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ANALYSIS OF REGIONAL DROUGHT SEVERITY OVER CENTRAL DRY ZONE OF VARANASI BY USING STANDARDIZED PRECIPITATION INDEX (SPI)

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ABSTRACT

Drought is a major environmental hazard that can have significant impacts on agricultural production, water resources, and the livelihoods of local populations. This study aimed to assess the severity and spatial patterns of drought in the central dry zone region of Varanasi, Uttar Pradesh, India, using the Standardized Precipitation Index (SPI). Monthly precipitation data from 1901 to 2020 was obtained from meteorological stations across the study area. The results showed that the central dry zone region experienced several moderate to severe drought events during the study period, with the most notable droughts occurring in some years. Spatial analysis revealed distinct spatial variations in drought severity, with some sub-regions experiencing more frequent and intense drought conditions compared to others. These findings can help guide the development of targeted drought mitigation and response strategies to improve the resilience of local communities in the central dry zone of Varanasi.

***Keywords* :** Drought, Standardized Precipitation Index (SPI), Environmental hazard

Introduction

Droughts are defined as extended periods of abnormally dry weather that endure long enough for the absence of precipitation to significantly lower moisture levels and produce a hydrological imbalance, as well as prolonged droughts that result in a shortage of water for any given activity (Gautam & Bana, 2014). For instance, a drought is defined differently by different experts (Noel *et al.*, 2020). A meteorologist may define it as below-average rainfall; an agriculturist may define it as a lack of moisture in the root zone (Wildemeersch *et al.*, 2015); a hydrologist may define it as below-average water levels in streams, lakes, reservoirs, and similar areas; an economist may interpret it as a scarcity of water that adversely affects the established economy. One may classify drought as a purely meteorological occurrence. The first and most noticeable event in the beginning and progression of drought conditions is a meteorological drought (Liu *et al.*, 2019). In India, droughts are a common natural occurrence that varies in severity and length depending on the region (Mishra & Singh, 2010). India is prone to droughts due to its varied climate, which ranges from humid tropical regions to arid and semi-arid regions (Jha & Srivastava, 2018). The effects of climate change, excessive groundwater extraction, unpredictable monsoons, and deforestation are some of the causes of India's drought. Droughts can have disastrous effects, especially for farmers and disadvantaged people, as they can result in crop failures, animal losses, water shortages, and economic hardship (Enfors & Gordon, 2008). India has seen twenty-four major droughts between 1970 and 2014: in 1891, 1896, 1899, 1905, 1911, 1915, 1918, 1920, 1941, 1951, 1965, 1966, 1972, 1974, 1979, 1982, 1986, 1987, 1988, 1999, 2000, 2002, 2009, and 2012; the frequency of these droughts increased between 1891 and 1920, 1965 and 1990, and 1999 and 2012. A complex interaction of natural and man-made elements is responsible for the ongoing drought conditions in the Varanasi district. Theoretically, the shifting patterns of the Indian monsoon system are a major cause of the region's recurrent droughts. The intensity, timing, and distribution of monsoon rains have changed due to climate change, which has had a major effect on Varanasi's water availability and agricultural production (Vijayakumar *et al.*, 2023). The unpredictability of the monsoon has also been connected to variations in the El Niño-Southern Oscillation (ENSO) phenomena and other large-scale climate patterns, resulting in extended dry spells in the district (Egbuawa *et al.*, 2023). In addition, Varanasi's water crisis has been made worse by the overuse of groundwater resources and insufficient ability to store surface water. The increase of water-intensive crops and other changes in land-use patterns, such as deforestation, have added to the district's already limited water supplies (Wheater & Evans, 2009). Significant reasons contributing to the persistence of drought conditions in Varanasi have also been found, including the absence of appropriate water management methods and the poor execution of policies intended to mitigate the drought. It will take a comprehensive, multifaceted strategy to address these intricate, interconnected issues, integrating sustainable land-use practices, water resource management, and climate adaptation to increase resilience and guarantee the region's long-term water security (Santos *et al.*, 2023). Understanding the intensity, duration, and spatial extent of droughts requires measuring and quantifying the variables that lead to them. Drought is measured using a number of established techniques and indices, each with specific advantages and uses. One of the most crucial stages in the risk management of drought analysis is the assessment of drought. Meteorological drought is mostly caused by rainfall. To monitor droughts, a variety of rainfall-based indicators are employed (Smakhtin and Hughes, 2007). One technique that is frequently used to track periods of unusually high or low precipitation is the Standardized Precipitation Index (SPI) McKee *et al.,* (1993) introduced it. Focusing on measuring precipitation deficiencies, the Standardized Precipitation Index (SPI) is one of the most popular drought indices. For a given location and timescale, which might be anywhere from one to twenty-four months, the SPI computes the standardized deviation of precipitation from the long-term mean. This enables the evaluation of long-term hydrological droughts in addition to short-term agricultural droughts. The SPI readings are then classified into various levels of drought severity, which makes it a useful tool for conveying and tracking drought conditions.

Materials and Methods

Study Area

The district of Varanasi Latitude 25.19°N to 25.36°N Longitude 82.56°E to 83.03°E is located in northeastern Uttar Pradesh, close to the state of Bihar, along the banks of the holy Ganges River. The districts of Chandauli to the east, Mirzapur to the west, and Jaunpur to the north encircle the about 1,535 square kilometer district.

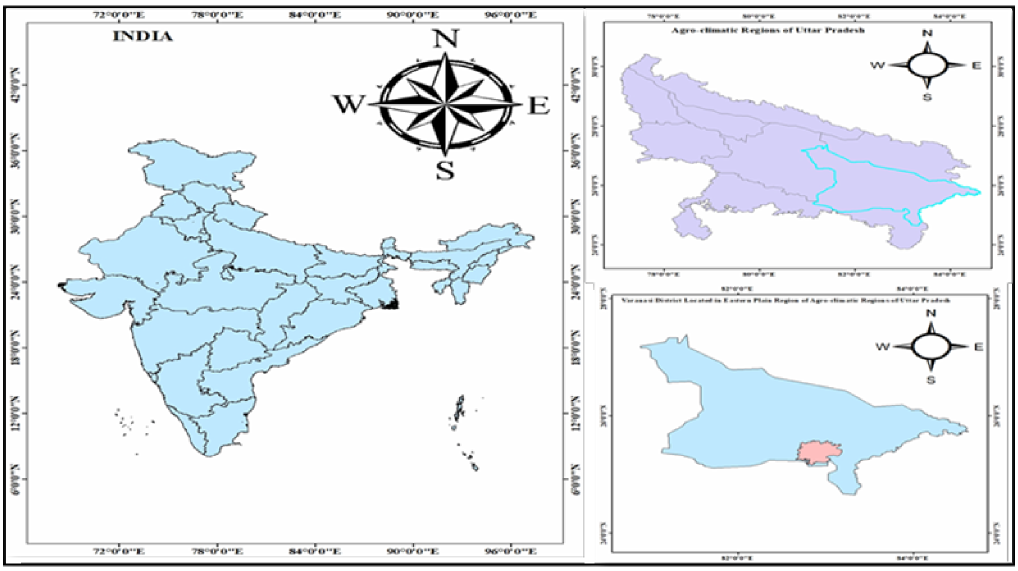

Fig. 1 : Description of study area (Varanasi district)

The Varanasi district's geographical location close to the Indo-Gangetic Plain and the Ganges River has contributed significantly to its centuries-long religious significance, rich cultural legacy, and economic growth. The district's problems with managing water resources and agricultural methods have also been influenced by the climate and hydrology of the area.

Climate and Weather condition:

The district sees a significant change in weather when the southwest monsoon arrives in July and brings with it a lot of rain (Ananthakrishnan, 1977). About 1,100 millimeters of precipitation on average occurs annually in the region; most of it falls during the monsoon season, which runs until September. This period's high humidity is a result of the Ganges River's moisture inflow, which makes the weather more uncomfortable and stuffier. Summertime temperatures often approach 45 degrees Celsius (113 degrees Fahrenheit), and the months of April through June are characterized by extreme heat and desert conditions. The sporadic dust storms and thunderstorms that occasionally break up the hot, dry weather during this time offer some brief respite from the intense heat. In October and November, the post-monsoon months, the monsoon gradually fades and the temperature moderates, making for more comfortable weather. December through March is considered the mildest season, with occasional lows of about 5 degrees Celsius (41 degrees Fahrenheit). Clear skies and low humidity are characteristic at this time of year, with sporadic fog and chilly periods. The Ganges River, which meanders through the Varanasi area on its eastern border, has a big impact on the climate there (Singh *et al.*, 2019). Particularly during the monsoon season, the river is a supply of moisture that adds to the high humidity levels while also helping to alleviate the extremely high temperatures. The Ganges River's close proximity to the area affects both the issues of managing water resources and agricultural methods.

Soil

The Indian state of Uttar Pradesh, which includes the Varanasi region, is endowed with a wide variety of soil types, each with special qualities and applicability for different kinds of agriculture (Suri, 2013). The alluvial soil that predominates in the Varanasi district was deposited over ages by the Ganges River and its tributaries. These rich, deep, well-drained, and organic matter-rich fertile alluvial soils are ideal for a variety of crops, such as cereals, pulses, oilseeds, and vegetables. The soils are more compact and heavier in texture in the locations nearer the Ganges River because of the higher silt and clay concentration. Rice is one of the main crops grown in the area, and these soils are especially suitable for its growth. These soils' great ability to retain moisture means that during the monsoon season, the water-intensive rice farming may continue.

Data Collection

Annual rainfall data for Varanasi district was obtained from Indian meteorological department Pune from 1901-1940.

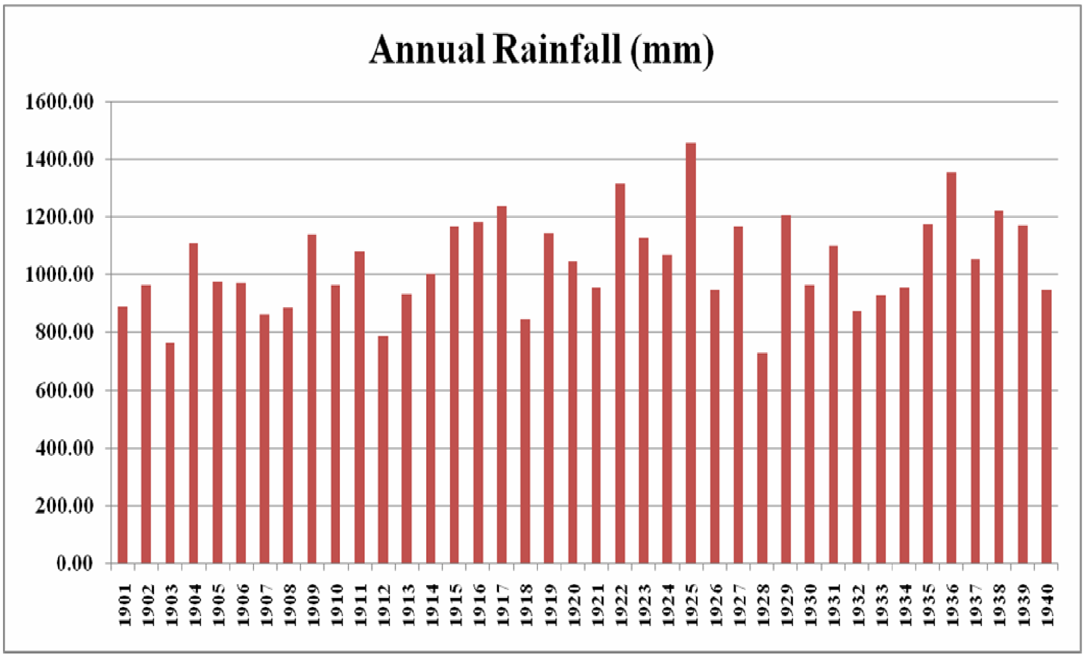

Fig. 2 : Annual rainfall from 1901-1940

The annual rainfall in the specified region is shown in the data for the years 1901 through 1940. During this time, there are notable variations in the amount of rainfall; the lowest annual rainfall of 728.12 mm was reported in 1928, while the maximum annual rainfall of 1455.27 mm was recorded in 1925. The rainfall pattern is very varied, according to the data, with some years seeing significantly more rainfall than others. For example, throughout the 15 years, yearly rainfall exceeded 1,100 mm, but in few other years, it was less. The region's agricultural and water management strategies must take this fluctuation in rainfall patterns into consideration.

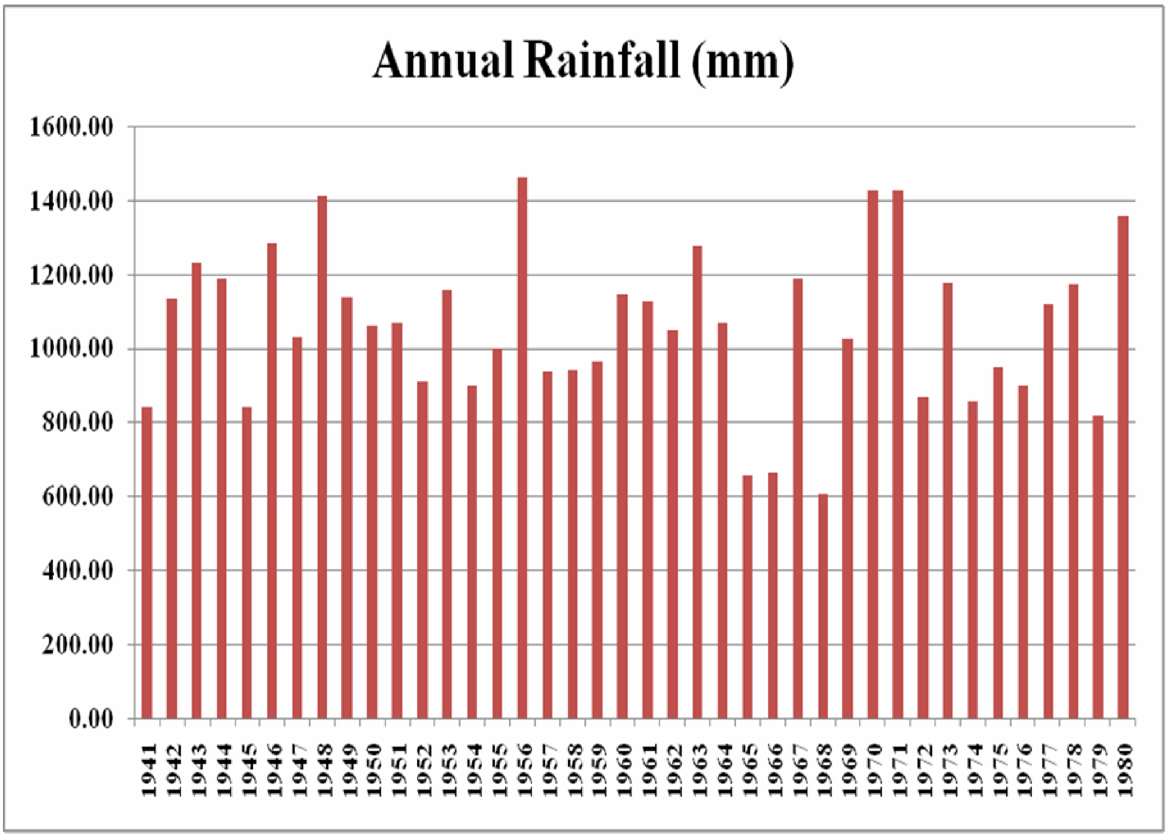

Fig. 3 : Annual rainfall from 1941-1980

The given data maintains the region's annual rainfall record for the years 1941 to 1980 in fig 3. The patterns of rainfall are still rather erratic throughout this time, with some years seeing noticeably more rain than others. During this period, the maximum annual rainfall recorded was 1461.41 mm in 1956, and the lowest was 603.67 mm in 1968. There have been 18 years with yearly rainfalls of more over 1,100 mm, and other years with less. The information demonstrates that the area still sees significant yearly rainfall variations, which is crucial information for its irrigation and farming methods. The necessity for solutions to successfully manage and adapt to these changes throughout time is highlighted by the variety in rainfall patterns.

The information given in fig 4 includes the same region's annual rainfall from 1981 to 2020. There is a great deal of variation in the rainfall patterns during this time period as well, with some years seeing significantly more rainfall than others. During this period, 1956 had the most yearly rainfall at 1461.41 mm, while 2009 had the least amount at 481.50 mm. There were six years with more than 1,100 mm of yearly rainfall and other years with less than that amount.

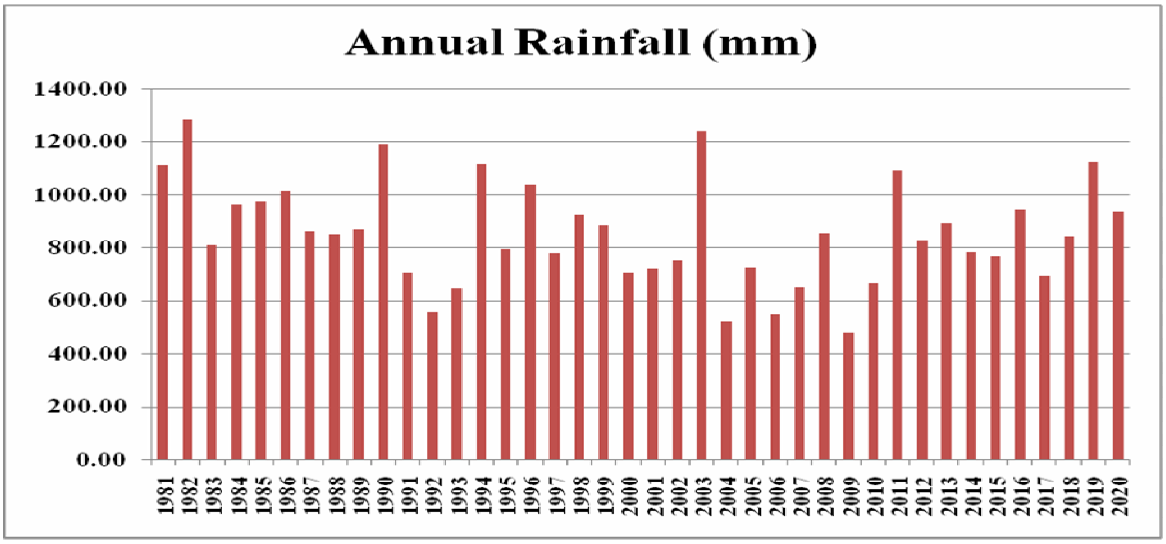

Fig. 4 : Annual rainfall from 1981-2020

The yearly variations in rainfall present the region with ongoing issues in managing its water supplies, with potentially dire consequences for infrastructure, agriculture, and overall water security. Long-term sustainability in the area will depend on methods to adjust to these shifting patterns of rainfall, including better water storage, irrigation systems, and crop selection resistant to drought.

Standardized Precipitation Index (SPI):

Standardized Precipitation Index (SPI) was used in the current study to quantify the deficiency of precipitation in various time scales. These periods cover both transient and persistent abnormalities in precipitation. While long-term anomalies are used for groundwater, stream flow, and reservoir storage studies, short-term anomalies are typically used in soil moisture investigations. McKee, (1993) first computed the SPI for timescales of 1, 3, 6, 9, 12, 24, and 48 months. All categories of SPI value are mention in Table 1.

Equation 1 is used to calculate Standardized Precipitation Index:

$$SPI = \frac{Xi - Xm}{Sx} \qquad Eq^n\ldots 1$$

Where:

X_i = Current data set

X_m = Mean precipitation

S_x = Standard deviation

Table 1 : Classification of SPI Value

Sr. No.	Category	SPI range
1	Extremely wet condition	2 or more
2	Severely wet condition	1.5 to 1.99
3	Moderately wet condition	1 to 1.49
4	Mildly wet condition	0 to 0.99
5	Mildly dry condition	0 to -0.99
6	Moderately dry condition	-1 to -1.49
7	Severely dry condition	-1.5 to -1.99
8	Extremely dry condition	-2 or less

Result and Discussion

The table spans the years from 1901 to 1940 and shows a mix of drought conditions over this time period in fig 5. Several years, such as 1904, 1905, 1906, 1909, 1911, 1919, 1920, 1915-1917, 1922-1925, 1927, 1929, 1931, 1935-1939, had positive SPI values, indicating no drought conditions. 14 Years with mild drought conditions, where the SPI values were less than 0 but greater than or equal to -0.99. Moderate drought conditions, with SPI values between -1.00 and -1.49, were observed in 1903, 1928. Severe drought conditions, with SPI values ranging from -1.50 to -1.99, no years have severe affect through drought.

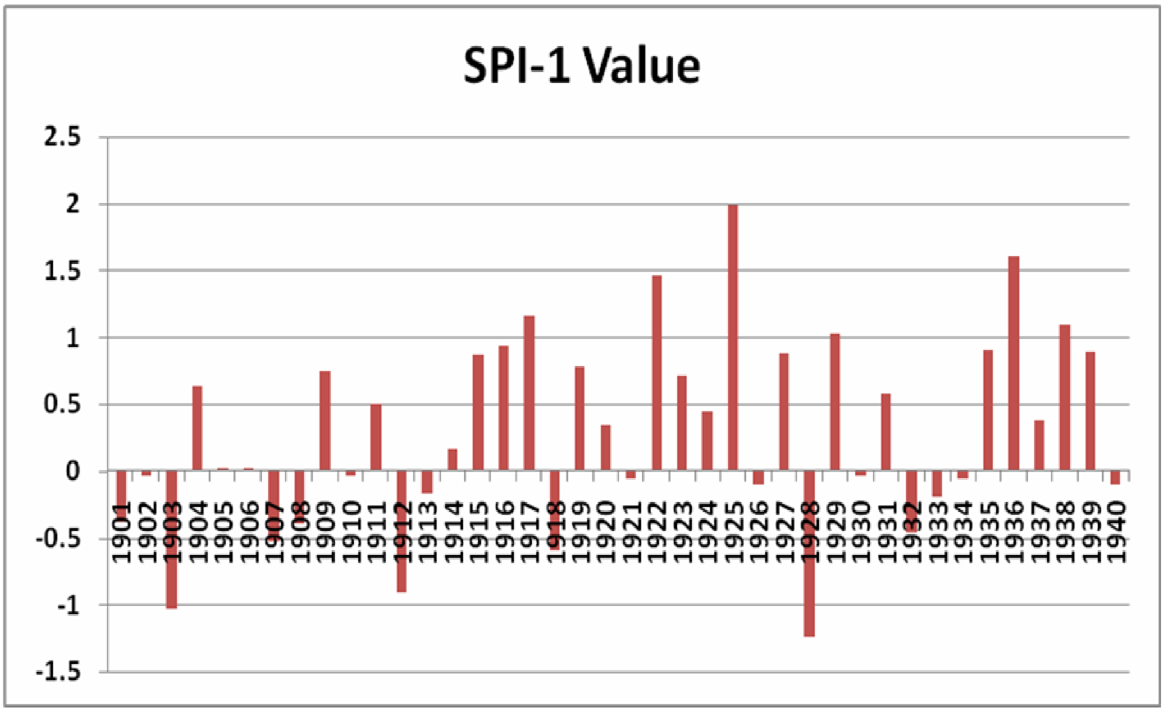

Fig. 5 : SPI-1 Value in different years from 1901-1940

However, the data does not show any years with extreme drought conditions, where the SPI value would be less than or equal to -2.00. Overall, the table reveals a mix of drought severities, with several years experiencing no drought, mild drought, moderate drought, and severe drought, but no extreme drought based on the provided thresholds.

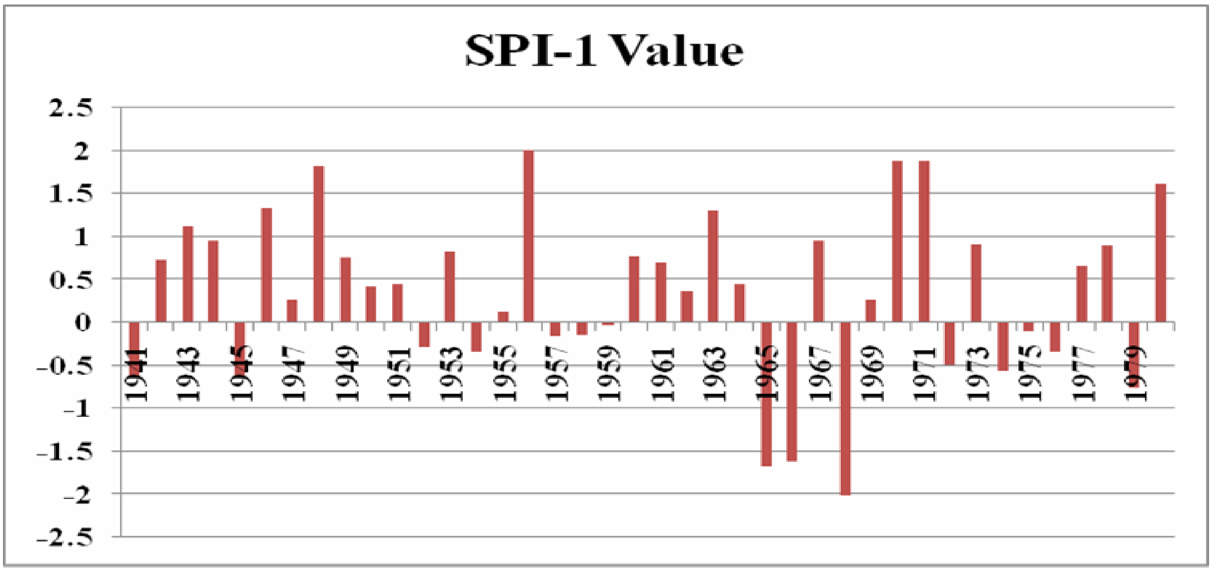

Fig. 6 : SPI-1 Value in different years from 1941-1980

Examining the Standardized Precipitation Index (SPI) data from 1941 to 1980, the following it is possible to make observations in fig 6: The table shows a mix of drought conditions during this time period. Out of 40 years, 25 years had positive SPI values, indicating no drought conditions. 11years with mild drought conditions, where the SPI values were less than 0 but greater than or equal to -0.99. Moderate drought conditions, with SPI values between -1.00 and -1.49, were observed in 1941 and 1945. Severe drought conditions, with SPI values ranging from -1.50 to -1.99, were present in 1965 and 1966. Notably, the table also shows one year, 1968, with an SPI value less than or equal to -2.00, indicating extreme drought conditions. Overall, the data reveals a mix of drought severities, with several years experiencing no drought, mild drought, moderate drought, severe drought, and even one instance of extreme drought during the 1941-1980 period.

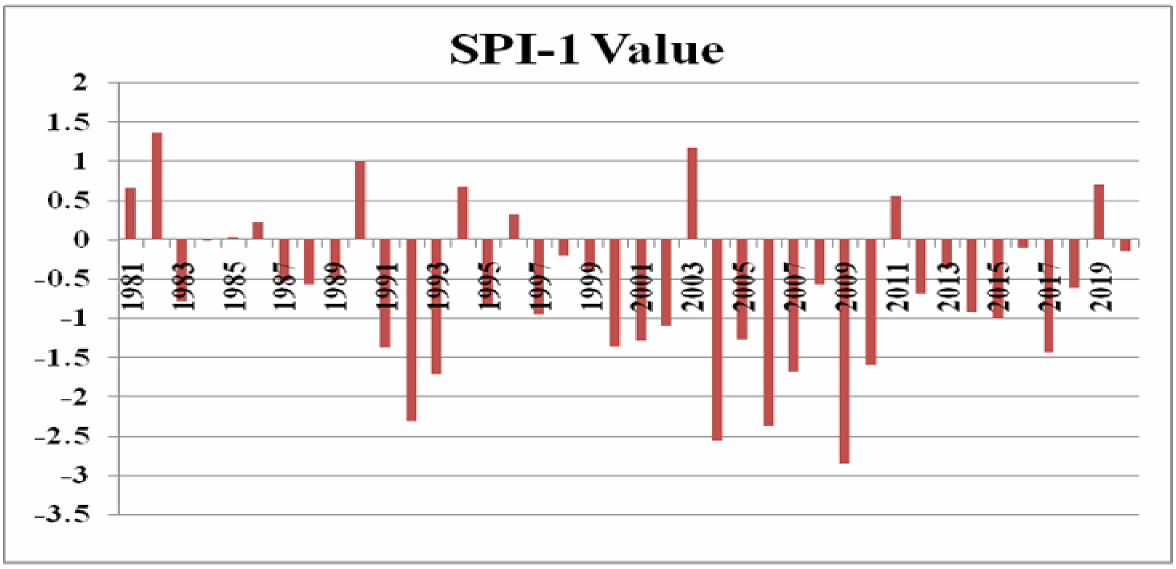

Fig. 7 : SPI-1 Value in different years from 1981-1920

The Standardized Precipitation Index (SPI) data from 1981 to 2020 reveals a more complex pattern of drought conditions compared to the previous period in Fig 7.

During this time, there were 10 years with no drought conditions. However, the data also shows a significant number of years with mild, moderate, severe, and even extreme drought conditions. Mild drought conditions, with SPI values less than 0 but greater than or equal to -0.99, were observed in 16 years. Moderate drought conditions, with SPI values between -1.00 and -1.49, were present in 6 years. Severe drought conditions, with SPI values ranging from -1.50 to -1.99, were observed in 3 years. Notably, the data also shows several instances of extreme drought conditions, with SPI values less than or equal to -2.00, in 1992, 2004, 2006, and 2009. This period from 1981 to 2020 demonstrates a more volatile and diverse range of drought conditions, with both prolonged and severe drought events interspersed with years of no drought or mild drought.

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