Chapter 2
Analyzing Extreme Events Using Standardized Precipitation Index During the 20th Century for Surat District, India

N.R. Patel, T.M.V. Suryanarayana and D.T. Shete

Abstract The study of floods and droughts requires the knowledge of wet and dry event sequences. They are the two important extreme conditions which directly or indirectly affects every field of environmental science. These extreme conditions are due to the change in one, of the many but most important parameter, rainfall. The standardized precipitation index is designed to quantify the rainfall for multiple time scales. These time scales reflect the impact of drought/floods on the availability of the different water resources. The modified classification by Agnew is referred for the classification of wet and dry events during the 20th Century for Surat district. The monthly rainfall data from 1901 to 2000 is utilized to determine the SPI values. SPI was calculated for 4, 6, 12, 24 and 48 months time scales. The area experienced more than 20% years of dry and wet events for the 20th Century. It is observed that the years 1942, 1945 and 1959 are identified as severe wet events for all the time scale. Year 1998 is identified as moderate wet event for all time scale. Years 1936 and 1987 are identified as severe dry events and year 1935 is identified as moderate dry event for all the time scales. No extreme wet event was observed. For extreme dry scenario all the years identified for different time scales are different.

Keywords SPI · Wet events · Dry events

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M. Majumder (ed.), *Application of Geographical Information Systems and Soft Computation Techniques in Water and Water Based Renewable Energy Problems*, Water Resources Development and Management, https://doi.org/10.1007/978-981-10-6205-6_2

2.1 Introduction

Floods and droughts are the two important aspects of hydrological hazard. Floods usually result either from heavy precipitation (rain or snow) or from rapid snowmelt or glacier discharge. Droughts are caused by dry weather conditions in which evaporation exceeds the available surface water. They are frequently characterised by water shortages. Understanding the causes and forecasting of heavy or scant precipitation and high evaporative demand (and hence of floods and droughts) form an important objective of any climate research scenario. These two types of extreme hydrological events are important to understand the climate..

Floods depend on many things such as climate, nature of the collecting basin, nature of the streams, soil, vegetative cover, amount of snow melt and overall rainfall. Annually, the Indian land mass receives rainfall of 88–89 cm with very high variation from region to region. In the state of Rajasthan, the rainfall is almost nil whereas in the state of Meghalaya, an average rainfall of 1000 cm occurred every year. So this variation in the occurrence of rainfall makes the country prone towards the situations like floods and droughts (http://nidm.gov.in/Chap6.htm).

Drought is a normal part of virtually every climate on the planet, even rainy ones. It is the most complex of all natural hazards, and it affects more people than any other hazard. It can be as expensive as floods and hurricanes. The impacts of drought are greater than the impacts of any other natural hazard. Droughts are periods of time when natural or managed water systems do not provide enough water to meet established human and environmental uses because of natural shortfalls in precipitation or streamflow.

The understanding that a deficit or excess of rainfall has different impacts on the ground water, reservoir storage, soil moisture, snowpack, and streamflow led McKee et al. [2] to develop the Standardized Precipitation Index (SPI). The SPI was designed to quantify the rainfall deficit for multiple time scales. These time scales reflect the impact of drought/floods on the availability of the different water resources. Soil moisture conditions respond to rainfall anomalies on a relatively short scale, while groundwater, streamflow, and reservoir storage reflect the longer-term rainfall anomalies. For these reasons, McKee et al. [2] originally calculated the SPI for 3, 6, 12, 24, and 48-month time scales.

The study by McKee et al. [2] showed the relationship between drought duration, drought frequency, and drought time scale using the Standardized Precipitation Index (SPI) given bywhere,

$$\mathrm{SPI} = \frac{X_i - \overline{X}}{\sigma} \tag{2.1}$$

σ standardized deviation for the station,
X_i precipitation for the ith observation,
$\overline{X}$ mean precipitation for the station

The index has the advantages of being easily calculated, having modest data requirements, and being independent of the magnitude of mean rainfall and hence comparable over a range of climatic zones. It does, however, assume the data are normally distributed, and this can introduce complications for shorter time periods. Because precipitation is not normally distributed for time scales shorter than 12 months, an adjustment is made which allows the SPI to become normally distributed. Thus, the mean SPI for a time scale and a location is zero and the standard deviation is one. This is an advantage because the SPI is normalized so that wetter and drier climates can be represented in the same way. In addition, wet periods can also be monitored using the SPI.

A new classification presented in Table 2.1, for drought intensity has been proposed by Agnew [1] based on the Standardized Precipitation Index (SPI). This uses probability classes rather than magnitudes of the SPI for classification and is therefore suggested as a more rational approach. The effect is most noticeable at the demarcation of mild and moderate droughts. But purely statistical definitions of meteorological drought should be treated with caution. Perhaps of equal significance is the omission within the SPI of any assessment of persistence. It is rare that drought in any one year causes major hardship. It is the sequence of low rainfalls

Table 2.1 Classification of SPI values for wet and dry periods

SPI	Probability of occurrence	McKee et al. [2] Classification	Agnew [1] Classification
Less than −2.00	0.023	Extreme dry (drought)	
Less than −1.65	0.050		Extreme dry (drought)
Less than −1.50	0.067	Severe dry (drought)	
Less than −1.28	0.100		Severe dry (drought)
Less than −1.00	0.159	Moderate dry (drought)	
Less than −0.84	0.201		Moderate dry (drought)
Less than −0.50	0.309		No dry (drought)
Less than 0.00	0.500	Mild dry (drought)	
Less than 0.50	0.692		No wet
Less than 0.84	0.967		Moderate wet
Less than 1.00	0.159	Moderate wet	
Less than 1.28	0.841		Severe wet
Less than 1.50	0.933	Severe wet	
Less than 1.65	0.951		Extreme wet
Less than 2.00	0.977	Extreme wet	

Fig. 2.1 Location of study area

that creates difficulties. For example, in England the drought of 1976 was really caused by the low rainfalls in the preceding year, while the drought of 1992 was the result of the low rainfalls from 1988. Thus the author concluded that the SPI needs to be developed from merely classifying intensities to include drought sequences, and the selection of appropriate averaging periods needs more attention.

2.2 Study Area

The present study analyses the occurrence of extreme events in the area considered for the study, i.e., Surat (Fig. 2.1) during the 20th century using the SPI for analyzing drought under various time scales and to determine the effectiveness of length of records for the same.

2.3 Methodology

Based on the methodology presented by Patel and Shete [3] best distribution is fitted to the precipitation dataset. The best distribution is selected using AIC and BIC criteria. The cumulative probability for the each rainfall event is then determined. The cumulative probabilities obtained are then transformed to the standard normal variate for determining SPI by Eq. 2.1. Both the rainfall and the SPI calculated are then plotted to study the behavior of SPI with respect to the rainfall values.

The SPI is calculated by taking the difference of the precipitation from the mean for a particular time scale, and then dividing by the standard deviation. The monthly rainfall data is then converted into 4, 6, 12, 24 and 48 months time scale. Thus SPI will be calculated for 4, 6, 12, 24 and 48. For determining the dataset using 24 and 48 months time scales the total of consecutive 12 months are considered. For example for SPI24 the total rainfall in 1902 is the sum of annual rainfall in 1901 and 1902. Similarly for 1903 the total rainfall is the sum of annual rainfall in 1902 and 1903. For SPI48 the total rainfall in 1904 is the sum of 1901, 1902, 1903 and 1904. Similarly for 1905 the total rainfall is the sum of 1902, 1903, 1904 and 1905. The time scales from 4 to 48 are considered for studying the short term as well as long term effect of rainfall. The wet and dry events are then classified based on Table 2.1 for observing the extreme events during 1901 to 2000 and the results are analyzed.

2.4 Results and Analysis

Based on AIC and BIC the best distribution fitted to the dataset is the inverse Gaussian and hence used for further analysis. The pdf for the distribution is given by

$$y = \sqrt{\frac{\lambda}{2\Pi x^3}} \exp\left\{-\frac{\lambda}{2\mu^2 x}(x-\mu)^2\right\} \tag{2.2}$$

where λ and μ are scale and shape parameters. The drought intensity is classified using the above methodology and the results are presented in Table 2.2.

From Tables 2.2 and 2.3 one can say that for SPI4 the total wet events were 29 and dry events were 22. For SPI6 the total wet events were 28 and dry events were 24. For SPI12 the total wet events were 29 and dry events were 23. For SPI24 the total wet events were 26 and dry events were 28. For SPI48 the total wet events were 26 and dry events were 28. One can say that as the time scale for the analysis increased the number of dry events exceeded the wet events.

It is observed that the years 1942, 1945 and 1959 are identified as severe wet events for all the time scale. Year 1998 is identified as moderate wet event for all time scale. Years 1936 and 1987 are identified as severe dry events and year 1935 is identified as moderate dry event for all the time scales. No extreme wet event was observed. For extreme dry scenario all the years identified for different time scales are different.

Figures 2.2, 2.3, 2.4, 2.5 and 2.6 represents the rainfall and SPI for time scales from 4 to 48. When the period of analysis is short, the variation between positive

Table 2.2 Wet events for Surat District based on SPI

SP I	Extreme	Severe	Moderate	Total events
4	No events	1914, 1942, 1945, 1946, 1947, 1954, 1959, 1964, 1970, 1976, 1983, 1994	1902, 1903, 1909, 1910, 1912, 1913, 1916, 1921, 1926, 1956, 1958, 1973, 1981, 1988, 1990, 1996, 1998	29
6	No events	1902, 1912, 1916, 1926, 1942, 1945, 1947, 1956, 1959, 1964, 1976, 1994	1903, 1921, 1931, 1939, 1944, 1946, 1954, 1958, 1973, 1975, 1981, 1983, 1988, 1990, 1996, 1998	28
12	No events	1942, 1945, 1946, 1959, 1970, 1976, 1983, 1994	1902, 1909, 1910, 1912, 1913, 1914, 1916, 1926, 1931, 1947, 1954, 1956, 1958, 1964, 1975, 1981, 1988, 1990, 1996, 1998,	28
24	No events	1913, 1914, 1917, 1943, 1945, 1946, 1947, 1959, 1976, 1984, 1994	1903, 1910, 1927, 1942, 1955, 1956, 1960, 1964, 1965, 1970, 1971, 1977, 1995, 1997, 1998	26
48	No events	1915, 1945, 1946, 1947, 1948, 1959, 1997	1914, 1916, 1917, 1942, 1944, 1949, 1956, 1957, 1958, 1960, 1961, 1976, 1978, 1984, 1991, 1994, 1996, 1998, 1999	26

Table 2.3 Dry events for Surat District based on SPI

SP I	Extreme	Severe	Moderate	Total events
4	1904, 1905, 1911, 1918, 1923, 1948, 1951, 1972, 1974	1901, 1915, 1920, 1936, 1982, 1987, 2002	1924, 1925, 1935, 1962, 1985, 1995	22
6	1911, 1918, 1925, 1974	1904, 1905, 1915, 1920, 1936, 1948, 1951, 1972, 1986, 1987	1901, 1923, 1930, 1935, 1952, 1957, 1978, 1980, 1982, 1999	24
12	1904, 1905, 1911, 1918, 1923, 1948, 1951, 1972, 1974	1901, 1915, 1920, 1936, 1982, 1987	1924, 1925, 1935, 1952, 1962, 1966, 1985, 1995	23
24	1905, 1924, 1952	1918, 1919, 1923, 1925, 1936, 1949, 1951, 1972, 1987	1906, 1911, 1935, 1937, 1953, 1962, 1963, 1966, 1969, 1973	28
48	1925, 1951	1906, 1907, 1920, 1921, 1923, 1924, 1926, 1937, 1938, 1952, 1953, 1974, 1975, 1987	1904, 1905, 1908, 1918, 1936, 1954, 1963, 1968, 1969, 1980, 1988, 1989	28

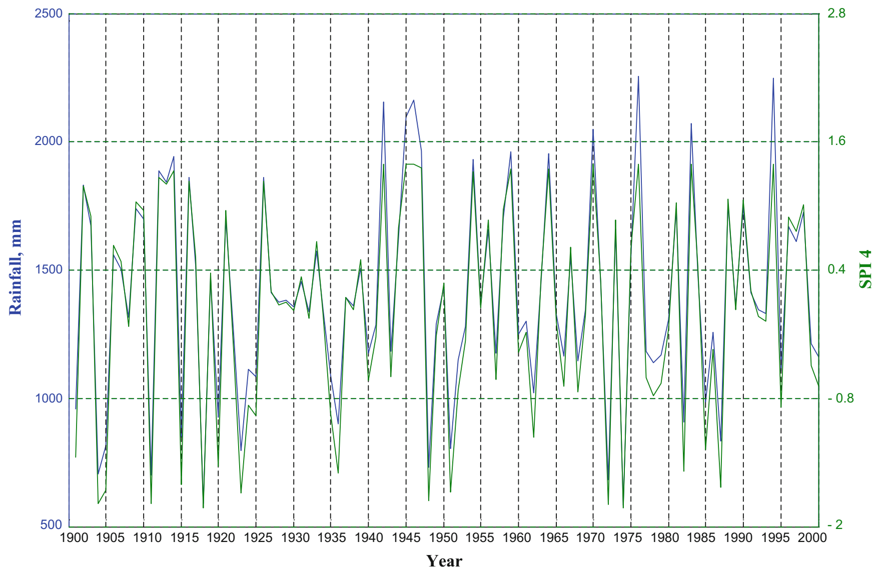

Fig. 2.2 Rainfall and SPI4 for Surat District

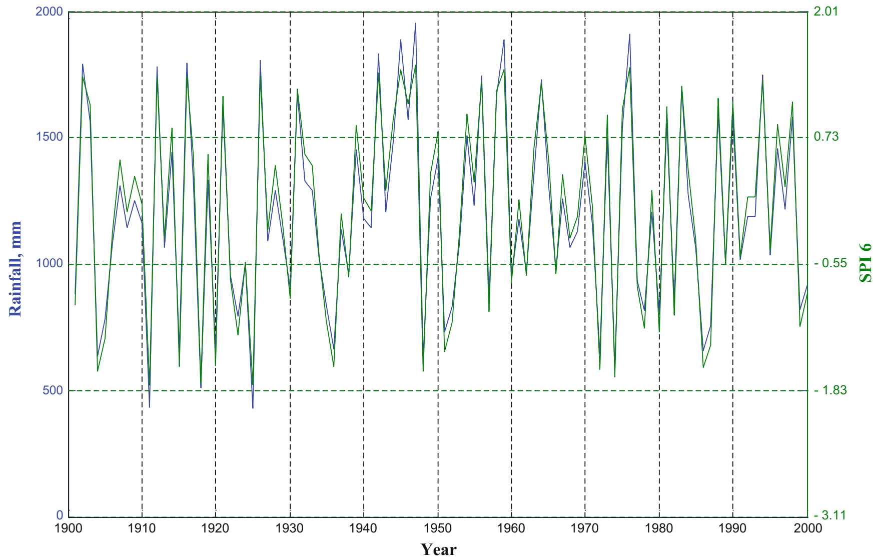

Fig. 2.3 Rainfall and SPI6 for Surat District

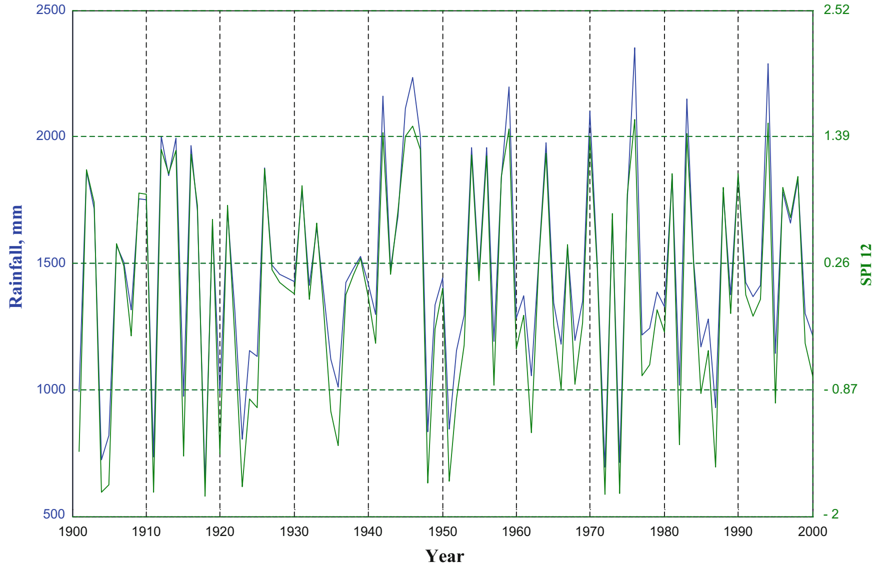

Fig. 2.4 Rainfall and SPI12 for Surat District

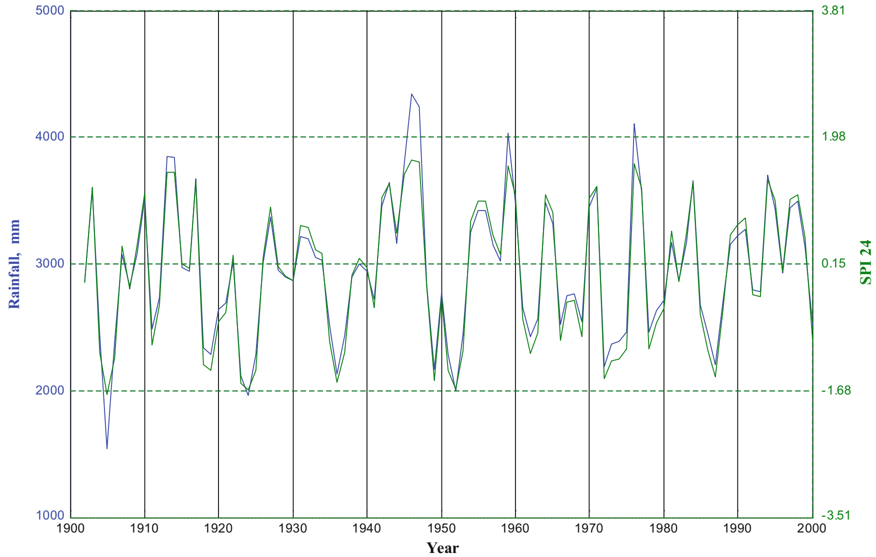

Fig. 2.5 Rainfall and SPI24 for Surat District

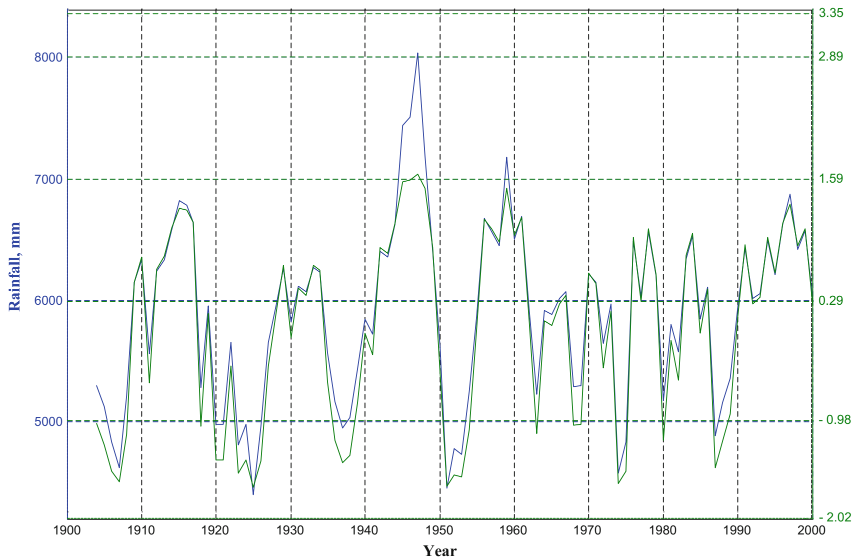

Fig. 2.6 Rainfall and SPI48 for Surat District

and negative values are seen more frequently and when the period of analysis increases, it is observed that the variation between positive and negative values are fewer. It is also observed that for 1000 mm rainfall the SPI values are 2.40, 0.36, 2.26, 1.83 and 1.30 for SPI4, SPI6, SPI12, SPI24 and SPI48 respectively. As SPI is directly proportional to the deviation of precipitation at any given unit of time from the mean precipitation, the SPI6 yields the better correlation with the rainfall.

2.5 Conclusions

The area under study experienced more than 20% years of dry and wet events for the 20th Century. As the time scale increases, the fluctuation from positive to negative or vice versa, decreases making the plot comparatively smooth. Also as the time scale for the analysis increased, the number of dry events exceeded the wet events. The superimposing of rainfall with SPI for various time scales leads to a conclusion that for the area taken under study, SPI6 yields better results, which means that the time scale of six months is to be preferred. Looking at this point, the dry events and wet events are 24 and 28 respectively. Thus the area has experienced comparatively more wet events.

Acknowledgements The rainfall data used for the analysis is obtained from the official website of India Water Portal, to whom the authors are very much thankful.

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http://www.springer.com/978-981-10-6204-9

Application of Geographical Information Systems and
Soft Computation Techniques in Water and Water
Based Renewable Energy Problems

Majumder, M. (Ed.)

2018, XIX, 191 p. 49 illus., 31 illus. in color., Hardcover
ISBN: 978-981-10-6204-9