

International Journal of Agriculture Extension and Social Development

Volume 7; SP-Issue 8; August 2024; Page No. 208-212

Received: 17-05-2024
Accepted: 27-06-2024

Indexed Journal
Peer Reviewed Journal

Evaluating the severity of the drought using multi-index drought investigation in Uttar Pradesh north-eastern plain region

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DOI: <https://doi.org/10.33545/26180723.2024.v7.i8Sd.981>

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Abstract

This study presents an analysis of the Annual Standardized Precipitation Index (SPI) and Percent of Normal Precipitation (PNP) values for a location over a 120-year period from 1901 to 2020. The SPI is a widely used metric for quantifying precipitation deficits or surpluses, with positive values indicating wetter than normal conditions and negative values indicating drier than normal conditions. The data shows a wide range of SPI values, with the maximum value of 2.15 occurring in 1980, indicating significantly higher than normal precipitation that year. Several other years also experienced notably high SPI values, such as 2.02 in 1936, 2.0 in 1925, and 1.67 in 1970, suggesting periods of substantially wetter than normal conditions. The findings from this analysis highlight the significant variability in precipitation patterns over the past century, with both extreme wet and dry conditions occurring at various points the study underscores the importance of continuous monitoring and analysis of precipitation data to support effective decision-making and resilience-building efforts. The highest PNP was recorded in 1980 at 149.062077%, indicating an exceptionally wet year. On the other hand, 1991 experienced the lowest PNP at 49.48%, marking it as an extremely dry year.

Keywords: Standardized Precipitation Index (SPI), multi-index drought investigation, Percent of Normal Precipitation (PNP)

Introduction

Droughts are prolonged periods of abnormally dry weather that significantly reduce moisture levels and create a hydrological imbalance (Haile *et al.*, 2020) ^[1]. Experts may characterize droughts differently - a meteorologist by below-average rainfall, an agriculturist by lack of moisture in the soil, a hydrologist by low water levels, or an economist by water shortages impacting the economy (Gautam & Bana, 2014) ^[2]. Drought can be categorized as a purely meteorological phenomenon, being the earliest and most obvious sign of drought conditions developing (Mainguet, 1999) ^[3]. Droughts are a common occurrence in India due to its diverse climate ranging from humid tropical to arid regions (Surendran *et al.*, 2019) ^[4]. Factors contributing to India's droughts include deforestation, unsustainable groundwater use, erratic monsoons, and climate change (Gupta *et al.*, 2011) ^[5]. Droughts can have

severe consequences like crop failures, livestock losses, water scarcity, and financial hardship, especially for farmers and the underprivileged (Miyan, 2015) ^[6]. Importantly, the impact of droughts disproportionately affects the more vulnerable sections of society, including small farmers, landless laborers, and marginalized communities. Addressing the recurring drought challenges in the north-eastern plain region of Uttar Pradesh requires a multi-pronged approach, involving improved water management, promotion of climate-resilient agriculture, and targeted support for the region's drought-affected communities to enhance their resilience and adaptability.

Study Area

India's Uttar Pradesh state encompasses the region dubbed the North Eastern Plain Zone shown in Figure 1.

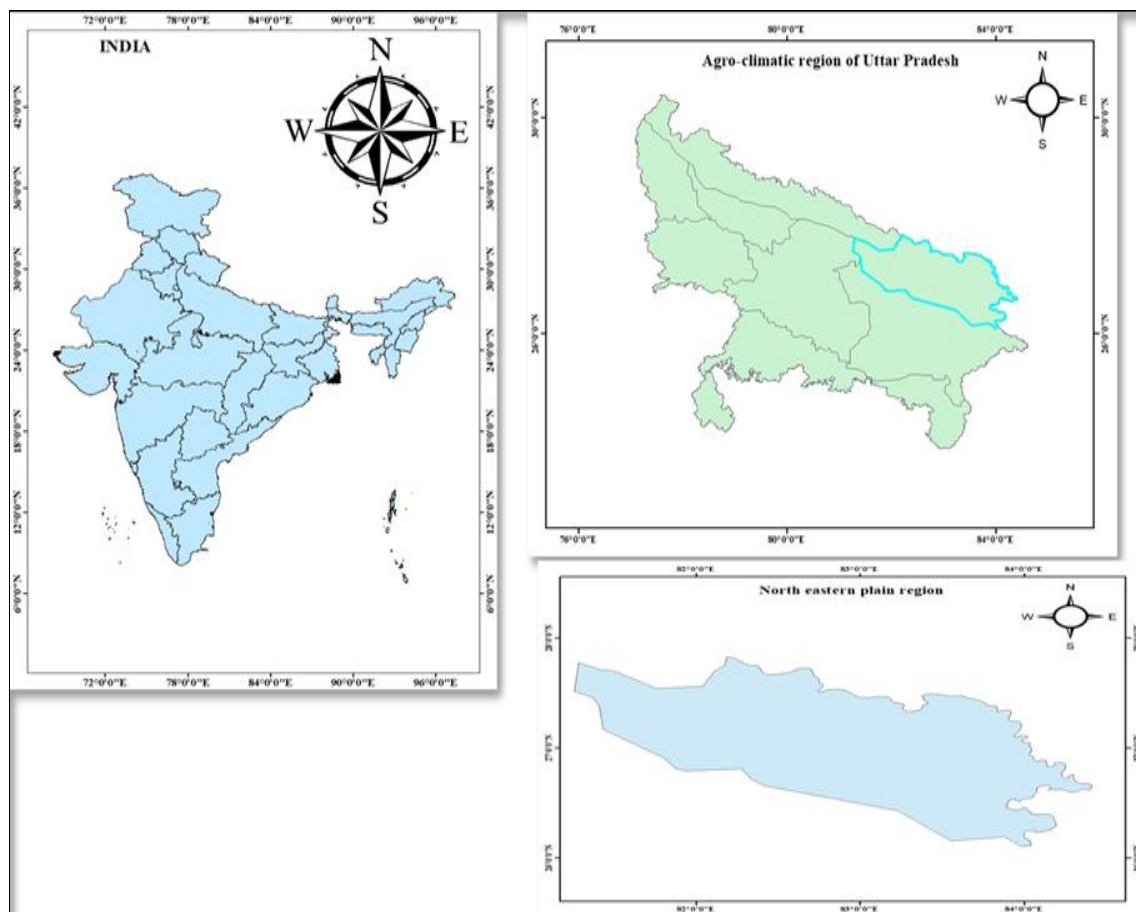


Fig 1: North eastern Plain Zone of Uttar Pradesh

The northeastern plain region of Uttar Pradesh, situated at the heart of the broader northeastern plain region of India, has had its physical geography and location profoundly shape its history and development. Nestled within this expansive alluvial plain, the northeastern districts of Uttar Pradesh benefit from highly fertile soils that have facilitated the growth of a diverse agricultural economy. The region's reliance on the summer monsoon rains, however, has also made it susceptible to the impacts of erratic and uneven precipitation patterns, leading to recurrent drought

conditions that pose significant challenges for the local farming communities. Compounding this vulnerability is the depletion of groundwater resources due to unsustainable extraction practices, as well as the disruption of natural water cycles due to land use changes like deforestation.

Data Collection

Annual rainfall data for north eastern plain zone of Uttar Pradesh was obtained from Indian Meteorological Department Pune from 1981-2020 shown in Figure 2.

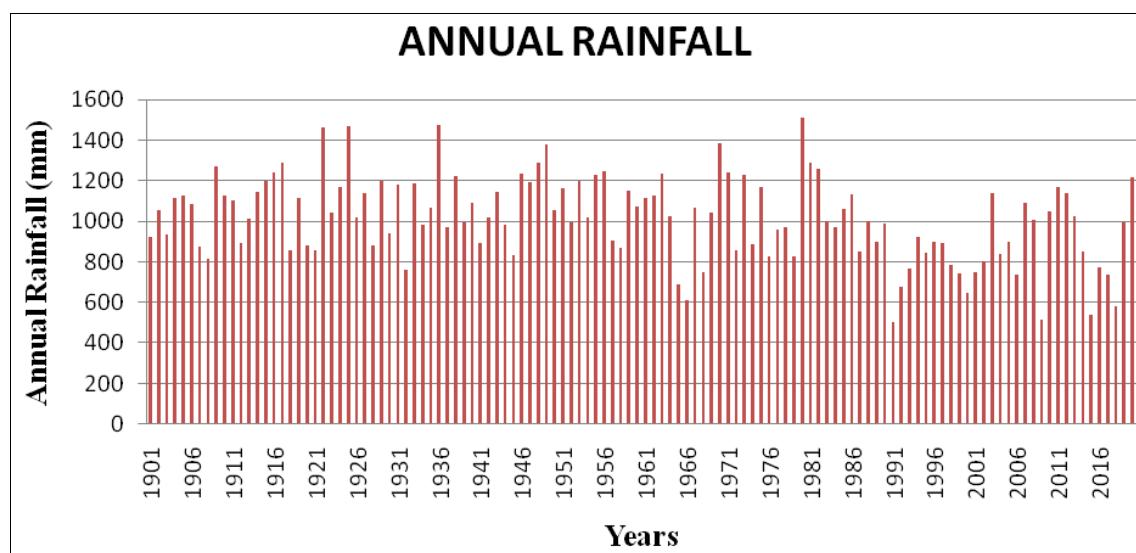


Fig 2: Annual rainfall data of North eastern plain region

This dataset appears to be a record of annual rainfall measurements in the North Eastern Plain region. The data spans from 1901 to 2020, providing a comprehensive look at the rainfall patterns in this area over the past century.

Looking at the values, we can see significant fluctuations in the annual rainfall over the years. Some years had very high rainfall, such as 1925 with 1,470.855 mm and 1936 with 1,475.795 mm. Conversely, there were also years with much lower rainfall, like 1921 with 854.751 mm and 1976 with 829.923 mm.

The overall trend seems to be variable, with no clear long-term pattern of increasing or decreasing rainfall. However, there are some notable periods, such as the relatively lower rainfall in the 1960s and 1970s, followed by a period of higher rainfall in the 1980s and early 1990s. This data could be useful for understanding the climate and weather patterns in the North Eastern Plain region, as well as for planning agricultural activities and water resource management. Analyzing the trends and variations in rainfall over time could provide insights into the region's climate and how it has changed or remained stable.

Methodologies

Standardized Precipitation Index

In order to assess the severity of droughts and their characteristics in various agro-climatic zones, the 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) ^[8] first computed the SPI for timescales of 1, 3, 6, 9, 12, 24, and 48 months. Long-term precipitation during a desired period is utilized to compute SPI, as suggested Edwards and McKee, (1995) ^[7] for any location. After that, a probability distribution is fitted to the long-term data, and that distribution is changed into a normal distribution so that the mean SPI for the specified period and place is zero. Positive SPI numbers represent precipitation that is higher than the median, while negative values represent precipitation that is lower than the median. Wetter and drier climates can be represented similarly in the SPI due to its normalization, which means that the SPI can also be used to track wet periods and other related events. The SPI's classification scheme was employed by McKee, (1993) ^[8] which is presented in Table 1.

Table 1: Classification of Standardized Precipitation Index

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

Steps for calculating SPI indices

Step 1: for calculation of mean equation 1 was used

$$X_m = \frac{\text{Sum of total Number data set}}{\text{Number of data set}} \quad \text{Eq}^n \dots 1$$

Steps: 2 for calculation of standard deviation equation 2 was used

$$S.D. = \frac{\sqrt{\sum (X - X_m)^2}}{N} \quad \text{Eq}^n \dots 2$$

Where:

X = Data set

X_m = Mean of data set

Steps: 3 equation 3 is used to calculate Standardized Precipitation Index

$$SPI = \frac{X_i - X_m}{S_x} \quad \text{Eq}^n \dots 3$$

Where:

X_i = Current data set

X_m = Mean precipitation

S_x = Standard deviation

Percent of Normal Precipitation Index (PNP)

To determine the severity of drought, the PNP formula involves dividing the actual monthly rainfall (P_i) by the average rainfall (P) and then multiplying the result by 100%. In general terms, the normal rainfall is calculated as the mean of 30 years of precipitation. The following equation 4 can also be used to express it, Table: 2 show the classification category for the drought index (Asrari *et al.*, 2011) ^[9].

$$PNPI = \frac{P_i}{P} * 100 \quad \text{Eq}^n \dots 4$$

Where:

P_i = Observed Precipitation

P = Normal Precipitation

Table 2: Percent of Normal Precipitation Index value

Sr. No	Category	PNP range
1	Humid	>=120
2	Normal	80-120
3	Light drought	70-80
4	Moderately drought	55-70
5	Severely drought	40-55
6	Extremely drought	<40

Results and Discussion

This dataset provides the Standardized Precipitation Index (SPI) values for the same location over the same 120-year period from 1901 to 2020.

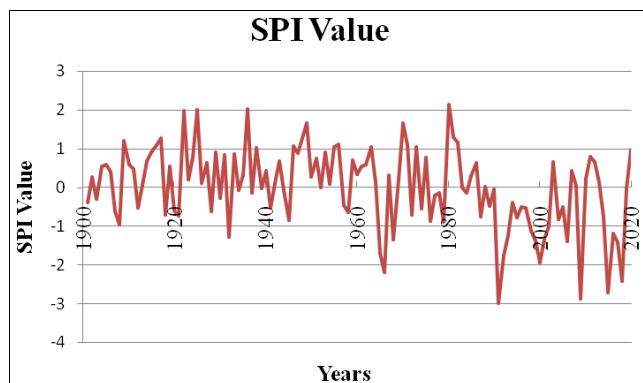


Fig 3: SPI Value of North eastern plain region

The Annual SPI (Standardized Precipitation Index) Value is a measure of the degree of dryness or wetness in a region, with positive values indicating wetter than normal conditions and negative values indicating drier than normal conditions. A value of 2.15 in 1980 indicates that the precipitation in that year was significantly higher than the normal or average precipitation for that location. The Standardized Precipitation Index is a widely used drought monitoring and assessment tool, with values typically ranging from -2 to +2. An SPI value of 2.15 in 1980 would suggest that the precipitation levels that year were well above the historical average, potentially leading to wetter than normal conditions or even flooding in the affected region Shown in Figure 3.

The other notable high values in the table include 2.02 in 1936, 2.0 in 1925, 1.97 in 1922, 1.66 in 1949, 1.67 in 1970, and 1.28 in both 1917 and 1948. These values all indicate significantly wetter than normal conditions in those respective years. Conversely, the lowest values in the table, such as -2.99 in 1991, -2.71 in 2015, and -2.41 in 2018, suggest much extremely drought conditions, potentially leading to drought conditions in those years.

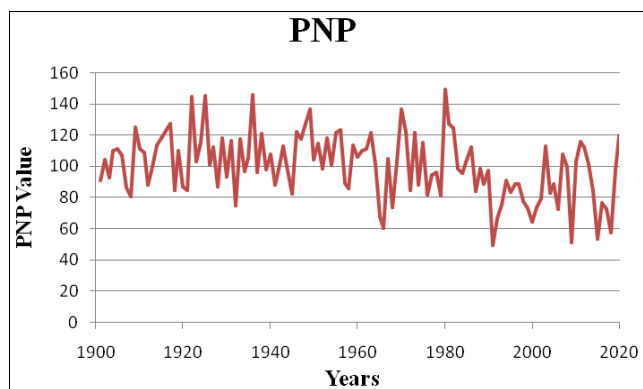


Fig 4: Percent of Normal Precipitation

Percent of Normal Precipitation Index

Percentage of Normal Precipitation (PNP) from the year 1901 to 2020 shown in Figure 4. Over this 120-year period, the PNP values have shown significant variability, reflecting changing climatic conditions. The highest PNP was recorded in 1980 at 149.06%, indicating an exceptionally wet year. On the other hand, 1991 experienced the lowest PNP at 49.48%, marking it as an extremely dry year. Years like 1922 (144.45%), 1936 (145.71%), and 1970 (136.80%)

also saw high PNP values, whereas years such as 1966 (60.36%) and 2018 (57.18%) had notably lower values. These fluctuations in PNP demonstrate the variability in precipitation patterns over the years, highlighting periods of both excess and deficit rainfall.

Summary

The provided table displays the Annual Standardized Precipitation Index (SPI) values for a location from 1901 to 2020. The SPI is a widely used measure of the degree of dryness or wetness in a region, with positive values indicating wetter than normal conditions and negative values indicating drier than normal conditions.

The data shows a wide range of SPI values over the 120-year period, with the maximum value being 2.15 in 1980, indicating significantly higher than normal precipitation levels that year. Other notable high values include 2.02 in 1936, 2.0 in 1925, 1.97 in 1922, 1.66 in 1949, 1.67 in 1970, and 1.28 in both 1917 and 1948, all of which suggest wetter than normal conditions in those years.

On the other hand, the data also shows several years with very low SPI values, such as -2.99 in 1991, -2.71 in 2015, and -2.41 in 2018, indicating much drier than normal conditions and potential drought conditions in those years.

Conclusion

The Annual SPI values provided in the table demonstrate the significant variability in precipitation patterns over the past 120 years, with both extremely wet and extremely dry years occurring at various points. The maximum value of 2.15 in 1980 and several other high values suggest that some years experienced substantially higher than normal precipitation, potentially leading to wetter than usual conditions or even flooding. Conversely, the very low SPI values in certain years point to prolonged drought periods, which can have serious implications for the region's water resources, agriculture, and overall ecosystem.

This data highlights the importance of ongoing monitoring and analysis of precipitation patterns and trends, as such information is crucial for effective water resource management, disaster preparedness, and adaptation to the impacts of climate change.

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