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# STANDARD PRECIPITATION INDEX TO IDENTIFY DROUGHT OCCURRENCES CAUSED BY RAINFALL ANOMALY

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**Abstract:**

This study aims to characterize the drought in the Bundelkhand region using precipitation data and SPI values. The outcome of the study evinces that the entire area of Bundelkhand is unshielded from drought.

Drought is an uncertain phenomenon that occurs due to scanty rainfall and dry spells in a specific domain, for a long duration of time. Resulting in moisture deficiency in the atmosphere for healthy crop development, these outbreaks are more prominent in Arid and Semi-arid zones. Annually a huge quarter of the earth turns drought-prone, creating agricultural, economical, and ecological damage. Bundelkhand, a region of Madhya Pradesh consisting of six districts namely Chhatarpur, Panna, Tikamgarh, Datia, Damoh, and Sagar falls under the purview ofa Semi-arid zone. To evaluate the Magnitude and severity of drought, we utilized the Standard Precipitation Index (SPI) at different time frames.

*KEYWORDS: SPI, Drought, Semi-arid zone, Indices and Indicators, R-studio*

## I INTRODUCTION:

Annually several parts of the earth face drought with varying severity. Its onset, sustainability, intensity, and spatial extent are hard to predict. It is not only detrimental to agriculture but it also affects the nature and socio-economic structure of that area for the time being. Numerous indices and indicators have been developed for the identification of the temperament of drought by quantification through mathematical equations, still, no indices were effective enough to give an accurate result in all states of affairs. The Standard Precipitation Index (SPI) is a well-established and widely-used index for monitoring drought, which incorporates precipitation as the sole input and can be applied at varioustime scales. SPI employs the gamma probability density function to identify both dry and wet conditions, making it a flexible indicator for detecting changes in moisture levels.

Similar to other natural disasters, droughts can be defined based on their location, duration, timing, and severity.[5] Being in relation to meteorological parameters i.e. rainfall and temperature whose uncertainty makes it difficult to formulate it.

**1.1 Drought in India:**

The drought-prone regions in India comprise 185 districts across 13 states, covering a geographical area of 120 million hectares [7]. There has been a ceaseless consistency in drought trends over the recorded years post-independence of the country leading to a remarkable impact on agricultural production and subsistence affecting the economy. India is a significant producer and exporter of various crops across the globe.

Since India gained independence, significant droughts affecting over one-third of the country were recorded in 1951, 1966-67, 1972, 1979, 1987-88, and 2002-03 [11]. During the past decade, the years 2009-10 and 2013-14 were marked by drought conditions, leading to significant negative impacts on agricultural output and livelihoods [5]. Accurately predicting the start and end of the monsoon season could be beneficial in maximizing rainwater utilization in semi-arid regions. [3, 4, 6, 9, 10]

**II LITERATURE REVIEW:**

Drought steadily influences the lives of a huge population, widely sustaining in many places around the world. Speaking of our own country, it suffers a blow of about two third of its net sown 142 million hectares of land vulnerable to drought. Droughts are typically categorized into four types based on their characteristics: Meteorological, Agricultural, Hydrological, and Socioeconomic.[8]

By analyzing historical precipitation data, it is possible to generate a probability of precipitation for a given location, which can be calculated for a range of timescales from 1 month to 48 months or more. Although the Standard Precipitation Index (SPI) can be computed using as few as 20 years of data, it is recommended to have a time series of at least 30 years of data, even after accounting for any missing data. Drought indices usually encompass a range of hydro-meteorological data, such as precipitation, stream flow, soil moisture, reservoir storage, groundwater, and water supply indicators. These data can be used independently or in combination to assess drought conditions (WMO 1975). (Wable et al., 2019). It measures the monthly rainfall, based on precipitation only, its computations exceeding 3 to 72 months. Where 3 to 4 months results are good for shorter durations while 6 to 12 months or above for longer terms. The scale used to measure intensity includes both positive and negative values. It varies by 2.0 or higher for extremely wet conditions while -2 or less for extremely dry conditions.

**1.1 Meteorological Parameters**: Drought monitoring depends upon many meteorological parameters like Precipitation, Temperature, Evapotranspiration, humidity, wind direction geographical area, and pressure collectively impacting drought development. Although these parameters are linked together. The study includes the monthly time series precipitation data as an input to calculate SPI .

**2.2 Area of Research**: The area of interest is Bundelkhand region, (Longitude $78^0$11' E to $81^0$30'E and Latitude $23^0$08N to $26^0$30'N) a part of Madhya Pradesh and Uttar Pradesh, lying in central India falls under a semi-arid zone. The districts of Madhya Pradesh are Damoh, Chhatarpur, Panna, Sagar, Tikamgarh and Datiaare much-affected areas.

The climate of Bundelkhand remains hot and dry throughout the year, The Bundelkhand region experiences an average temperature of around 26 degrees Celsius, with humidity levels ranging between 50 to 57 percent. Heat waves occur in the area, with the mean maximum temperature reaching 46.15 degrees Celsius inMay, and a minimum of 16.6 degrees Celsius in December.

The maximum population of Madhya Pradesh depends upon agriculture, hence completely dependent on the monsoon. Maximum rainfall, above 91% is, received during the monsoon season i.e. June to September, and the remaining 9% during other seasons. The average temperature of Bhopal is $25.51^0$c while the district falls in semi-arid zones having temperature higher than $26.2^0$c. Normally rain in the Monsoon season comes from the southwest winds and North East windsfrom June to July.

The Occurrence of rainfall is much less than 1000mm (normal rainfall). This scarcity and irregularity with many dry spells cause water stress in that area.

## III METHODOLOGY AND TOOLS

There are many indices used for the calculation of drought conditions. Some of them exhibit good results in short-term drought conditions while others are good for long-term drought impacts. Rainfall is the most significant parameter for drought monitoring. The Standard Precipitation Index (SPI) utilizes statistical techniques to evaluate drought conditions by analyzing precipitation data. Short-term assessments of drought can be conducted using SPI-1 and SPI-3, which take into account factors like soil moisture, snowpack, and small stream flow. On the other hand, medium and long-term evaluations of drought are better served by SPI-6, SPI-9, SPI-12, and SPI-24, which consider groundwater levels and reservoirstorage.

### 3.1 The mathematical equation of SPI is as follows:

$$SPI \equiv (X_{ij} - X_{im}) / \sigma \qquad \sigma \qquad \text{.....} (1)$$

Where, $X_{ij}$is the seasonal precipitation at $i_{th}$ rain-gauge station and $j_{th}$ observation,

$X_{im}$is it's long-term seasonal mean and

$\sigma$ is its standard deviation.

The past precipitation data is fitted to a probability distribution, specifically the gamma distribution, which is then converted into a normal distribution to achieve aSPI value of zero for the mean of that specific location and time period.

| **SPI** | **Drought Category** |
|---|---|
| 0 to -0.99 | Mild drought |
| -1.00 to -1.49 | Moderate drought |
| -1.5 to -1.99 | Severe drought |
| -2.00 or less | Extreme drought |

Table 1: Drought categories from SPI (Source: Mc Kee et al., 1993)

The following study has used the R studio software to analyze data. It is a free, open-source, and Integrated development environment (IDE), which is based on the concept of gamma probability distribution function (PDF). It uses monthly precipitation data as input for different time scales. Here data from 40 years (1981 to 2021) of the Bundelkhand area has been obtained from NASA which is an independent agency of the United States of America.

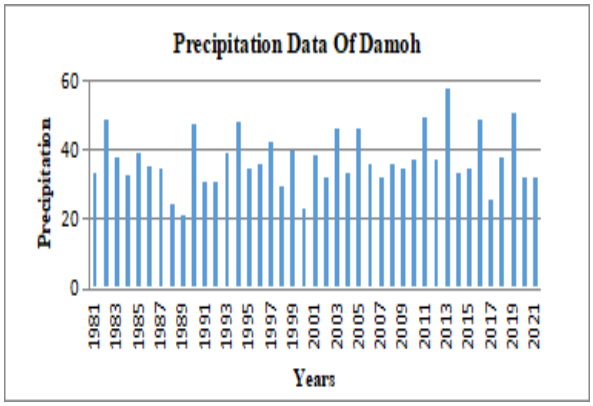


**Fig1.A**

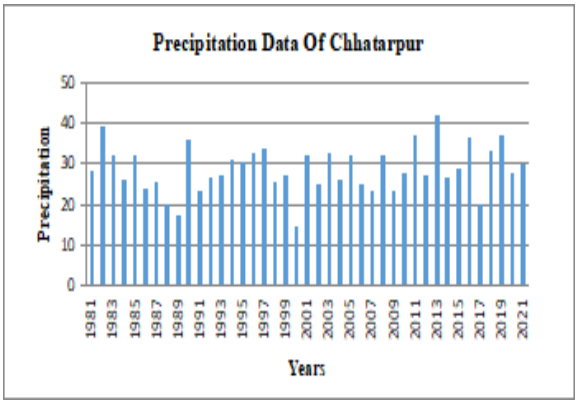


**Fig 1.B**

**Fig. 1(A and B):** Annual precipitation data of Damoh and Chhatarpur station from 1981 to 2021

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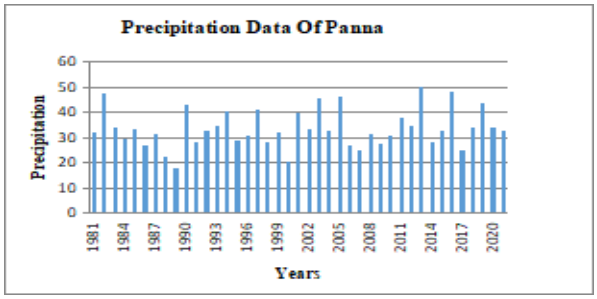



**Fig 1.C**

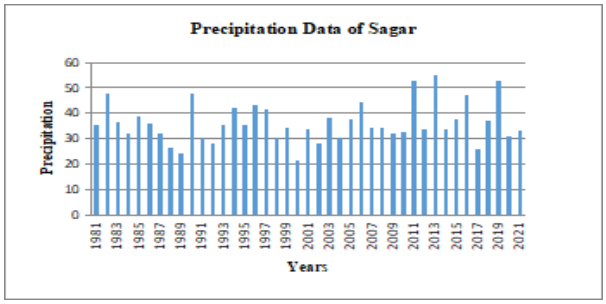



**Fig 1.D**

**Fig. 1(C and D):** Annual precipitation data of Panna and Sagar station from 1981 to 2017

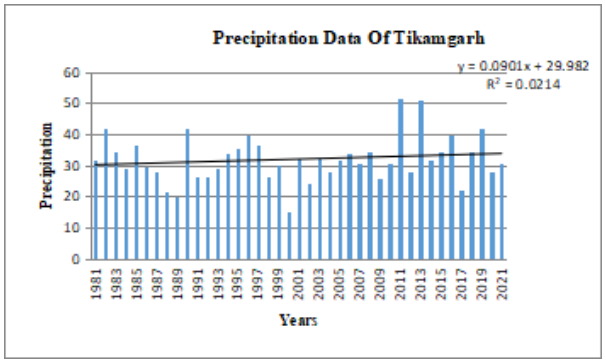



**Fig 1.E**

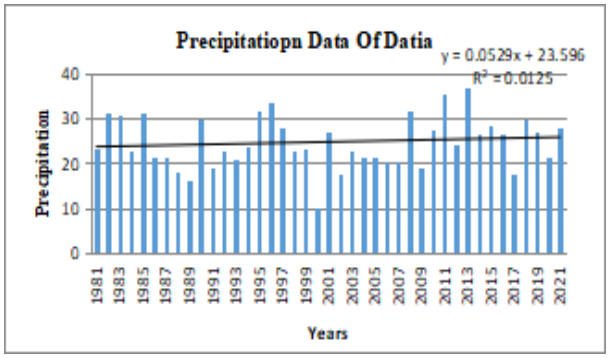
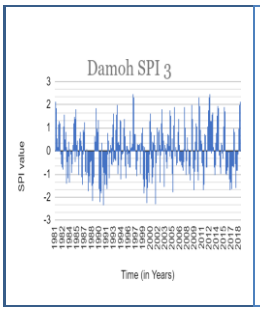


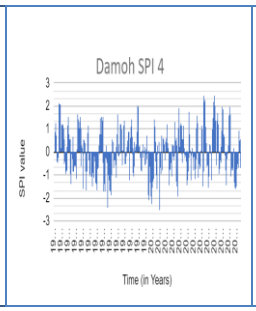

**Fig 1.F**

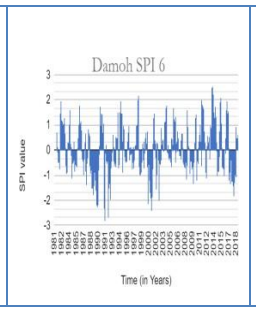
**Fig. 1(E and F):** Annual precipitation data of Tikamgarh and Datia station from 1981 to 2021

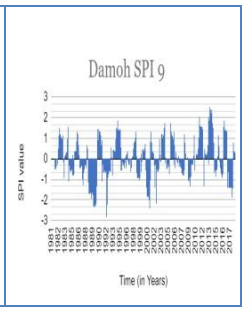
The research stations' data spanning from 1981 to 2011 reveals significant fluctuations in yearly precipitation in the region. This Precipitation directly affect the standard precipitation indexes.

The graphs of different standard precipitation indexes at SPI-3, SPI-4, SPI-6, SPI-9, and SPI-12 for all the stations to see the variation in the severity at different time scales are also showcased.



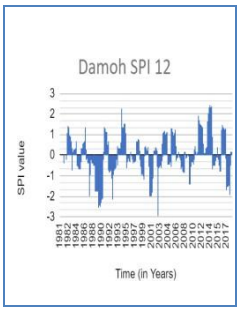




**Fig.1 Damoh SPI3** **Fig.2 Damoh SPI34** **Fig.3 Damoh SPI6** **Fig.4 Damoh SPI9** **Fig.5 Damoh SPI12**

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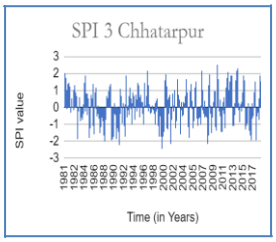
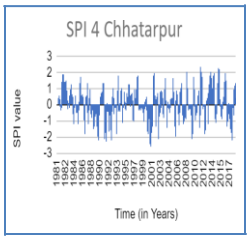
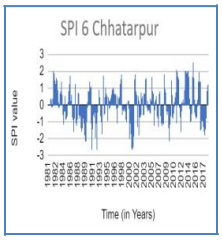
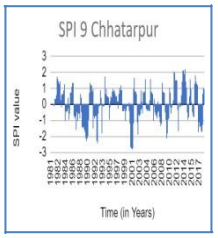


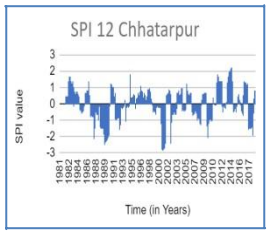
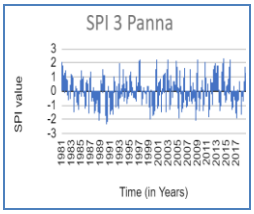
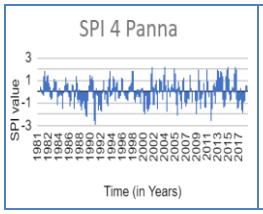
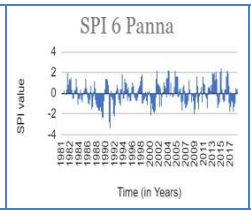
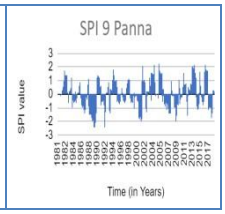




**Fig.6 Chhatarpur SPI3 Fig.7 Chhatarpur SPI4 Fig.8 Chhatarpur SPI6 Fig.9 Chhatarpur SPI9 Fig.10 Chhatarpur SPI12**



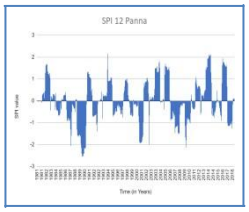
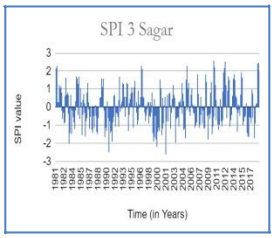
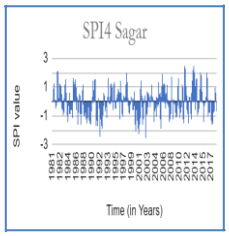
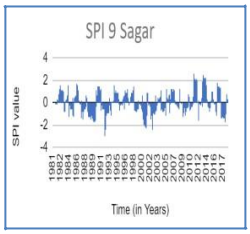
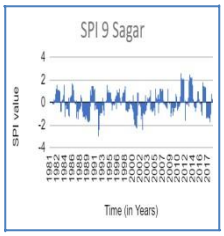




**Fig.11 Panna SPI3 Fig.12 Panna SPI4 Fig.13 Panna SPI6 Fig.14 Panna SPI9 Fig.15 Panna SPI12**



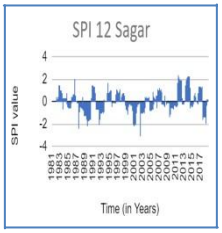
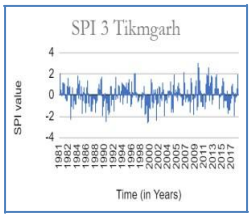
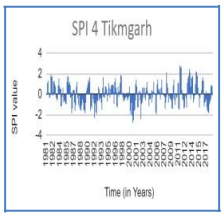
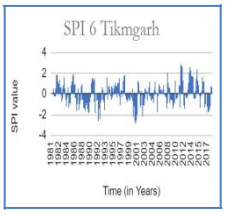
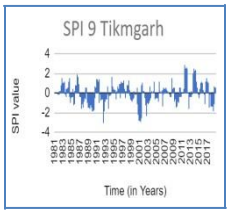




**Fig.16 Sagar SPI3 Fig.17 Sagar SPI4 Fig.18 Sagar SPI6 Fig.19 Sagar SPI9 Fig.20 Sagar SPI12**



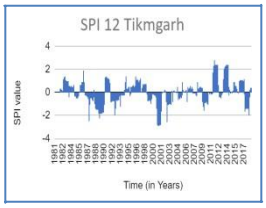




**Fig.21 Tikamgarh SPI3 Fig.22 Tikamgarh SPI4 Fig.23 Tikamgarh SPI6 Fig.24 Tikamgarh SPI9 Fig.25 Tikamgarh SPI12**

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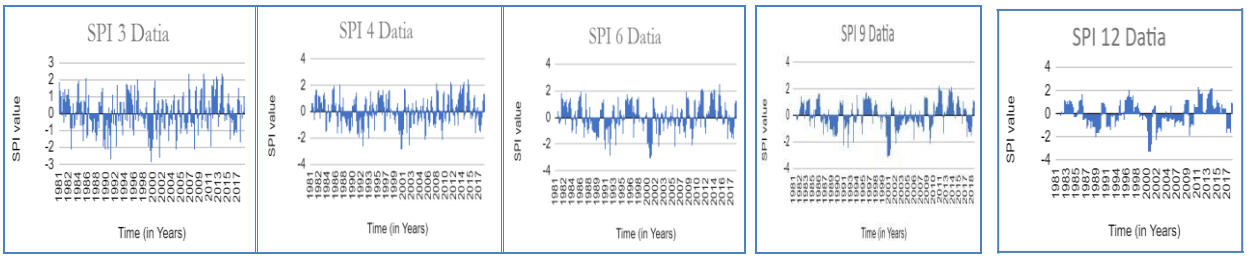


**Fig.26 Datia SPI3** **Fig.27 Datia SPI4** **Fig.28 Datia SPI6** **Fig.29 Datia SPI9** **Fig.30 Datia SPI12**

**IV RESULTS AND DISCUSSION**:

We have calculated the SPI using the precipitation data for our research area of Bundelkhand for short-term and long term impact. In this calculation SPI 3 and SPI 4 for immediate impact or short time scale, which is closely related to the soil moisture having the maximum severity recorded in the year 1991 is much less than -2 (Fig1, Fig16, Fig21and Fig26) for all the stations other than in monsoon season except Panna and Chhatarpur . Besides this 1989, 2000, 1988, 2017, 2007, 2002, 1998, and 2009 are witnessing very low rainfall in all of the Bundelkhand area, so the occurrence of severe and moderate droughts is indicated by Fig(3,4,8,9,13,14,18,19,23,24). It is also observed that there is very less impact of the presence of water in the next months, but its cumulative nature impacts long term in all types of drought.

SPI-6, SPI-9, and SPI-12 are better suited for long-term drought analysis. Additionally, there has been an observed increase in the frequency of dry spells occurring annually. Conclusively, the frequency of drought occurrence is higher in the short term and reduces as we move towards the long-term scale.

We observed that most of the time either there is a negative tendency of the SPI or a very low value. Normally the SPI values lie between -1 to +1. The frequency of low rainfall occurrences in Datia , Tikamgarh, Panna ,Chhatarpur, Damoh, and Sagar is high as compared to other regions.

The study found that for short-term analysis (using SPI-3), as well as medium (SPI-6 and SPI-9) and long-term analysis (SPI-12) Fig (5,10,15,20,25,30), the predicted results were closely aligned with the actual outcomes. In these cases, the SPI time series were used as inputs, highlighting that many of these time series exhibit seasonal patterns.

Based on the minimum values of different scales from our research stations, it can be concluded that the 3-month period experienced a severe drought condition in Tikamgarh, Sagar, Panna, Datia, Damoh, and Chhatarpur. The SPI3 values of these locations were -2.64, -2.61, -2.36, -2.84, -2.35, and -2.46, respectively. Furthermore, the SPI4, SPI6, SPI9, and SPI12 values indicate that the severity of the drought is progressively

increasing over time. These findings demonstrate the need for immediate action to manage the drought's impacts on water resources, agriculture, and other sectors that rely on precipitation.

## V CONCLUSION

This study after the analysis of drought data in our research area through the different scales of SPI shows that low and negative values of SPI indicate that there is either very low or average rainfall in the area. This is also approved by the Drought that occurred during the period. The result indicates that the frequency of occurrence of extremely dry or severe drought conditions is low, but moderate drought and mild drought conditions are more. The result has shown that drought has occurred most of the years for a short duration in the area.

The years 1989, 2000, 1991, 1988, and 2017 were characterized by the most severe drought, with very low SPI values recorded across all stations. Although it has no certain pattern of drought. It has also been observed by the result that most of the time either there is a negative tendency of the SPI or very low values that indicate very low rainfall in the area. This is also approved by the Drought that occurred during the period.

The SPI values can have severe consequences on water resources, agricultural production, and ecological systems. Therefore, these indices are valuable tools that decision-makers and stakeholders can use to plan, manage and prepare for droughtsand their potential impacts.

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