 365 days EDI values were ≤ -0.7.

Drought Duration

The onset dates, end (withdrawal) dates, duration (in number of days) and severity of droughts in the six agro-climatic zones of Assam were determined and are presented in Table 4. The first date of such series is the onset date of drought and the total number of days with negative values in the series is the drought duration.

Twenty-two different cases of drought were observed in LBVZ of which nineteen cases marked their onset during

Table 3. Seasonal number of drought days under different drought classes in six agro-climatic zones of Assam (1902-2013)

	LBVZ			NBPZ			UBVZ		
Season	**Moderate**	**Severe**	**Extreme**	**Moderate**	**Severe**	**Extreme**	**Moderate**	**Severe**	**Extreme**
Monsoon	2463	83	0	2177	297	66	2042	123	0
Pre-monsoon	1405	15	0	1517	158	92	1444	92	0
	CBVZ			**HZ**			**BVZ**		
Season	**Moderate**	**Severe**	**Extreme**	**Moderate**	**Severe**	**Extreme**	**Moderate**	**Severe**	**Extreme**
Monsoon	2734	417	86	2680	574	97	2606	530	38
Pre-monsoon	1392	92	92	1393	237	92	1216	132	92

the monsoon months (June to October), two cases in the month of November and one in the month of May (pre-monsoon period). In terms of severity, the most severe drought having peak EDI of -1.96 was observed during 23rd July 1962. Based on the duration of drought, the drought which has onset date on 8th October 1965 was the longest (2448 days) of all the observed cases. All the cases except the most severe observed in this zone fall within the moderate drought criteria. In NBPZ, 15 cases of dry spells were observed, in which, 11 cases were moderate, 3 cases were severe and the remaining one (Case no. 15) was extreme. The drought which occurred for the longest duration (2319 days) started on 14th May 1997 and continued till 18th September 2003. The number of drought cases found in UBVZ was minimum (only 13 cases). The longest drought that had occurred in this zone was the drought of 15th December 1993 which lasted for around 5 years and 9 months, although the drought condition during this period was moderate. All the drought cases observed are moderate condition with the exception of one severe drought condition which started on 6th September 2011. There were 19 cases of droughts in CBVZ in which two each were severe and extreme, and the rest were moderate. The longest drought observed in this zone is the drought of 17th September 2008 that continued for 1932 days. The most extreme drought occurred in this zone marked its onset on 8th December 1975 and ends on 24th June 1980 after a spell of 1661 days. This drought case was very extreme having peak EDI of -3.53 and it was observed from December 1975 to September 1976.

A great number of drought cases (23 cases) were

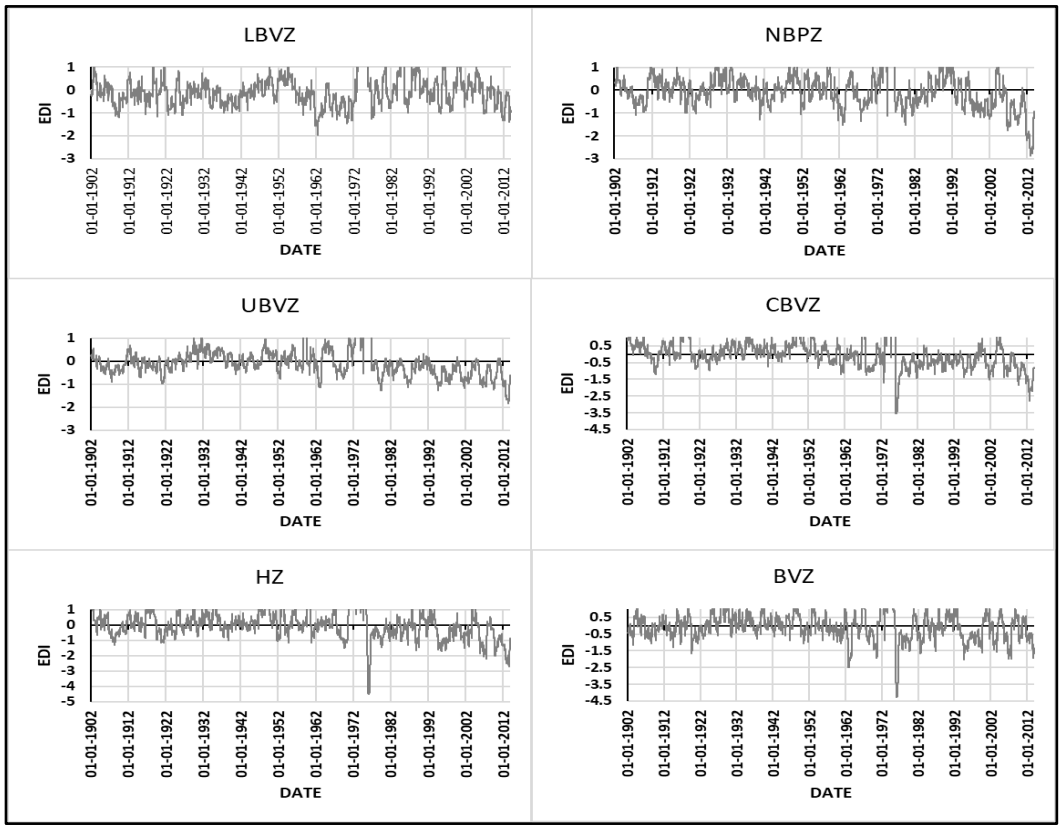

Fig. 2 EDI time series (1902-2013) of six agro-climatic zones of Assam

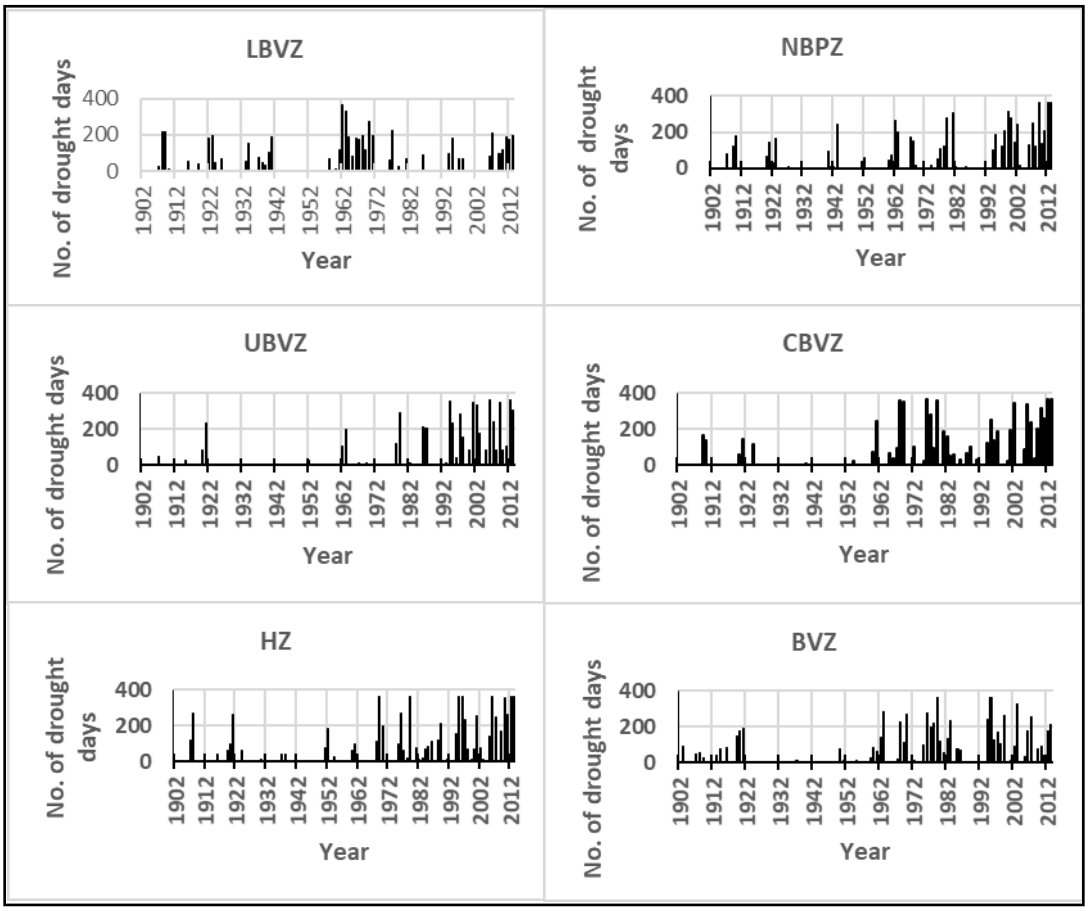

Fig. 3Yearly variation of number of drought days in six agro-climatic zones of Assam(1902-2013)

observed in HZ in which five were severe, two were extreme and the rest were moderate. The most severe drought in this zone was the case no. 12 which started on 23rd September, 1975 and lasted over a span of 5 years having peak EDI value of -4.5. This is the most severe case of drought which was observed among all the zones under study. The BVZ experienced maximum (30) number of drought cases. The most severe drought in this zone was the drought of 28th September 1975 (EDI = -4.28), which is the second most severe most drought in the state. Out of these 30 cases, 8 were severe, one was extreme, and the rest were moderate. The longest drought spell in this zone was found as the drought of 22nd October 1993 which lasted for 2178 days. The dry spells in Assam range from 23 days to 2448 days, a critical situation from agriculture point of view.Parida and Oinam (2015) have also reported that the north-eastern region of India had witnessed frequent drought during the period 2000 to 2014 having a 54% probability of drought as compared to western India with a probability of 27% only.

Trend analysis of EDI series

The Mann-Kendall (MK) trend test and Sen's slope (magnitude of the slope) estimator test was applied to seasonal and annual EDI series of the six agro-climatic zones of Assam and the results are shown in Table 5. It is very interesting to note from the table that the decreasing trends were observed for EDI series of monsoon and pre-monsoon season in five zones and were significant in NBPZ, UBVZ, CBVZ, and BVZ zones at 5% level. It indicated that the drought severity in these zones is increasing during monsoon and pre-monsoon seasons. The average annual EDI series showa significant decreasing trend in all the zones except LBVZ. Similar results are obtained by Hangshing and

Table 4. Onset and end dates, duration, and severity of meteorological droughts in the six agro-climatic zones of Assam (1902-2013)

Case No.	LBVZ				HZ			
	Start Date	End Date	Duration	Severity	Start Date	End Date	Duration	Severity
1	8-Oct-1907	16-Sep-1911	1440	-1.19	12-May-1907	6-May-1910	1091	-1.31
2	11-Jul-1916	11-Jul-1918	731	-1.06	2-Jul-1916	5-Oct-1916	96	-0.85
3	22-Aug-1919	11-May-1920	264	-1.16	3-Sep-1919	1-Sep-1922	1095	-1.15
4	10-Jun-1922	17-Aug-1924	800	-1.09	12-Jun-1924	18-Nov-1924	160	-0.99
5	1-May-1926	11-Jun-1927	407	-1.11	13-Jun-1930	21-Nov-1930	162	-0.75
6	7-Nov-1933	6-Aug-1934	273	-0.84	30-May-1937	29-Aug-1937	92	-0.83
7	22-Aug-1936	25-Jun-1942	2134	-1.01	27-Aug-1938	4-Jul-1939	312	-1.01
8	23-Sep-1943	28-Dec-1943	97	-0.90	1-Sep-1951	23-Aug-1952	358	-1.08
9	10-Jul-1958	8-Jul-1959	364	-1.10	9-Sep-1954	30-Apr-1955	234	-1.19
10	25-Jun-1960	14-Sep-1960	82	-0.87	30-Oct-1960	9-Oct-1961	345	-1.18
11	3-Sep-1961	22-Sep-1964	1116	-1.96	9-May-1968	18-Sep-1970	863	-1.50
12	8-Oct-1965	20-Jun-1972	2448	-1.46	23-Sep-1975	21-Sep-1980	1826	-4.50
13	2-Nov-1976	22-Sep-1977	325	-1.28	30-Jun-1981	3-Jul-1982	369	-1.04
14	12-Jun-1979	5-Oct-1979	116	-0.92	10-Sep-1982	18-Sep-1983	374	-0.91
15	19-Jun-1981	11-Jul-1982	388	-0.80	11-Oct-1984	13-Aug-1985	307	-1.06
16	3-Jun-1986	29-Jun-1987	392	-0.98	19-Jun-1986	9-Oct-1986	113	-1.30
17	27-Sep-1994	14-Aug-1995	322	-1.02	5-Aug-1988	24-Sep-1989	416	-1.66
18	2-Sep-1997	2-Sep-1998	366	-0.95	18-Aug-1991	26-Dec-1991	131	-0.75
19	18-Sep-2001	3-Jul-2002	289	-0.72	11-Jun-1994	24-Nov-1998	1628	-1.72
20	27-Aug-2006	7-Sep-2007	377	-1.05	24-Apr-1999	29-Aug-1999	128	-0.74
21	5-Sep-2009	19-Jul-2010	318	-0.98	20-Oct-2000	12-Sep-2003	1058	-1.52
22	18-Jun-2011	31-Dec-2013	928	-1.39	29-Jul-2005	16-Nov-2007	841	-2.21
23					1-Jul-2009	31-Dec-2013	1645	-2.70
Case No.	**BVZ**				**CBVZ**			
1	30-May-1903	18-Oct-1903	142	-1.16	19-Jul-1909	19-Sep-1910	428	-1.19
2	26-Oct-1906	2-Nov-1908	739	-1.08	26-Oct-1920	23-Sep-1921	333	-0.89
3	12-Sep-1909	2-Aug-1910	325	-0.87	3-Jul-1924	11-Aug-1925	405	-0.96
4	9-Oct-1913	4-Jun-1915	604	-1.31	15-Oct-1940	5-Jun-1941	234	-0.76
5	9-Jul-1916	7-Oct-1916	91	-1.09	15-Sep-1954	4-Aug-1955	324	-0.81
6	7-Aug-1919	8-Nov-1921	825	-1.66	19-Oct-1960	15-Dec-1961	423	-1.22
7	28-Oct-1922	16-Jun-1923	232	-0.78	14-Oct-1965	17-Jul-1966	277	-0.91
8	25-Jul-1937	28-Aug-1937	35	-0.81	9-Sep-1967	3-Oct-1970	1121	-1.23
9	28-Sep-1946	20-Oct-1946	23	-0.88	6-Aug-1972	25-Nov-1972	112	-1.72
10	9-Jun-1950	18-May-1951	344	-1.04	8-Dec-1975	24-Jun-1980	1661	-3.53

11	23-Sep-1951	8-Aug-1952	321	-0.99	11-Jun-1981	25-Sep-1983	837	-1.42
12	12-Oct-1955	9-Nov-1955	29	-0.87	17-Oct-1984	24-Sep-1987	1073	-1.22
13	8-Oct-1958	28-Mar-1959	172	-0.85	24-Sep-1988	5-Nov-1989	408	-1.07
14	28-Aug-1959	19-Aug-1961	723	-1.06	10-Aug-1991	2-Sep-1993	755	-0.88
15	14-Aug-1962	25-Oct-1963	438	-2.49	29-Aug-1994	26-Sep-1997	1125	-1.40
16	1-Aug-1965	26-May-1966	299	-0.78	1-Nov-1997	21-Apr-1998	172	-0.74
17	14-Dec-1967	9-Sep-1968	271	-1.12	21-Oct-2000	6-Sep-2003	1051	-1.53
18	7-Sep-1969	5-Oct-1970	394	-1.96	8-Oct-2005	16-Sep-2007	709	-1.37
19	6-Oct-1972	17-Nov-1972	43	-0.89	17-Sep-2008	31-Dec-2013	1932	-2.77
20	28-Sep-1975	26-Jun-1980	1734	-4.28				
21	23-Oct-1981	5-Sep-1983	683	-1.68				
22	29-Dec-1984	14-Aug-1985	229	-0.88				
23	6-Jul-1986	6-Jun-1987	336	-1.51				
24	22-Oct-1993	8-Oct-1999	2178	-2.02				
25	19-Sep-2001	7-Nov-2001	50	-0.80				
26	5-Oct-2002	21-Dec-2003	443	-1.57				
27	13-Sep-2005	17-Oct-2007	765	-2.00				
28	6-Oct-2009	18-Jun-2010	256	-1.05				
29	12-Aug-2010	16-Sep-2010	36	-0.72				
30	21-Nov-2011	31-Dec-2013	772	-1.94				
Case No.		**NBVZ**				**UBVZ**		
1	23-Apr-1907	9-Oct-1910	1266	-1.09	7-May-1907	30-May-1911	1485	-0.93
2	11-Oct-1920	13-Sep-1921	338	-0.99	11-Mar-1915	9-Sep-1915	183	-0.71
3	26-Nov-1922	16-Aug-1924	630	-1.02	8-Oct-1920	26-Dec-1921	445	-0.99
4	29-Sep-1940	18-Sep-1941	355	-1.29	20-Jun-1952	11-Oct-1952	114	-0.77
5	31-Dec-1942	25-Jul-1944	573	-0.95	9-Sep-1962	24-Aug-1963	350	-1.16
6	31-Aug-1951	7-Sep-1952	374	-1.05	6-Sep-1967	7-Aug-1970	1067	-0.81
7	11-May-1960	3-Sep-1960	116	-0.83	28-Aug-1978	14-Aug-1980	718	-1.27
8	8-Aug-1961	1-Oct-1963	785	-1.53	6-Sep-1982	25-Oct-1983	415	-0.84
9	11-Jun-1967	13-Sep-1969	826	-1.35	16-Sep-1985	4-Sep-1988	1085	-1.16
10	14-Nov-1976	9-Aug-1980	1365	-1.55	15-Dec-1993	15-Sep-1999	2101	-1.29
11	1-Jan-1981	13-Sep-1983	986	-1.12	2-Sep-2000	7-Oct-2004	1497	-1.17
12	3-Sep-1994	10-Sep-1995	373	-1.06	30-Sep-2005	1-Aug-2010	1767	-1.23
13	14-May-1997	18-Sep-2003	2319	-1.27	6-Sep-2011	31-Dec-2013	848	-1.85
14	24-Aug-2006	16-Sep-2010	1485	-1.76				
15	3-Jun-2011	31-Dec-2013	943	-2.87				

Dabral (2018) for annual SPI series (1901-2013) in Assam. Dominant nature of decreasing trends has shown that the severity of droughts in Assam is increasing. It is also clear from the table that the magnitudes of trends (Sen's slope values) are high which indicates that the severity of drought occurrence in the region had been increased rapidly.

Periodicity of drought

In order to identify cyclic patterns in the effective drought indices of the six agro-climatic zones of Assam, power spectrum analysis was carried out for yearly minimum EDI series. The results of the analysis are presented in Fig.4. Periodicities which are statistically significant at 95% confidence level are discussed.

sunspot cycles of 24.7 years were also observed. The QBO of 2.2 and 2.3 years in NBPZ indicated that the occurrence of drought is more frequent as compared to other zones. In case of UBVZ, no significant periodicity was observed. The dominant cyclic patterns of medium-range periodicities of 6.2, 6.7, 7.4 and 8.2 years were observed in the HZ. A long-range cycle of 74 years and a medium-range cycle of 6.2 years characterized the periodicity of BVZ. It was observed that the yearly minimum EDI series of LBVZ and HZ contain various cycles which are statistically significant at 0.95 level. In general, the agro-climatic zones of Assam exhibited medium-ranged periodicity that indicate the occurrence of drought in between 4 to 9 years.

CONCLUSIONS

The meteorological droughts during 1901–2013 were investigated using Effective Drought Index (EDI) in six agro climatic zones of Assam in humid north-eastern region

Table 5. MK trend test statistics and Sen's slope of EDI in the agro-climatic zones of Assam (1902-2013)

Agro-Climatic Zones	Monsoon (Jun-Oct)		Pre-Monsoon (Mar-May)		Annual	
	MK Statistics	**Sen's slope**	**MK Statistics**	**Sen's slope**	**MK Statistics**	**Sen's slope**
LBVZ	0.62	0.001	0.54	0.001	0.48	0.001
NBPZ	-2.98*	-0.005	-2.66*	-0.006	-3.08*	-0.005
UBVZ	-3.63*	-0.005	-3.22*	-0.005	-3.81*	-0.005
CBVZ	-5.64*	-0.010	-5.06*	-0.009	-5.82*	-0.010
HZ	-3.59*	-0.008	-3.17*	-0.007	-3.82*	-0.007
BVZ	-1.85	-0.010	-1.69	-0.009	-2.07*	-0.010

* Significant at 5% level

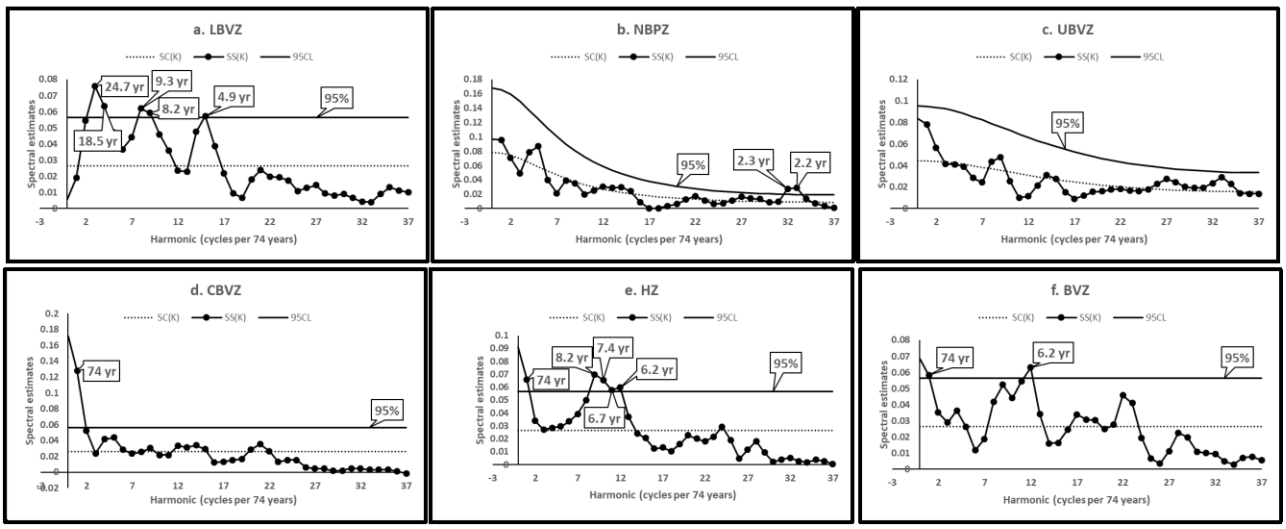

Fig. 4 Power spectrum plots for yearly minimum EDI series of six agro-climatic zones of Assam.

Periodicities in LBVZ are characterized generally by a short-range of 4.9 years and medium-range of 8.2 and 9.3 years. Periodicities of sunspot cycles of 18.5 and double

of India. Temporal analysis of averaged EDI during the last eleven decades showed an increasing in their frequency, severity and duration over the agro-climatic zones of

Assam. The results showed that the longest and most intense dry period (2448) was 1965-1972 in LBVZ followed by 1997-2003 in NBPZ. The period from 1975-1980 was the most drought period as the EDI values of -4.5, -4.28 and -3.53 were recorded in HZ, BVZ and CBVZ, respectively. The trend analysis showed that there is a clear evidence of a statistically significant increase in the severity and intensity of drought on all time scales in all the zones. The main results showed that the majority of extreme drought periods were recorded within the monsoon season in all the six agro-climatic zones and the highest magnitude of drought of -0.10 per decade was noticed in CBVZ zone. The most recent decade showed that the drought like phenomenon is creeping in the study area. The drought is having dominant periodicities in the medium-range of 4 to 9 years in all the zones except NBPZ where it may occur after every 2 to 3 years. Since, the main crop of Assam is paddy which is grown in monsoon season (*Kharif*), there is an urgent need to develop a crop contingency plan, drought early warning systems and proper water management plan for the sustainable agriculture and social development.

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