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Reconnaissance of meteorological drought by using Standardized Precipitation Index and India Meteorological Department criteria for five districts of south Gujarat

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ABSTRACT

Assessment of drought is one of the most important steps in risk management of drought. The standardized precipitation index (SPI) can be used for indicating the associated temporal and spatial variations of rainfall. The aim of this research is the assessment of the characteristics such as intensity, frequency and duration of meteorological drought using SPI with 12 months time scales in south Gujarat. On the basis of SPI more wet events were found in Valsad district, followed by Surat and Navsari. Similarly more dry events were observed in Navsari district followed by Bharuch and Dangs districts. SPI values of the high rainfall district showed slightly better stretching in both positive and negative directions, compared to that of the low rainfall district. The trend analysis shows increasing trend of SPI for Navsari district and decreasing trend of SPI for Dangs, Valsad, Surat and Bharuch districts. On the basis of IMD criteria, the frequency of occurrence of drought at Navsari and Bharuch districts is higher as compared to Dangs, Valsad and Surat districts. Similarly, the frequency of occurrence of excess rainfall at Dangs and Surat districts is higher as compared to Navsari, Valsad and Bharuch districts. Drought anomaly was found that frequency of mild drought occurrence was quite high and occurred at regular interval at all the locations.

1. INTRODUCTION

The drought is a natural hazard that has significant impact on Indian economy which affects the agricultural production resulting in decreased growth rate (GDP). In recently years it has been observed that the Indian economy is affected by agricultural drought as well as meteorological drought. The western regions of India (Rajasthan and Gujarat provinces) suffered with severe droughts at many times in the past. The frequent occurrence of drought in these regions is due to poor and untimely monsoon, abnormally high temperature especially in the summer and various other unfavorable meteorological conditions. Drought is a disastrous natural phenomenon that cause significant impact on socio-economic, agricultural, and environmental spheres. It differs from other natural hazards by its slow accumulating process and its indefinite commencement and termination. Being a slow process although drought often fails to draw the attention of the world community, its impact persists even after ending of the event. Beside, the concept of drought varies among regions of differing climates (Dracup *et al.*, 1980). In general, drought gives an impression of water scarcity resulted due to insufficient precipitation, high evapo-transpiration, and over-exploitation of water resources or combination of these parameters. There are various methods and indices for drought analysis and they

measure different drought-causative and drought-responsive parameters, and identify and classify drought accordingly. Rainfall is the primary driver of meteorological drought. There are numerous indicators based on rainfall that are being used for drought monitoring (Smakhtin and Hughes, 2007; Kumar and Patel, 2012; Kumar *et al*., 2015; Kumar *et al*., 2015a). Deviation of rainfall from normal *i.e.* long term mean is the most commonly used indicator for drought monitoring. On the basis of rainfall deviations, four categories are used in India for monitoring and evaluating the rainfall patterns across the country during the monsoon season; ±20% deviation as normal, -20 to -60% deviation as deficit, less than -60% deviation as scanty and greater than 20% deviation as excess (www.imd.gov.in). Meteorological drought is declared based on rainfall deviations measured using the season's total actual rainfall and long term mean rainfall. If the total season's rainfall is less than 75% of the long term mean, the meteorological sub-division is categorized to be under drought. Severe drought occurs when the season's rainfall is less than 25% of normal (www.imd.gov.in). The deviation criteria for declaring drought vary. Computation of SPI requires long term data on precipitation to determine the probability distribution function which is then transformed to normal distribution with mean of zero and standard deviation of one. Thus, the values of SPI are expressed in standard deviations with positive SPI values indicating greater than median precipitation and negative values indicating less than median precipitation (Edwards and McKee, 1997). Since SPI values fit a typical normal distribution, these values within one standard deviation at approximately 68% of the time, within two standard deviations 95% of the time and within three standard deviations 98% of the time. In recent years SPI has been increasingly used for assessment of drought intensity in many countries (Vicente-Serrano *et al*., 2004; Wilhite *et al*., 2005; Wu *et al*., 2006; Krishna *et al*., 2017; Kumar *et al*., 2017). Homogeneous climatic zones were derived using SPI in Mexico (Giddings *et al*., 2005). The interpretation of drought at different time scales using SPI has also been proved to be superior to the Palmer Drought Severity Index (Guttman, 1998). Goodrich and Ellis (2006) have used both SPI and yearly values of the Palmer Drought Severity Index to rank the years according to drought severity. Smakhtin and Hughes (2007), developed software to compute and apply different rainfall based indicators including SPI for quantitative assessment of meteorological drought, and McKee *et al.* (1993) suggested the SPI ranges corresponding to different severity levels of drought. These time scales reflect the drought specific effects on the ability to access different water resources. The soil moisture conditions react toward precipitation short-term abnormalities, while groundwater, river flow, reservoir storage and agriculture production are affected by precipitation long-term abnormalities. In the present study analysis have been done to assess the response for seasonal SPI values for drought situation and rainfall deviations from normal for five districts of south Gujarat.

2. MATERIALS AND METHODS

In south Gujarat five locations were selected for assessment of rainfall intensity and frequency *viz*., 1) Navsari (23.15°N and 69.49°E, altitudes 11.0 m), 2) Bharuch (22.98°N and 70.21°E, altitudes 3.0 m), 3) Surat (22.98°E and 70.21°E, altitudes 3.0 m), 4) Valsad (22.35°N and 72.35°E, altitudes 6.10 m) and 5) Dangs (20.51°N and 70.21°E, altitudes 440 m) (Fig. 1). The historical monthly and annual rainfall data were used of 115 years (1901-2015).

Standardized Precipitation Index (SPI)

The definition of drought proposed by Mckee *et al.* (1993) employing the SPI is used to measured drought for time scale ranging from 3, 6, 12, 24 and 48 months. The gamma distribution has been found to fit climatological precipitation time series well therefore: computation of the SPI involves fitting a gamma probability density function given a series of monthly precipitation totals for station. The resulting parameters are then used to find the probability of a particular precipitation event over a given time scale. This

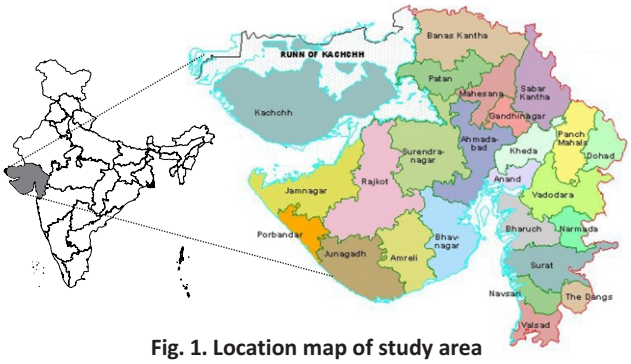

Fig. 1. Location map of study area

probability is then converted to the standard normal random variable Z, which is the SPI index value.

SPI was developed in Colorado by McKee *et al.* (1993), is based on the probability distribution of precipitation and requires less input data and calculation efforts then PDSI, and is reported to be able to identify emerging droughts sooner than Palmer Index. The basis of SPI approach is the calculating probabilities of precipitation for each time scale. In a general point of view, for analyzing the precipitation data in monthly scale during a record period (preferably 30 years or more), it is required to form total precipitation time series in an ideal scale. The main problem in this case is fitting an appropriate statistical distribution on a particular time series. (Edwards and Mckee, 1997) realized that gamma distribution fits well for some climatological data such as precipitation time series. To obtain experimental accumulation probabilities, first precipitation data will be arranged as ascendant then the value of experimental probabilities. For an easy access to Z or SPI values, it is better to use (Edward and Mckee, 1997) this approximation transform the accumulation possibilities to standard normal random variant. Actually SPI is a standard variant that shows diversion values upper or lower than average. Different applications of SPI including:

(1) Drawing SPI series (in each time scale) in a chart is a good index of drought phenomenon in a particular place.
(2) SPI can be used for spatial analysis of drought, so makes it possible to compare different stations in various climatic regions ignoring differences between their normal precipitations.
(3) SPI can be calculated for short time scales (for example, one month).
(4) By studying drought, it is possible to analyze frequency and duration of different values of SPI.

Calculation of SPI

The SPI was developed by Mckee *et al.* (1993) to quantify precipitation anomaly with respect to long-term normal conditions for multiple time scales. SPI can be calculated at various time scales on which precipitation deficits/surpluses can affect different aspects of the hydrologic cycle, which is the main advantage of the SPI. This advantage is crucial because it can reflect the natural lags in the response of different water sources, such as river discharge and storage, to precipitation anomalies (Paulo *et al.*, 2005). Also follow WMO, 2012, SPI guideline for calculating SPI.

In order to analysis the impact of rainfall deficiency on drought development in this terrain, SPI has been used to quantify the precipitation deficit in the monsoon and the non-monsoon periods since 1901 upto 2015, Table 1. The SPI is calculated using the following equation, written as:

$$SPI = (X_{ij} - X_{im}) / \sigma \quad \ldots(1)$$

Where, X_{ij} is the actual rainfall, X_{im} is normal rainfall and σ is its standard deviation.

Drought Intensity Calculation as per IMD Criteria

The drought analysis of annual rainfall over south Gujarat is calculated by based on India Meteorological Department (IMD) criteria. The frequencies of excess and deficient rainfall month have been determined by the criteria adopted by IMD and these frequencies are presented in Table 2. As per IMD criteria, if the actual rainfall in a month is higher than the long period average (Normal rainfall) by 0-25%, it is called a mild excess. If the actual rainfall in a month is higher than the long period average (Normal rainfall) by 25-50%, it is called a moderate excess. If the actual rainfall in a month is higher than the long period average (Normal rainfall) by more than 50%, it is called a severe excess. Similarly deficit calculation, if the actual rainfall in a

Table: 1
Categories of dryness/wetness based on SPI values

Class	Symbol	SPI
Extremely wet	EW	>2
Severely wet	SW	1.5 to 1.99
Moderately wet	Mw	1 to 1.49
Near Normal	NN	-0.99 to 0.99
Moderately dry	MD	-1 to -1.49
Very dry	VD	-1.5 to -1.99
Extremely dry	ED	< -2

Table: 2
Criterion for drought intensity

Departure of rainfall from normal (%)	Drought intensity
-0-25%	Mild
-26-50%	Moderate
->50%	Severe
+0-25%	Mild excess
+26-50%	Moderate excess
+>50%	Severe excess

month is less than the long period average (Normal rainfall) by -0 to -25%, it is called a mild deficit. If the actual rainfall in a month is less than the long period average (Normal rainfall) by -26 to -50%, it is called a moderate deficit. If the actual rainfall in a month is less than the long period average (Normal rainfall) by more than -51%, it is called a severe deficit.

3. RESULTS AND DISCUSSION

Excess (wet events) Analysis based on Standard Precipitation Index (SPI)

SPI is a probability index for monitoring drought. This drought index is developed to detect drought and wet period for different time scale in various region of the world. Additionally, it defines an event a drought when the SPI becomes -1.0 or less. On the basis of SPI criteria past 115 year rainfall data of Dangs, Valsad, Surat, Navsari and Bharuch district were analyzed.

Extremely wet

At Dangs district highest extremely wet rainfall events were observed in years *viz.,* 1912, 1976, 1983, 1994 and 2005, followed by Bharuch district *viz.,* 1917, 1959, 1796 and 2010. Similarly, at Navsari (1917, 1970 and 1976), Valsad (1921, 1954 and 1976) and Surat (1945, 1976 and 2005) districts extremely wet events were found in 3 years (Table 3, 4 and 5). The frequency of occurrence of extreme wet at Dangs district ones in 23 years, Bharuch district ones in 29 years as well as at Valsad, Surat and Navsari districts once in 38 years (Table 3).

Severely wet

The SPI values were found to be on the higher side (1.5 to 1.99), for the events of severely wet rainfall. The Navsari and Surat districts revealed that 5 years were severe wet. At Dangs, Valsad and Bharuch districts severely wet were recorded in 4 years (Table 3, 4 and 5). The frequencies of occurrence of severe wet at Navsari and Surat districts are once in every 23 years while occurrence in Dangs, Valsad and Bharuch districts are every 29 years.

Moderately wet

The SPI values were observed on the higher side (1.0 to 1.49), for the events of moderate wet rainfall.

Table: 3
The value of rainfall intensity and frequency on the basis of Standard Precipitation Index (SPI) at Valsad, Surat and Dangs for the year of 1901 to 2015

Intensity	Years	Total years	Frequency
	Valsad		
Extremely wet	1921, 1954, 1976	3	38
Severely wet	1926, 1988, 1994, 1999	4	29
Moderately wet	1913, 1914, 1997, 1917, 1959, 1964, 1969, 1970, 1983, 2003, 2005	12	10
Near normal	1901, 1902, 1903,1906, 1907, 1908, 1909, 1910, 1912, 1913, 1914, 1916, 1918, 1919, 1921, 1922, 1923, 1924, 1926, 1927, 1928, 1929, 1930, 1931, 1932, 1933, 1934, 1935, 1936, 1937, 1938, 1940, 1941, 1942, 1943, 1944, 1945, 1946, 1947, 1949, 1950, 1953, 1954, 1955, 1956, 1957, 1958, 1960, 1961, 1962, 1963, 1966, 1967, 1968, 1971, 1973, 1975, 1976, 1977, 1978, 1979, 1980, 1981, 1982, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1997, 1999, 2000, 2001, 2002, 2004, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014	80	1
Moderately dry	1915, 1920, 1925, 1939, 1952, 1965, 1996, 2015	8	14
Very dry	1904, 1905, 1911, 1951, 1972, 1974	6	19
Extremely dry	1948, 1998	2	58
	Surat		
Extremely wet	1945, 1976, 2005	3	38
Severely wet	1917, 1926, 1959, 1970, 1988	5	23
Moderately wet	1905, 1912, 1914, 1945, 1953, 1954, 1964, 1983, 2004, 2006	10	12
Near normal	1902, 1903, 1906, 1907, 1908, 1909, 1910, 1913, 1916, 1919, 1920, 1921, 1922, 1923, 1924, 1927, 1928, 1929, 1930, 1931, 1932, 1933, 1934, 1935, 1937, 1938, 1939, 1940, 1941, 1942, 1943, 1944, 1946, 1947, 1948, 1949, 1950, 1955, 1956, 1957, 1958, 1960, 1961, 1962, 1963, 1965, 1966, 1967, 1968, 1969, 1971, 1972, 1973, 1975, 1977, 1978, 1979, 1980, 1981, 1982, 1984, 1986, 1989, 1990, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2002, 2003, 2007, 2008, 2009, 2010, 2011, 2013, 2014	80	1
Moderately dry	1901, 1911, 1915, 1925, 1936, 1952, 1974, 1985, 1987, 1991, 2000, 2001, 2015	14	8
Very dry	1904, 1918, 1951, 2012	3	38
Extremely dry	0	0	0

Table: 4
The value of rainfall intensity and frequency on the basis of Standard Precipitation Index (SPI) at Navsari and Bharuch for the year of 1901 to 2015

Intensity	Years	Total years	Frequency
	Navsari		
Extremely wet	1917, 1970, 1976	3	38
Severely wet	1914, 1954, 1959, 2005, 2013	5	23
Moderately wet	1903, 1912, 1919, 1921, 1958, 1964, 1977, 1988, 1994, 2010	10	12
Near normal	1901, 1902, 1904, 1906, 1907, 1908, 1909, 1910, 1913, 1915, 1916, 1922, 1924, 1926, 1927, 1928, 1929, 1930, 1931, 1932, 1933, 1934, 1937, 1938, 1940, 1941, 1942, 1943, 1947, 1949, 1950, 1953, 1955, 1956, 1960, 1961, 1962, 1963, 1965, 1966, 1967, 1968, 1969, 1971, 1972, 1973, 1974, 1975, 1978, 1979, 1983, 1984, 1985, 1987, 1989, 1990, 1992, 1993, 1995, 1996, 1998, 2001, 2002, 2003, 2004, 2006, 2007, 2008, 2009, 2011, 2012, 2014, 2015	74	2
Moderately dry	1905, 1911, 1918, 1920, 1925, 1935, 1936, 1939, 1944, 1945, 1946, 1951, 1952, 1957, 1980, 1981, 1982, 1986, 1991, 1997, 1999, 2000	22	5
Very dry	1948	1	115
Extremely dry	0	0	0
	Bharuch		
Extremely wet	1917, 1959, 1976, 2010	4	29
Severely wet	1942, 1945, 1970, 1983	4	29
Moderately wet	1912, 1913, 1916, 1946, 1990, 1994, 2005, 2006, 2013	9	13
Near normal	1902, 1903, 1906, 1907, 1908, 1909, 1910, 1914, 1919, 1920, 1921, 1922, 1924, 1925, 1926, 1927, 1928, 1929, 1930, 1931, 1932, 1933, 1934, 1935, 1936, 1937, 1938, 1939, 1940, 1941, 1943, 1944, 1947, 1949, 1950, 1953, 1954, 1955, 1956, 1957, 1958, 1960, 1961, 1962, 1963, 1964, 1965, 1966, 1967, 1968, 1969, 1971, 1973, 1975, 1977, 1978, 1979, 1980, 1981, 1984, 1985, 1986, 1988, 1989, 1991, 1992, 1993, 1995, 1996, 1998, 2000, 2002, 2003, 2004, 2007, 2008, 2011, 2012, 2014, 2015	80	1
Moderately dry	1901, 1904, 1905, 1911, 1915, 1952, 1982, 1987, 1997, 1999, 2001, 2009	12	10
Very dry	1918, 1923, 1948, 1951, 1972, 1974	6	19
Extremely dry	0	0	0

The Valsad district showed highest moderate wet 12 years. The frequencies of occurrence of moderately wet are once in every 10 years, shows Table 3. Similarly Navsari and Surat districts was found 10 moderately wet years. Calculated demonstrate the frequencies of occurrence of moderately wet are once in every 12 years, Table 3 and 4. In case of Bharuch district 9 moderate wet years were observed. Every ones year occurrence frequencies for moderately wet event are after 13 years (Table 4). In Dangs district the moderately wet events were reported in 8 years. The frequencies of occurrence of moderately wet are once in every 17 years, Table 5.

Drought Analysis based on Standard Precipitation Index (SPI)

Moderately dry

The performance of SPI at various time scales in representing individual drought events appears different from identifying dry period. SPI at the longer time scales show greater utility, but performed poorly at time scale less than 6 months. For moderately dry events, as shown in Table 3, for Valsad district 8 major events matched exactly with the 8 negative value of SPI at the annual time scale, which is the same time scale of the moderate dry situation for agriculture crops. The SPI peaks at longer time scale are clearly associated with these 8 events, because the averaging effect of short term accumulated precipitation over long period. This highlights the usefulness of SPI at the annual time scale representing dry events. The frequencies of occurrence of moderately drought are once in every 14 years.

The Surat district for moderately dry events, as shown in Table 3, 14 major events matched exactly with the 14 negative value of SPI at the annual time scale, which is the same time scale of the moderate dry situation for agriculture crops. The SPI peaks at longer time scale are clearly associated with these 14 events, because the averaging effect of short term accumulated precipitation over long period. This highlights the usefulness of SPI at the annual time scale representing drought events. The frequencies of occurrence of moderately drought are once in every 8 years.

Table: 5
The value of rainfall intensity and frequency on the basis of Standard Precipitation Index (SPI) at Dangs for the year of 1903 to 2015

Intensity	Years	Total years	Frequency
	Dangs		
Extremely wet	1912, 1976, 1983, 1994, 2005	5	23
Severely wet	1910, 1915, 1925, 1944	4	29
Moderately wet	1917, 1945, 1946, 1950, 1970, 1988, 1993, 2013	8	17
Near normal	1901, 1902, 1903, 1904, 1905, 1906, 1907, 1908, 1909, 1911, 1913, 1914, 1919, 1920, 1921, 1922, 1924, 1926, 1927, 1928, 1929, 1930, 1931, 1932, 1933, 1934, 1935, 1937, 1938, 1939, 1940, 1941, 1942, 1943, 1947, 1949, 1953, 1954, 1955, 1958, 1959, 1961, 1963, 1964, 1965, 1966, 1967, 1968, 1969, 1971, 1973, 1977, 1978, 1980, 1981, 1982, 1984, 1985, 1989, 1990, 1991, 1992, 1995, 1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2006, 2007, 2008, 2010, 2011, 2012, 2014, 2015	80	1
Moderately dry	1918, 1923, 1948, 1952, 1956, 1962, 1972, 1975, 1979, 1986, 1987, 2009	12	10
Very dry	1916, 1936, 1951, 1957, 1960, 1974	6	19
Extremely dry	0	0	0

Similarly the Navsari district for moderately dry events, as presented in Table 4, 22 major events matched exactly with the 22 negative value of SPI at the annual time scale, which is the same time scale of the moderate dry situation for agriculture crops. The SPI peaks at longer time scale are clearly associated with these 22 events, because the averaging effect of short term accumulated precipitation over long period. This highlights the usefulness of SPI at the annual time scale representing dry events. The frequencies of occurrence of moderately drought are once in every 5 years.

For moderately drought events Bharuch district showed 12 major events matched exactly with the 12 negative value of SPI at the annual time scale, which is the same time scale of the moderate dry situation for agriculture crops. The SPI peaks at longer time scale are clearly associated with these 12 events, because the averaging effect of short term accumulated precipitation over long period. This highlights the usefulness of SPI at the annual time scale representing dry events. The frequencies of occurrence of moderately dry are once in every 10 years (Table 4).

Moderately drought events at the Dangs district showed 12 major events matched exactly with the 12 negative value of SPI at the annual time scale, which is the same time scale of the moderate drought situation for agriculture crops. The SPI peaks at longer time scale are clearly associated with these 12 events, because the averaging effect of short term accumulated precipitation over long period. This highlights the usefulness of SPI at the annual time scale representing dry events. The frequencies of occurrence of moderately dry are once in every 10 years, Table 5. It reported that Patel *et al.* (2007), it can be seen that during the drought years of 1982 and 1987, negative SPI values noticed in western, central and southwestern Gujarat, which indicate that there was rainfall deficit in these areas during the southwest monsoon season, *i.e.* during June-September. In 1987, the spatial patterns of 3 month SPI across crucial months for *kharif* crops depicts negative SPI, with a majority of areas having an SPI value below -2.0. Thus, the spatio-temporal evolution of the SPI clearly indicates that 1987 was a severe drought year taking into account the magnitude, duration and extent of a negative SPI. The results are also in agreement with those reported earlier (Gore and Sinha Ray, 2002).

Very dry

Pai *et al*. (2010) and Kumar *et al*. (2009) those reported earlier. The most suitable time scale for detecting drought may differ due to the magnitude or duration of each drought events. For example, in years *viz.*, 1904, 1905, 1911, 1951, 1972 and 1974, the Valsad region suffered very dry multi-seasonal droughts. However, the drought event was best represented with the annual frequencies occurred once in every 19 years, Table 3.

The SPI values were observed that on the negative higher side (-1.50 to -1.99), for the events of very dry wet rainfall. The Surat district was found very dry 3 years *viz.*, 1904, 1918, 1951 and 2012. The frequencies of occurrence of very dry are once in every 38 years (Table 3).

Similarly, Navsari districts were found single very dry year *viz.*, 1948. Calculated demonstrate the frequencies of occurrence of moderately wet are once in every 115 years, Table 4.

Both Bharuch and Dangs districts found 6 very dry years *viz.*, 1918, 1923, 1948, 1951, 1972 and 1974 and 1916, 1936, 1951, 1957, 1960 and 1974. Every ones year occurrence frequencies for very dry event are after 19 years, presented in Table 4 and 5.

Extremely dry

SPI values of the high rainfall district indicated an enhanced range of values, -2.0 or less for very low rainfall districts. Since rainfall and its variations are very critical in low rainfall districts, SPI values should assume wider range to represent the degree of dryness resulting in better assessment of drought situation. For extremely dry events however, as shown in Table 3, Valsad district two major events in 1948 and 1998 matched exactly with the two negative value of SPI at the annual time scale, which is the same time scale of the extremely dry situation for agriculture crops. The SPI peaks at longer time scale are clearly associated with these two events, because the averaging effect of short term accumulated precipitation over long period. This highlights the usefulness of SPI at the annual time scale representing dry events. The frequencies of occurrence of extremely dry are once in every 58 years, Table 3. This proves that the 3-month SPI of September accurately captured the deficiency or excess of precipitation for detecting seasonal drought in Gujarat. The results are also in agreement with those reported earlier (Gore and Sinha Ray, 2002) and Patel *et al.* (2007), also reported that Sadiq *et al.* (2014), this standardization allows the SPI to determine the rarity of a current drought, as well as the probability of the precipitation necessary to end the current drought.

Trend analysis on Standard precipitation index (SPI)

Precipitation trend analysis, on different spatial and temporal scales, has been of great concern during the past century because of the attention given to global climate change from the scientific community: they indicate a small positive global trend, even through large areas are instead characterized by negative trends (IPCC, 1996).

Trend analysis of SPI presented in Fig. 2 for Navsari district is shows that increasing trend of SPI 0.016 mm. Remaining districts Valsad, Dangs, Surat and Bharuch shows decreasing trends of SPI *viz.*, -0.0459, -0.0038, -0.0393 and -0.0532 mm presented in Fig. 3, 4, 5 and 6, respectively.

Drought Analysis Based on IMD Criteria

Drought analysis

Drought of different intensities at Dangs, Valsad, Surat, Navsari and Bharuch districts are demonstrated in Table 6 and 7. The analysis of data revealed that during past 115 years Navsari district experienced 30 mild, 27 moderate and 4 severe droughts. The frequencies of occurrence of mild and moderate droughts are once in every 4 years, while occurrence of severe drought in every 29 years.

Dangs district encountered 44 mild, 17 moderate and 2 severe droughts. The frequencies of occurrence for mild and moderate droughts are once in every 3 and 7 years, respectively, while incidence of severe drought in every 57 years, Table 6.

Valsad district experienced 38 mild, 17 moderate and 5 severe droughts. The frequencies of occurrence

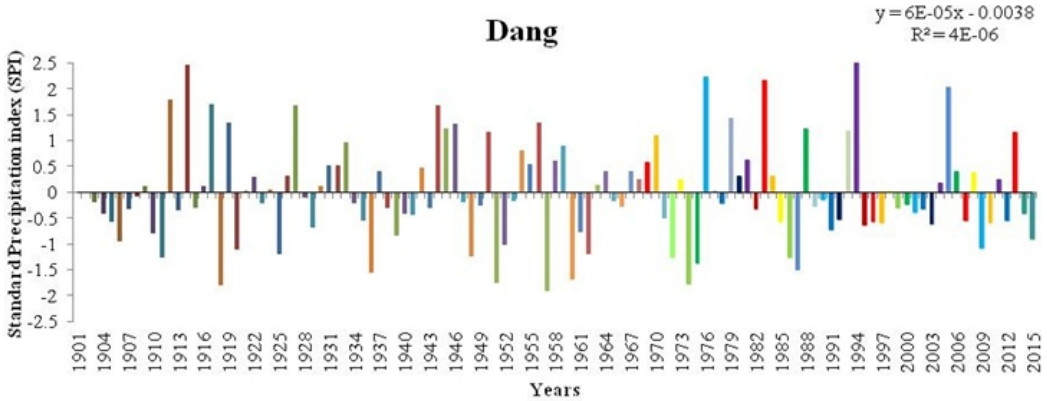

Fig. 2. Annual Standard Precipitation Index (SPI) over Dangs during 1903-2015

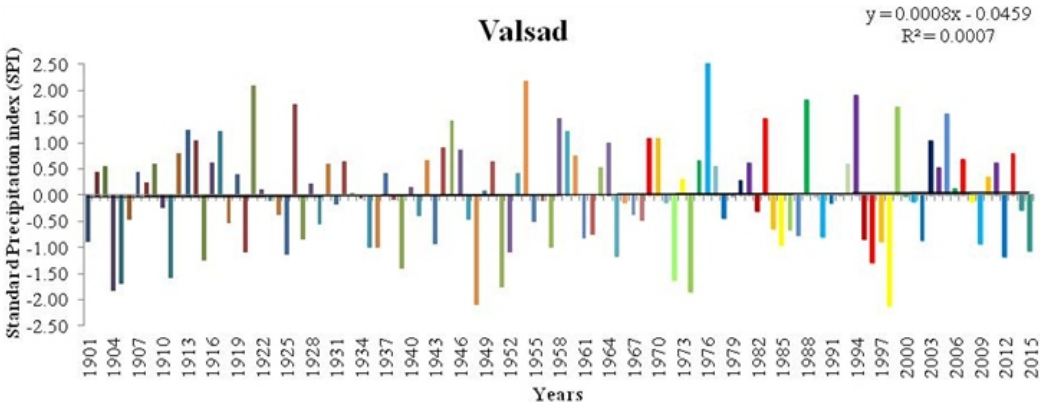

Fig. 3. Annual Standard Precipitation Index (SPI) over Valsad during1901-2015

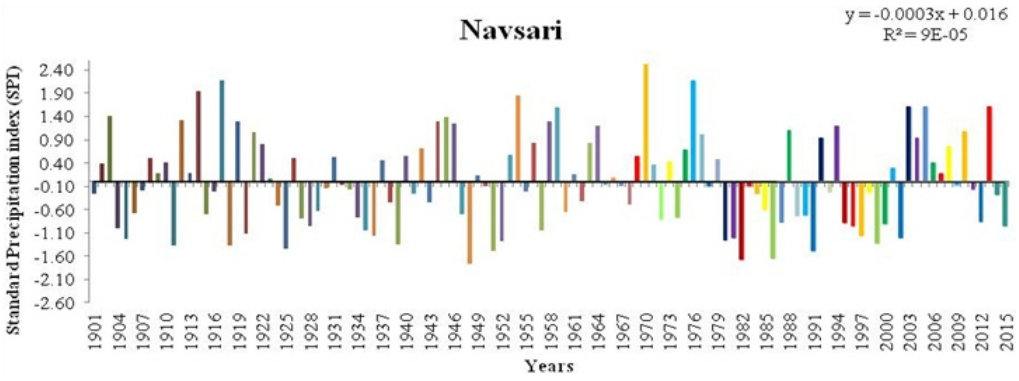

Fig. 4. Annual Standard Precipitation Index (SPI) over Navsari during 1901-2015

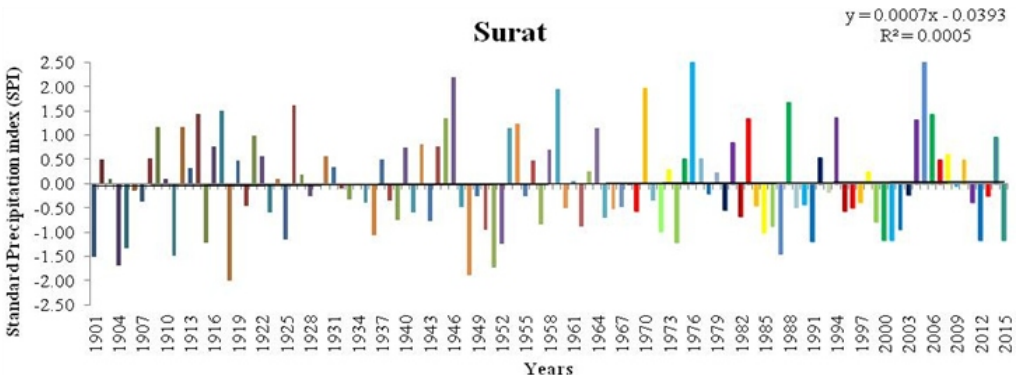

Fig. 5. Annual Standard Precipitation Index (SPI) over Surat during 1901-2015

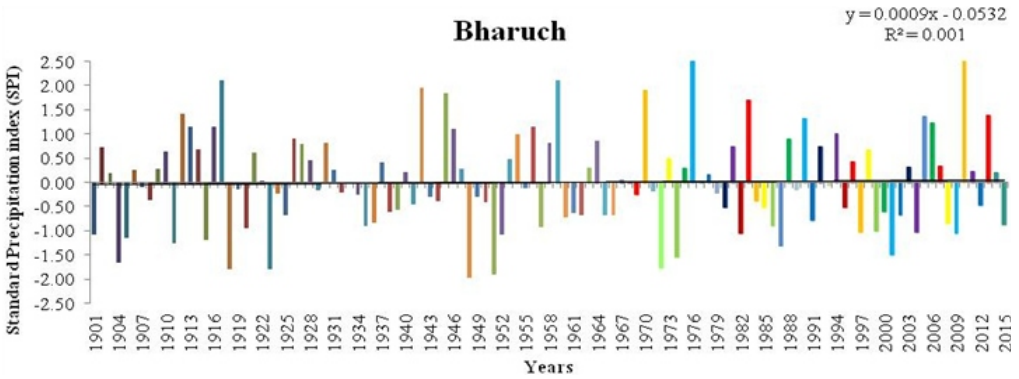

Fig. 6. Annual Standard Precipitation Index (SPI) over Bharuch during 1901-2015

for mild and moderate droughts are once in every 3 and 7 years, respectively, while occurrence of severe drought in every 23 years, Table 6.

Surat district acknowledged 38 mild, 20 moderate and 6 severe droughts. The frequencies of occurrence regarding mild and moderate droughts are once in every 3 and 6 years, respectively, while appearance of severe drought in every 20 years, Table 6.

Bharuch district experienced 28 mild, 19 moderate and 12 severe droughts. The frequencies of occurrence for mild and moderate droughts are once in every 4 and 6 years, respectively, while exigency of severe drought in every 10 years, Table 7. The frequency of happening of drought at Bharuch district is much surpassing as compared to Dangs, Valsad, Surat and Navsari districts. Drought anomaly was found that frequency of mild drought occurrence was quite high and occurred at regular interval at all the locations. The frequency of occurrence of drought at Bharuch is much higher as compared to Dangs, Valsad, Surat and Navsari Bharuch district shows had higher rainfall deficit years than excess. Decreasing monsoonal phenomenon may adversely affect the water availability in Bharuch region.

Excess analysis

Dangs, Valsad and Navsari districts are categorized as heavy rainfall zone of south Gujarat and the rainfall severity was observed towards higher side. South Gujarat receives 97% rainfall from south west monsoon (24 to 39 standard weeks) during the months of June to September. The least attempts had been made for assessing the intensity and frequency of

Table: 6
The value of rainfall intensity and frequency at Valsad, Surat and Dangs for the year of 1901 to 2015

Intensity	Years	Total years	Frequency
	Valsad		
Mild	1902, 1903, 1907, 1908, 1909, 1910, 1913, 1916, 1919, 1922, 1923, 1928, 1930, 1936, 1943, 1947, 1955, 1961, 1962, 1966, 1967, 1968, 1971, 1978, 1982, 1984, 1985, 1986, 1987, 1989, 1990, 1995, 1996, 1997, 2002, 2009, 2012, 2015	38	3.03
Moderate	1901, 1906, 1915, 1920, 1924, 1925, 1927, 1929, 1935, 1939, 1941, 1951, 1952, 1957, 1965, 1972, 1974	17	6.76
Severe	1904, 1905, 1911, 1918, 1948	5	23.00
Mild excess	1912, 1914, 1917, 1926, 1931, 1932, 1933, 1934, 1937, 1938, 1940, 1942, 1949, 1950, 1953, 1956, 1960, 1963, 1964, 1973, 1975, 1977, 1979, 1980, 1981, 1991,1992, 1998, 2000, 2001, 2008, 2014	32	3.59
Moderate excess	1921, 1944, 1945, 1946, 1958, 1969, 1970, 1983, 1988, 1993, 1999, 2004, 2006, 2007, 2010, 2011, 2013	17	6.76
Severe excess	1954, 1959, 1976, 1994, 2003, 2005	6	19.17
	Surat		
Mild	1903, 1906, 1907, 1910, 1913 , 1920, 1924, 1927, 1928,1929, 1933, 1935, 1938, 1939, 1941, 1943, 1947, 1949, 1955, 1960, 1965, 1966, 1967, 1969, 1971, 1978, 1980, 1982, 1984, 1989, 1990, 1995, 1996, 1997, 1999, 2003, 2011, 2013	38	3.02
Moderate	1901, 1905, 1911, 1915, 1923, 1925, 1936, 1950, 1952, 1957, 1962, 1972, 1974, 1985, 1986, 1991, 2000, 2001, 2002, 2012	20	5.75
Severe	1904, 1918, 1948, 1951, 1987, 2015	6	19.67
Mild excess	1902, 1908, 1909, 1912, 1914, 1916, 1919, 1921, 1922, 1930, 1931, 1932, 1934, 1937, 1956, 1961, 1963, 1968, 1973, 1975, 1977, 1979, 1993, 1998, 2009	25	4.6
Moderate excess	1917, 1926, 1940, 1942, 1944, 1953, 1954, 1958, 1964, 1981, 1992, 2007, 2008, 2010, 2014	15	7.67
Severe excess	1945, 1946, 1959, 1970, 1976, 1983, 1988, 1994, 2004, 2005, 2006	11	10.45
	Dangs		
Mild	1903, 1907, 1908, 1909, 1913, 1915, 1916, 1921, 1922, 1923,1924, 1926, 1928, 1930, 1935, 1938, 1939, 1940, 1941, 1943, 1948, 1949, 1952, 1963, 1965, 1966, 1971, 1977, 1978, 1982, 1985, 1989, 1990, 1991, 1992, 1995, 1996, 1997, 2003, 2007, 2009, 2010, 2012, 2015	44	2.57
Moderate	1904, 1905, 1906, 1910, 1911, 1920, 1925, 1929, 1936, 1951, 1957, 1960, 1961, 1962, 1972, 1986, 1987	17	6.64
Severe	1918, 1974	2	56.5
Mild excess	1912, 1917, 1919, 1927, 1931, 1932, 1934, 1937, 1942, 1947, 1949, 1953, 1954, 1955, 1958, 1964, 1967, 1968, 1969, 1970, 1973, 1980, 1981, 1984, 1998, 1999, 2000, 2001, 2002, 2014	30	3.77
Moderate excess	1914, 1933, 1944, 1945, 1946, 1950, 1956, 1959, 1979, 1988, 2004, 2006, 2008, 2011	14	8.07
Severe excess	1976, 1983, 1993, 1994, 2005, 2013	6	18.83

Table: 7
The value of rainfall intensity and frequency on the basis of Standard Precipitation Index (SPI) at Navsari and Bharuch for the year of 1901 to 2015

Intensity	Years	Total years	Frequency
	Navsari		
Mild	1901, 1906, 1907, 1915, 1923, 1924, 1927, 1929, 1930, 1934, 1935, 1938, 1943, 1947, 1957, 1960, 1961, 1962, 1965, 1966, 1967, 1968, 1978, 1983, 1984, 1993, 1998, 2009, 2011, 2014	30	3.83
Moderate	1904, 1905, 1911, 1918, 1920, 1925, 1928, 1936, 1939, 1948, 1951, 1952, 1972, 1974, 1985, 1987, 1989, 1990, 1991, 1995, 1996, 1997, 1999, 2000, 2002, 2012, 2015	27	4.26
Severe	1980, 1981, 1982, 1986	04	28.75
Mild excess	1902, 1908, 1909, 1910, 1913, 1916, 1922, 1926, 1932, 1933, 1941, 1949, 1950, 1955, 1963, 1969, 1971, 1973, 1975, 1979, 1992, 2001, 2004, 2006, 2007, 2008	26	4.42
Moderate excess	1903, 1912, 1919, 1921, 1931, 1937, 1940, 1942, 1953, 1956, 1964, 1977, 1988, 1994, 2003, 2005, 2010, 2013	18	6.39
Severe excess	1914, 1917, 1944, 1945, 1946, 1954, 1958, 1959, 1970, 1976	10	11.5
	Bharuch		
Mild	1907, 1908, 1919, 1922, 1924, 1925, 1929, 1935, 1936, 1938, 1939, 1941, 1944, 1950, 1957, 1960, 1967, 1968, 1969, 1971, 1977, 1979, 1980, 1984, 1985, 1989, 1993, 2012	28	4.11
Moderate	1901, 1905, 1911, 1915, 1920, 1952, 1961, 1962, 1965, 1966, 1982, 1986, 1991, 1995, 1999, 2000, 2002, 2008, 2015	19	6.05
Severe	1904, 1918, 1923, 1948, 1951, 1972, 1974, 1987, 1997, 2001, 2004, 2009	12	9.58
Mild excess	1902, 1903, 1906, 1909, 1910, 1914, 1921, 1926, 1927, 1928, 1930, 1931, 1932, 1933, 1934, 1940, 1943, 1947, 1949, 1955, 1963,1973, 1975, 1978, 1981, 1996, 2003, 2007, 2011, 2014	30	3.83
Moderate excess	1912, 1913, 1916, 1937, 1953, 1954, 1958, 1964, 1988, 1990, 1992, 1994, 1998	13	8.85
Severe excess	1917, 1942, 1945, 1946, 1956, 1959, 1970, 1976, 1983, 2005, 2006, 2010, 2013	13	8.85

drought as well as excess rainfall for this region. Excess rainfall of different intensities at Dangs, Valsad, Surat, Navsari and Bharuch is demonstrated in Table 6 and 7.

From Table 7, past 115 years data exhibited that, Navsari district acknowledged 26 mild, 18 moderate and 10 excess rainfall appearances. The frequencies of occurrence for mild and moderate excess once in 4 and 6 years, respectively, while appearance of severe excess in every 12 years.

Dangs district experienced 30 mild, 14 moderate and 6 excess rainfall situations. The frequencies of occurrence for mild and moderate excess once in 4 and 8 years, respectively, while appearance of severe excess in every 19 years, Table 6.

Valsad district recognized 32 mild, 17 moderate and 6 excess rainfall incidents. The frequencies of occurrence for mild and moderate excess once in 4 and 7 years, respectively, while appearance of severe excess in every 19 years, Table 6. The frequency of mild and moderate excess comes after every 4 year for Dangs and Valsad districts. Similarly severe excess comes after every 19 year for Dangs and Valsad districts.

Surat district experienced 25 mild, 15 moderate and 11 excess rainfall events. The frequencies of occurrence for mild and moderate excess once in 5 and 8 years, respectively, while occurrence of severe excess in every 10 years.

Bharuch district encountered 25 mild, 13 moderate and 13 excess rainfall pursuits. The frequencies of occurrence for mild and moderate, severe excess once in 4 and 9 years, respectively. This increasing trend of annual rainfall affects the cropping pattern, crop growth and yield of the region.

4. CONCLUSIONS

Based on the study it can be concluded that the SPI values of high rainfall district showed wider range in both positive and negative directions compared to that of the low rainfall district. The positive SPI values indicating wetness in annual rainfall, in the high rainfall of different districts in south Gujarat. The Dangs district was found highest extremely wet rainfall event occurrence as compared to Bharuch, Valsad, Surat and Navsari districts. The Dangs district is occurrence of extremely wet year is likely to be much faster than other district. The Navsari and Surat districts high severe wet rainfall events were found as

compared to other district. The highest moderately wet years were observed that Valsad district and the probability of event comes after lowest years as compaired to Dangs, Surat, Navsari and Bharuch districts. On the basis of SPI value moderately drought was more number of years for Navsari district as compared to Bharuch, Valsad, Surat and Dangs districts. The very dry situation occurrence is much higher in Bharuch, Dangs and Valsad districts as compared to Surat and Navsari districts. The Extremely dry situation suffers on Valsad district as compared other. On the basis of IMD criteria, the frequency of happening of drought at Bharuch district is much surpassing as compared to Dangs, Valsad, Surat and Navsari districts. Drought anomaly was found that frequency of mild drought occurrence was quite high and occurred at regular interval at all the locations. The frequency of occurrence of drought at Navsari is much higher as compared to Dangs, Valsad, Surat and Bharuch. Navsari district shows had higher rainfall deficit years than excess. Decreasing monsoonal phenomenon may adversely affect the water availability in Navsari region. In drought condition the agriculture sector is the first and important sector that effected from it. Drought period can be significant losses to crop yields, increasing the risk of forest fires and triggering processes of land degradation and desertification. With experience of consecutive droughts and depletion of available water resources, more accurate planning based on capabilities and constraints in all regions are necessary for increasing productivity of water and soil resources.

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