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Assessment of drought by using standardized precipitation index (SPI)

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Abstract
Bundelkhand needs extra care to combat the impact of drought in the region which frequency has been increased due to climate change. This study presents a methodology for spatial and temporal assessment of drought in each 13 districts come under Bundelkhand region. Standardized Precipitation Index (SPI) methods were used to identify meteorological drought in terms of SPI and it was calculated by in different time steps 1 and 3-months time scales for the duration of 1990-2019. In most of districts it was found severe to extreme drought condition in the years 1991, 1993, 2000 and 2015 in Bundelkhand region. It was found that based on 1 and 3-months scale extreme dry condition was there during 1991, 1993, 2000, 2006, 2012, 2015 and 2018 in Banda district. In Chhatarpur district, 1-month scale SPI indicates that during 1992, 2000, 2001, 2002 and 2009, extreme drought condition was prevailing. In these years dry spell periods were also long. in the 3-month scale of SPI indicates 1991, 1992, 2000, 2002, 2005 and 2009 were affected by extreme drought condition in Datia. Likewise, in Chitrakoot, Damoh, Hamirpur, Jalaun, Mahoba, Jhansi, Lalitpur and Panna these years were drought affected either extreme drought or severe drought in the scales of 1 month and 3 months. In 1-month scale of SPI, 1991 and 2002 were extreme drought years whereas 1992, 2000, 2001,2005, 2007, 2009, 2011, 2017, 2018 were severe drought affected years in Sagar district. In the years 1991, 1992, 2000, 2002, 2004, there was extreme dry condition and severe dry condition was prevailing in the years 2006, 2010 and 2018 indicated by 3-months scale of SPI. In Tikamgarh district, there was extreme drought condition in the years 1992, 2001, 2002 and 2017 whereas in the years 1991, 2000, 2004, 2005, 2009 and 2013 there was severe dry condition as shown by 1-month scale of SPI. Drought analysis can provide a tool to diagnose the impacts on food production associated with drought and for early warning of crop yield by predicting the yield at an early stage of the crop growth.

Keywords: Drought, standardized precipitation index (SPI), extreme, severe, impact

Introduction
Drought has largely non-structural characteristics and damages larger geographical areas when compared with other natural hazards. The impacts of drought are often categorized as hydrologic, agricultural, economic, social, health, ecological, and environmental. Besides, some of these impacts are difficult to quantify because of the non-structural nature of droughts. Drought preparedness planning should be considered to minimize the effects of drought on people and resources.

The occurrence of drought makes the land incapable of cultivation throughout the year and this situation renders harsh and inhospitable environmental condition for human being, livestock population and biomass potential and plant species (Siddiqui, 2004) [10]. So, there is an urgent need to make an effort to monitor and mitigate drought disaster with reference to span of time (Rathore, 2004) [8]. A well-designed mitigation and preparedness plan can help the decision makers to reduce the effect of drought. In this context, monitoring of onset, duration, intensity and extent of drought has become important for managing the adverse impact of drought A well-designed mitigation and preparedness plan can help the decision makers to reduce the effect of drought. In this context, monitoring of onset, duration, intensity and extent of drought has become important for managing the adverse impact of drought.

Drought indices are commonly used to detect the potential risk of occurrence and severity of drought, and to study spatial–temporal reasoning. Many of these indices have been developed for detecting temporal variability and magnitude of the drought actions in interesting regions. There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Some of the widely used drought indices include Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Standardized Precipitation Index (SPI), and Surface Water Supply Index (SWSI).

The Standardized Precipitation Index (SPI) is a very useful tool as well as an index to monitor meteorological drought which is exclusively based on precipitation data. According to McKee *et al.* (1993) [4], SPI gives an easy and flexible way to monitor drought at a different scale ranging from near normal (-0.99) to extreme drought condition (<-2.0) and it has been recommended by various studies for its suitability to estimate meteorological drought at different time lag (Guttman, 1998, Dutta *et al.*, 2013; Zhang and Jia, 2013) [2, 14].

Materials And Methods

Study area

The Bundelkhand region includes thirteen districts: seven in Uttar Pradesh- Jhansi, Jalaun, Lalitpur, Hamirpur, Mahoba, Banda and Chitrakoot, and 6 in Madhya Pradesh - Datia, Tikamgarh, Chattarpur, Damoh, Sagar and Panna. it's situated below the Indo-Gangetic plain to the north with the undulating Vindhyan range spread across the northwest to the south. It covers a neighborhood of around seven million hectares and is situated between 23°20' and 26°20' N latitude and 78°20' and 81°40' E longitude. The masses live below poverty level which may be due to the disturbance in their livelihood activities i.e., agriculture and livestock rearing. The droughts have increased the scarcity of food grains and have made their lives more challenging. Agriculture in Bundelkhand is rainfed and very risky. additionally, extreme weather, like drought, short term rain increases the uncertainties and seasonal migrations. The scarcity of water within the semi-arid region, with poor soil and low productivity further aggravates the matter of food security.

Meteorological Data

The material which was utilized in this study is monthly precipitation data set that pertains to stations which is found in 13 districts of Bundelkhand region. There are 13 counties within the Bundelkhand region and there is one station in each county, supported the National Oceanic and Atmospheric Administration (NOAA) database system. A minimum of 20 years of knowledge is required for statistical analysis (Guttman, 1994) [3]. Wu and Wilhite (2004) [14] says that the longer the length of knowledge set utilized in drought index calculation, the more reliable drought index values are going to be. The daily climatic data (maximum temperature, minimum temperature, mean temperature and rainfall) for the amount of 1990 to 2019 were downloaded and were extracted by R environment with Python from gridded data of India Meteorological Department, Pune, India (Pai *et al.*, 2014, Srivastava *et al.*, 2009) [11]. Monthly mean, maximum and minimum temperature and monthly rainfall were estimated for all 13 districts (Banda, Chhatarpur, Chitrakoot, Damoh, Datia, Hamirpur, Jalaun, Jhansi, Lalitpur, Panna, Sagar and Tikamgarh) of Bundelkhand region for duration 1990–2019.

Drought Index

The literature teems with innumerable drought indices, and none of those indices is freed from limitations (Mishra and Singh, 2010) [5]. During this study, Standardized precipitation index (SPI) was used to assess the drought condition within the Bundelkhand region.

Standardized precipitation index (SPI)

The SPI calculation is predicated upon the long-term precipitation data for various time steps, 1 and 3-months. Within the classical approach of obtaining an SPI, the cumulative distribution function of precipitation totals is made from the fitted distribution. Then the possibilities from the fitted cumulative distribution function are transformed to the quality Gaussian distribution by using the inverse standard Gaussian distribution. the tactic, therefore, consists of a change of probability distribution (e.g., gamma or Pearson type III) to a different (standard normal distribution). This study used the gamma distribution which is defined by its probability density function:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1}e^{-x/\beta}, \quad \text{for } x > 0 \qquad (1)$$

where $\alpha > 0$ is α shape parameter, $\beta > 0$ may be a scale parameter, and $x > 0$ is that the amount of precipitation. $\Gamma(\alpha)$ is that the gamma function. Fitting the distribution to the info requires α and β to be estimated for every station, for every time-scale of interest (1 and 3-months). Thom (1966) [12] used tables of the unfinished gamma function to define G(x), the cumulative probability. It's possible to possess several zero values during a sample set and therefore the gamma distribution is undefined for zero values. Cumulative probability was defined accordingly as below:

$$H(x) = q + (1 - q)G(x) \qquad (2)$$

where q is that the probability of a zero-precipitation value. If m is that the number of zeros during a given dataset of n values, then q is often estimated by m/n (Thom, 1966) [12]. H(x), the cumulative probability, was transformed to the quality normal variate Z (or the SPI value). The SPI value, which is obtained from the quality Gaussian distribution has 0 mean and variance of 1. Details of computation of SPI are taken from Hughes and Saunders (2002). Each probability density function is then transformed into the standardized Gaussian distribution. Thus, the SPI is claimed to be normalized in location and duration. Each probability density function is then transformed into the standardized Gaussian distribution. (Meteorological Drought Monitoring) MDM software (Salhenia *et al.*, 2017) [9] was used to calculate SPI for various time periods (1 and 3-months). Monthly duration SPI was calculated by choosing option monthly SPI in MDM software and other time-scales were calculated by moving average in the same way. Drought was analyzed for various districts of Bundelkhand region consistent with its intensity and severity as given by Mckee *et al.*, 1993 [4] (Table 1).

Results And Discussion

Meteorological Drought assessment

Meteorological Drought is a natural phenomenon detecting its onset and end time. Drought characterizations were detected to analyze meteorological drought condition in the Bundelkhand region that has been investigated based on the SPI during 1990-2019.

Drought monitoring using Standardized precipitation index (SPI)

The SPI is a drought index which has been frequently used to assess the meteorological drought by decision makers for monitoring the intensity of drought events. Except these, SPI is useful for identifying spatiotemporal extent of long-term historical droughts. In the present study, Standardized Precipitation Index (SPI) was used to assess the occurrence of meteorological drought, its intensity and spatiotemporal extent in the region in different time scales. Standardized precipitation index (SPI) was calculated for 1 and 3-months scale for each 13 districts of Bundelkhand region.

It was found that based on 1 and 3-months scale extreme dry condition was there during 1991, 1993, 2000, 2006, 2012, 2015 and 2018 in Banda district (Fig. 1). In Chhatarpur district, 1-month scale SPI indicates that during 1992, 2000, 2001, 2002 and 2009, extreme drought condition was prevailing but in 3-months scale during 1991, 2000, 2009 and 2018 extreme drought condition was existing (Fig. 1). In Chitrakoot district, SPI for 1 month scale shows that there was extreme drought condition in the years 1993 and 2009 while in scale of 3 month it indicates extreme drought condition in the years 1991, 1993, 2000, 2006, 2009 and 2018. Severe to moderate drought condition was existing in most of years during 1990-2019 in 1 month scale whereas in 3-month scales, moderate to severe drought condition in the years 1992, 2000, 2010, 2015, 2017 and 2018 (Fig. 1). In 1991, 2000, 2002 and 2017 extreme drought condition was prevailing in Damoh district which was shown by 1-month scale of SPI whereas there was severe drought condition during 1997, 2014 and 2018. In 3-month scale, there was extreme dry condition in 1991, 2000 and 2002 but severe drought condition was prevailing in large area in the years 1992, 2000, 2006, 2010. 2012, 2017 and 2018 in Damoh district (Fig. 1).

In Datia district, 1-month scale of SPI indicates that there was extreme dry condition in the years 1992, 2001, 2002 and 2005 where as in the 3-month scale of SPI indicates 1991, 1992, 2000, 2002, 2005 and 2009 were affected by extreme drought condition (Fig. 2). Severe drought condition was prevailing in years, 1991, 1993, 1995 and 2009 as it is indicated by 1-month scale of SPI and 1993, 1994, 2001, 2004, 2006 and 2008 were severe drought condition years as shown by 3-months scale of SPI. In Hamirpur district, 1991, 1993, 2001 and 2014 were extreme dry years and in the years 1992, 2002, 2006, 2008 and 2012, there were severe drought condition as indicated by 1-month scale of SPI (Fig. 2). In the years, 1991, 1993, 2000, 2006, 2012 and 2015, there were extreme dry years and moderate dry years were found in the years 1992, 1994, 2009, 2014 and 2018 as indicated by 3-month scale of SPI in Datia district. In the years, 2001 and 2002 extreme dry condition was prevailing in Jalaun district as indicated by 1-month scale of SPI and severe drought years were prevailing for long duration of 1991 to 1995, 2005, 2012 and 2018 in Jalaun district (Fig. 2). In 1991, 1992, 1994, 2000, 2006 and 2018, there were extreme dry condition and in the years 1993, 2002, 2012, 2014, and 2017 were severe drought condition as indicated by 3-months scale of SPI. In Jhansi district, 1992, 2001, 2002 and 2005 were extreme dry years as indicated by 1-month scale of SPI whereas 3-month scale shows 1991, 1992, 2000, 2002 and 2009 were extreme dry years (Fig. 2). There was severe drought condition prevailing in the years 1991, 1993, 1995, 2000, 2013 and 2018 shown by 1-month scale of SPI whereas 3-months scale shows 1993, 1994, 2005 to 2007, 2012 and 2018 as severe drought years.

In 1-month scale of SPI, it was found extreme drought condition in the district Lalitpur in the years, 1991, 1992, 2002, 2005 and 2017 whereas years 2000, 2001, 2013 and 2018 were severe dry years as indicated by the same time scale of SPI (Fig. 3). In case of 3-months scale of SPI, 1991, 1992, 2000, 2002, 2004 extreme drought condition was prevailing but in the years 1993, 2006, 2009 and 2017, there was severe drought condition in the same time scale of SPI in this district. In 1992, 2001, 2002 and 2009 extreme drought condition was found in the district Mahoba and severe drought condition was prevailing during 1991 to 1995, 2000, 2013 and 2018 as indicated by 1-month scale of SPI (Fig. 3). In the scale of 3-months of SPI, 1991, 1992, 2000, 2009 and 2018, there was extreme drought condition where as in the years 1993, 2002, 2006, 2014 and 2017, there was severe dry condition. In Panna district, 2001 and 2009 were facing extreme drought condition whereas in most of years there was moderate to severe drought condition as indicated by 1-month scale of SPI (Fig. 3). As indicated by 3-months scale of SPI, in 1991, 2000 and 2009, there was extreme drought condition in the area and severe drought condition was existing in the years 1992. 1993, 2012, 2014, 2017 and 2018. In 1-month scale of SPI, it was found that 1991 and 2002 were extreme drought years whereas 1992, 2000, 2001, 2005, 2007, 2009, 2011, 2017, 2018 were severe drought affected years in Sagar district (Fig. 3). In the years 1991, 1992, 2000, 2002, 2004, there was extreme dry condition and severe dry condition was prevailing in the years 2006, 2010 and 2018 as indicated by 3-months scale of SPI.

In Tikamgarh district, there was extreme drought condition in the years 1992, 2001, 2002 and 2017 whereas in the years 1991, 2000, 2004, 2005, 2009 and 2013 there was severe dry condition as shown by 1-month scale of SPI (Fig. 4). In 3-months scale of SPI, 1991, 1992, 2000 and 2002 were extreme drought affected years and severe drought condition was prevailing in the years 1993, 2004, 2006, 2009, 2010, 2017 and 2018.

Table 1: Classes of drought condition on the basis of SPI given by Mckee *et al.*, 1993 [4].

SPI values	Class
>2	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
(-0.99) to 0.99	Near normal
(-1) to (-1.49)	Moderately dry
(-1.5) to (1.99)	Severely dry
< (-2)	Extremely dry

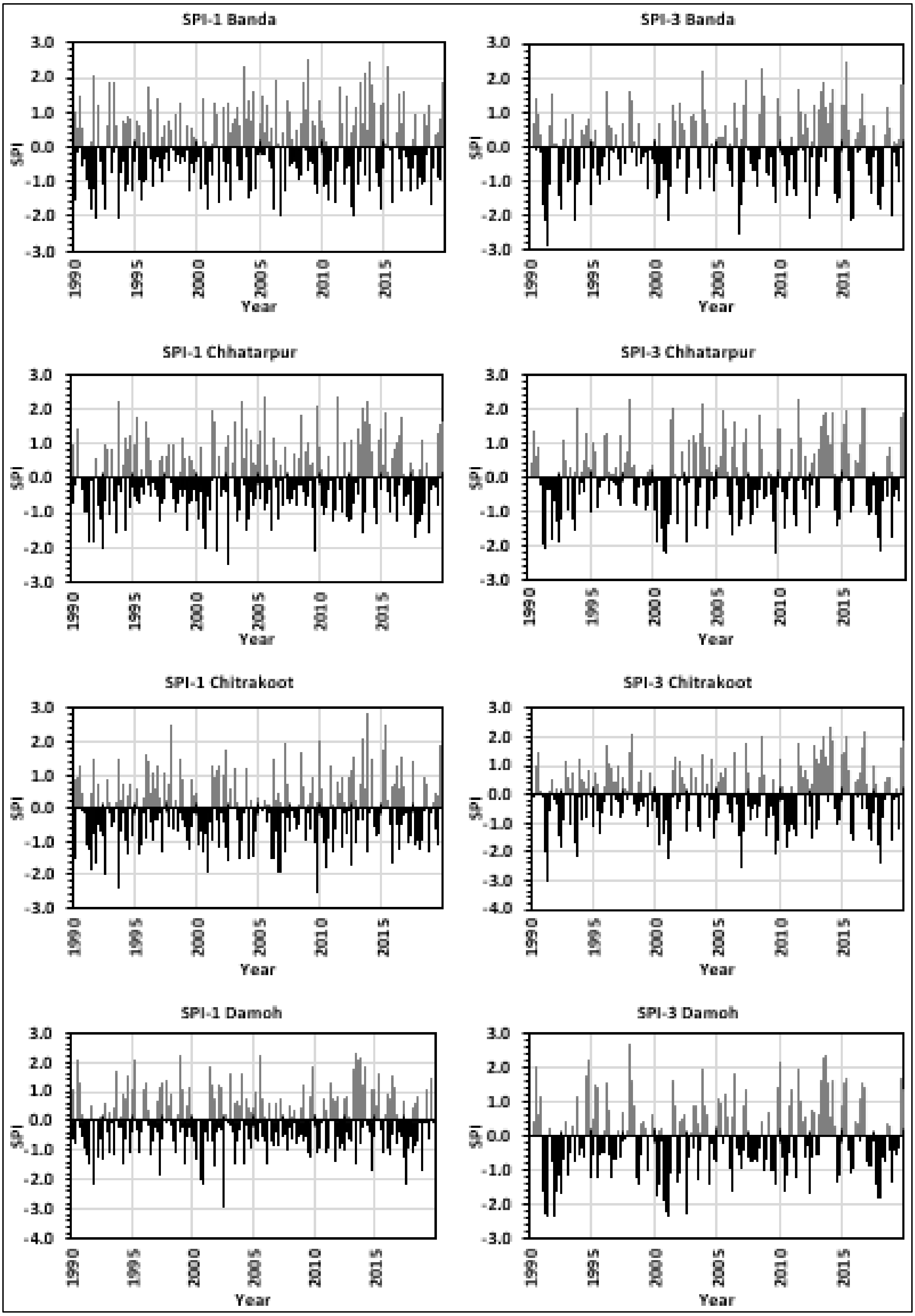

Fig 1: Time series of SPI values for Banda, Chhatarpur, Chitrakoot and Damoh of Bundelkhand region for 1-month and 3-months time scales

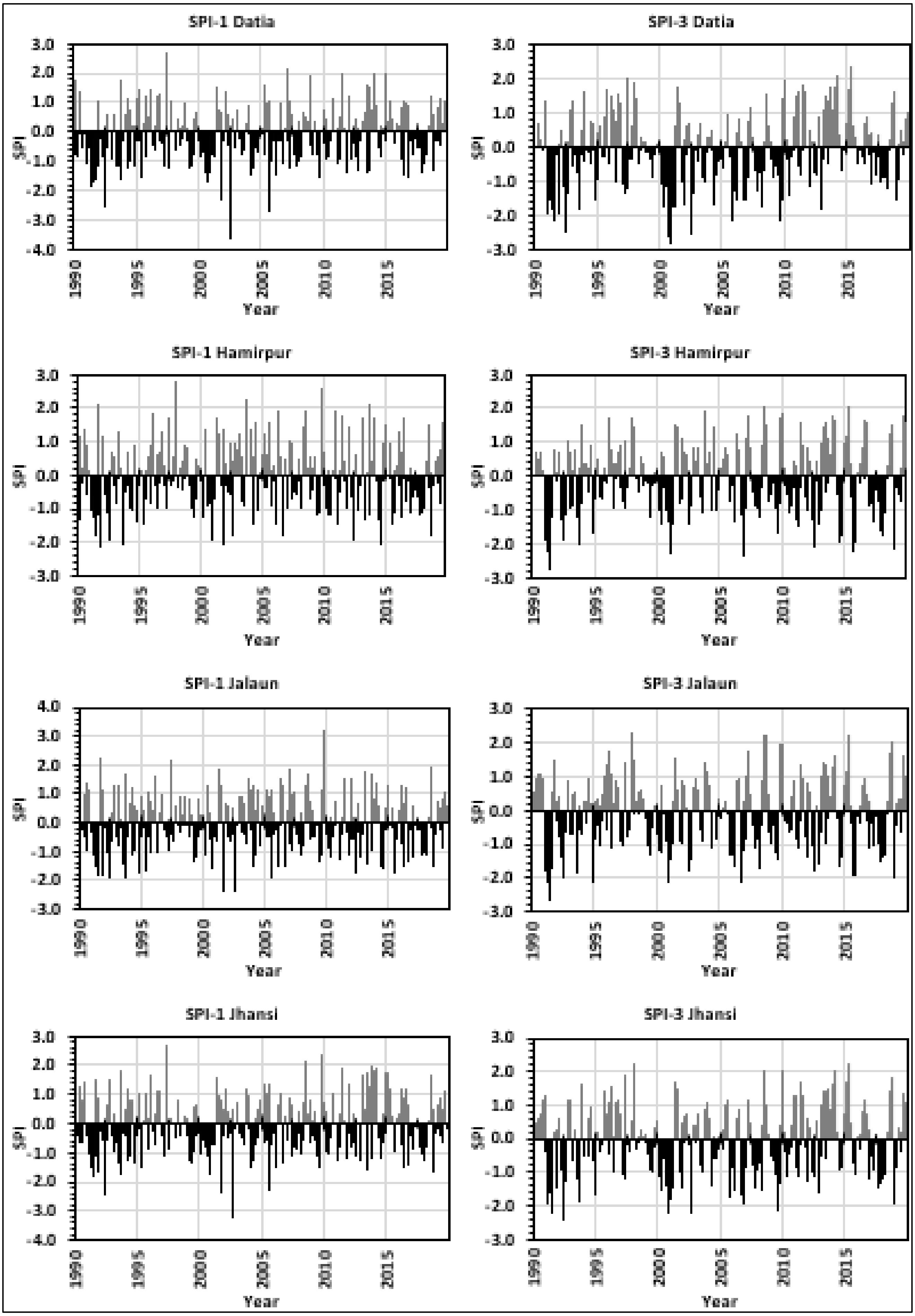

Fig 2: Time series of SPI values for Datia, Hamirpur, Jalaun and Jhansi of Bundelkhand region for 1-month and 3-months time scales

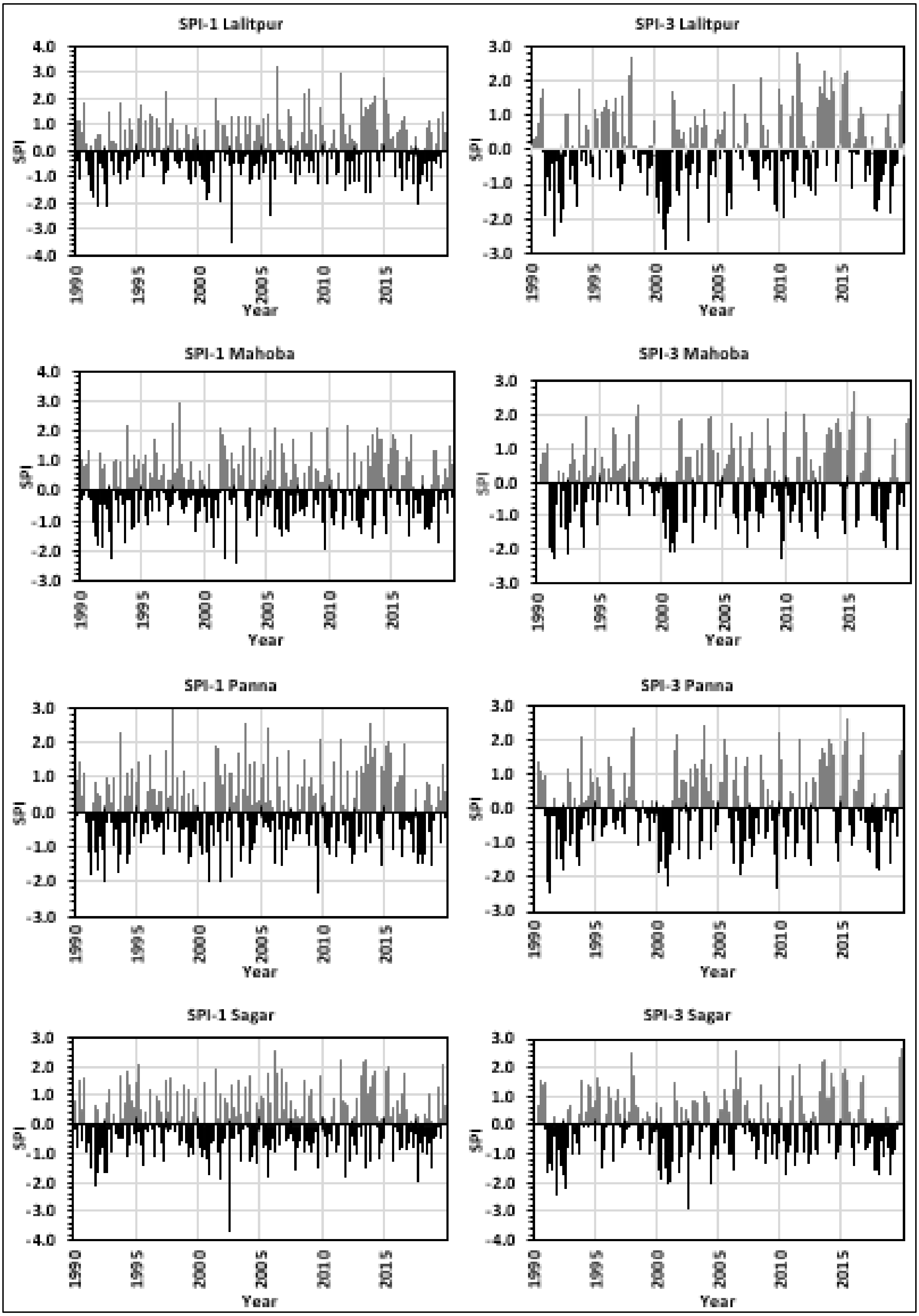

Fig 3: Time series of SPI values for Lalitpur, Mahoba, Panna and Sagar of Bundelkhand region for 1-month and 3-months time scales

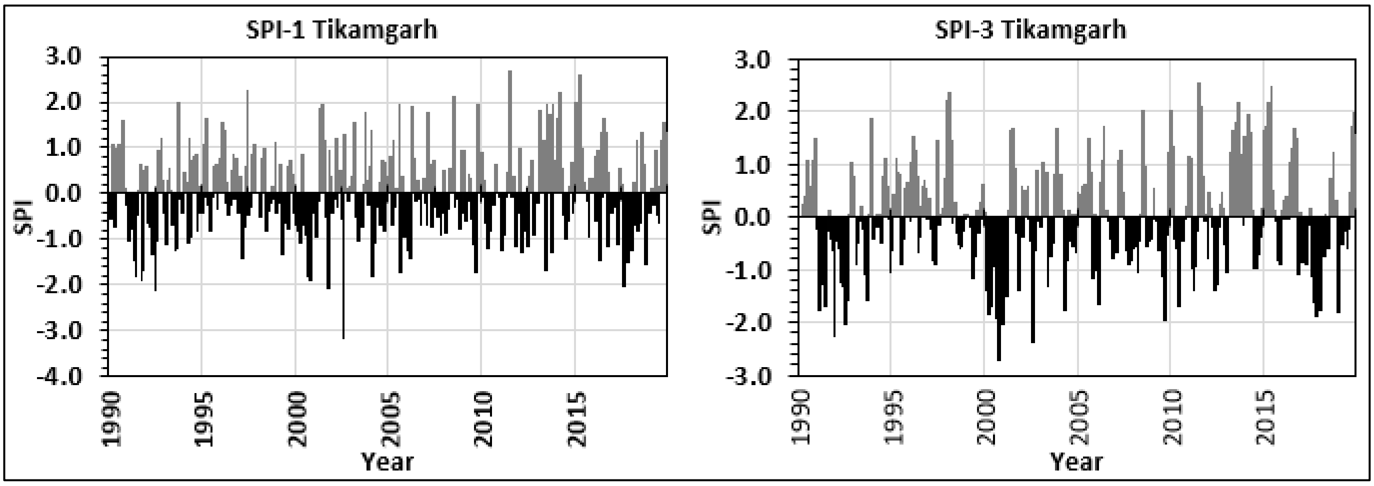

Fig 4: Time series of SPI values for Tikamgarh of Bundelkhand region for 1-month, 3-months, 6-months 12-months, 24-months and 5-months (*kharif* season) time scales

Conclusions

The results obtained have marked implications for improving the drought security in the agriculture sector since they indicate corresponding drought condition in the region. In the context of climate, the drought condition presented herein can be used by the concerned authorities in their protection plans as regards the yield of major crops grown in Bundelkhand region. The drought analysis is very promising in three aspects. First, it can provide a tool to diagnose the impacts on food production associated with drought, i.e., can be used for early warning of crop yield by predicting the yield at an early stage of the crop growth. Second, it helps to bridge some of the gaps between the theoretical concepts of climate risk and decision making.

Precipitation observations and length of data play a key role to analyze drought and the greater number of stations and longer historical data set used, the more reliable results and the confidence level with which drought risk is measured. It will be important to evaluate the risk of drought in different time scales, as these time scales are more appropriate for measuring the dry spells in different seasons or annually. SPI can be used to monitor drought and is found simpler and is getting to be a popular drought index because of its reliable results and simplicity. It is strongly suggested that drought assessment with SPI must be addressed to plan the crop cultivation and for choosing crop in particular region.

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