ANALYSIS

1(4), October - December, 2015

ISSN 2394–8558 EISSN 2394–8566

Climate Change

Evaluation of the meteorological drought over the Bundelkhand region using geo-spatial techniques

Kundu A[1], Denis DM[2], Patel NR[3]

1. Department of Soil, Water, Land Engineering & Management, Sam Higginbottom Institute of Agriculture, Technology and Sciences, Allahabad, Uttar Pradesh, India; Email: arnknd@gmail.com
2. Department of Soil, Water, Land Engineering & Management, Sam Higginbottom Institute of Agriculture, Technology and Sciences, Allahabad, Uttar Pradesh, India; Email: derrick.denis@shiats.edu.in
3. Indian Institute of Remote Sensing, Indian Space Research Organization, Dehradun, Uttarakhand, India; Email: nrpatel@iirs.gov.in

Article History

Received: 05 August 2015

Accepted: 08 September 2015

Published: October-December 2015

Citation

Kundu A, Denis DM, Patel NR. Evaluation of the meteorological drought over the Bundelkhand region using geo-spatial techniques. *Climate Change*, 2015, 1(4), 418-424

ABSTRACT

Drought is a climate based natural hazard occurs in almost all climatic zones irrespective of high or low rainfall areas. Generally, drought is considered as a dry weather condition that lasts over several weeks to months, with no or little rainfall. It happens due to imbalance in water availability. There are several types of drought that can be defined from various perspectives such as agricultural, hydrological, meteorological and socio-economical. Meteorological drought generally defined as a condition, where the annual precipitation is less than the normal for a prolonged period (month, season or year) over an area. Among the several proposed meteorological drought indices, the Standardized Precipitation Index (SPI) is a popular drought index, solely based on precipitation and it measures how much precipitation for a given period of time has deviated from historically observed precipitation of an area.

Technically, SPI represents the number of standard deviation of the observed value deviated from the long-term mean, for a normally distributed random variable i.e. Z-variate. SPI can estimate the drought features with different time scales (1, 3, 6, 9, 12, 24 and 48 months), it has been broadly applied to analyze different aspects of droughts. Normally, the ''drought'' part of the SPI range is arbitrary split into moderately dry (-1.0 > SPI > -1.49), severely dry (-1.5 > SPI > -1.99) and extremely dry conditions (SPI < -2.0). The present study attempts to assess the meteorological drought response to extreme climate condition. Long-term rainfall data (2002-2013) have been taken for Standardized Precipitation Index (SPI) analysis. A detailed spatio-temporal analysis of drought dynamics was carried out using the SPI, which revealed the occurrence of a severe drought in Bundelkhand region during several years.

Keywords: Rainfall, Standardized Precipitation Index (SPI), Meteorological Drought, Remote Sensing, GIS.

1. INTRODUCTION

Drought is one of the harshest natural hazards originating from deficiency of precipitation and it results into shortage of water and is often associated with other climatic factors. Climate change makes it likely to become more frequent and extensive in many areas across the world in the 21st century (Bates et al. 2008). The severity of drought impacts requires targeted management with monitoring and forecasting as essential elements. The major reason of any drought is a deficiency in rainfall in particular, the timing, distribution and intensity of this deficiency in relation to the existing water storage, demand, and use. Therefore, drought is a prolonged period of water deficit, and typically occurs when an area receives precipitation below usual levels for several months (Gocic and Trajkovic, 2014; Pabitra Aryal, 2015; Tushar Pandey et al. 2015).

Meteorological drought basically depends on inadequacy of rainfall. Among various established indices of meteorological drought, the Standardized Precipitation Index (SPI) is a popular and robust tool for monitoring meteorological drought (McKee et al. 1993; Heim, 2000; Wilhite et al. 2000; Rossi and Cancelliere, 2002; Raziei et al. 2009; Ibrahim et al. 2010). According to Guttman (1998), the SPI is a probability index that uses monthly rainfall data as input. It has been demonstrated to perform better in comparing drought across different regions. Hayes et al. (1999) showed that SPI can be used operationally to detect the start of a drought, its spatial extension and temporal progression. The SPI has the advantages of being easy to calculate, having modest data requirements and being independent of the magnitude of mean rainfall and hence comparable over a range of climatic zones (Agnew, 2000). Patel et al. (2007) indicated that the SPI at a 3-month timescale is effective in capturing seasonal drought patterns over space and time in Gujarat. In their study, Pai et al. (2011) found that the SPI is more suitable than the percent of normal precipitation for district-wise drought monitoring over India during the southwest monsoon season.

Geospatial techniques play an important role for drought monitoring, especially in studying spatio-temporal dynamics of drought (Kogan, 1995; Wang et al. 2001; Wan et al. 2004). Bhuiyan et al. (2006) discussed about drought dynamics in the Aravalli region (India) using different indices based on ground and remote sensing data. Dutta et al. (2013; 2015) discussed how agricultural drought is interrelated with meteorological drought in semi arid region of India using geospatial techniques. Another study done by Sahoo et al. (2015) focused on the meteorological and hydrological drought assessment through remote-sensing derived indices.

2. STUDY AREA

Bundelkhand region is a part of central zone of India and geographically located between $23^0$20'N and $26^0$20'N latitude and $78^0$20'E and $81^0$40'E longitude. The region covering is characterized by hard rocks, undulating terrain of varied slope with an area of over 7.08 Million hectares (Mha) in Uttar Pradesh and Madhya Pradesh. The area is predominantly under agrarian economy; over 80% of population is dependent on agriculture, livestock and forest sector. Cereals share majority of food grain production (54.6%) followed by pulses (32.4%), oilseeds (8.0%), sugarcane (0.2%) and other crops (4.8%) under normal rainfall years. Historical data reflect that normal yearly rainfall in Bundelkhand region is ranging between 800–1,000 mm and average number of rain days in the region is 40–42. This region is primarily rain-fed and has less than 25% of cropland with double cropping. The Bundelkhand region has faced recurring drought events with propensity of seven droughts in last 10 years (Patel and Yadav, 2015).

3. MATERIALS & METHODS

3.1. Dataset

Long-term monthly rainfall data (2002–2013) were collected from the NOAA Climate Prediction Center (CPC), RFE2.0 daily rainfall estimates for southern Asia area (http://www.cpc.ncep.noaa.gov/products/fews/SASIA/rfe.shtml). The details about data are given below:

Spatial domain: 70.0-110.0E; 5.0-35.0N
Temporal domain: May 01, 2001 - present
Resolution: 0.1 x 0.1 degree
File structure: binary, 4-byte floating point

The daily rainfall data have been stacked together for monthly basis and then it had taken for the Standardized Precipitation Index (SPI) calculation.

3.2. Methods

Standardized Precipitation Index (SPI) was calculated using the following formula and classification scheme as proposed by Mckee et al. (1993). SPI was estimated to observe the spatio-temporal extent and intensity of meteorological drought event. The SPI is a dimensionless index where negative and positive values indicate drought and wet situation respectively. The intensity, magnitude and duration of drought as well as the historical database probability emerging from a specific drought can be determined by a thorough analysis of SPI values. The normalized series of SPI values represent wetter and drier climates in the same way. The SPI has been applied to quantify monthly precipitation deficit anomalies on single time scale (1 month) for the period during 2002–2013. Computation of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation for a given station. It represents a statistical *z*-score or the number of standard deviation (following a gamma probability distribution transformation to a normal distribution); above or below that an event is demarcated with reference to mean (Edward and Mckee, 1997). The gamma distribution is normally defined as:

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

Where, $\alpha > 0$ is a shape parameter, $\beta > 0$ is a scale parameter, x is the precipitation amount and $\Gamma(\alpha)$ is the gamma function.

4. RESULTS

The SPI maps were prepared following the aforesaid equation and the study reveals that the area has been affected by meteorological drought many times during the period, 2002-2013. We have divided the SPI values into four major classes as per the classification scheme of Mckee et al. (1993), namely no drought, mild drought, moderate and severe drought classes (Table 1). It was found from the study that most of the districts of Bundelkhand region except Chitrakoot and some part of Jalaun and Banda district of Uttar Pradesh experienced mild meteorological drought during August, 2003 (Fig. 1). The scenario had become changed in few pockets during the month of September. Some drought affected areas like parts of Sagar, Damoh, Banda and Mahoba districts overcome the situation. However, the rest of the districts were under mild drought during the month. There was another notable drought scenario during the year 2012, when most of the Bundelkhand region faced mild and moderate drought. On the other hand, 2007 was a year with normal rainfall and the maximum districts were under no drought class. However, there were mild drought situation in parts of Hamirpur, Mahoba, Jhansi and Lalitpur districts. In order to study the long term trend of meteorological drought over Bundelkahnad region, we have chosen few hot spot areas and the secenario have shown through the line graph (Fig. 2a). In site 1, the graph shows fall in SPI graph during the years 2003-2006 and 2012 indicating the occurrence of drought event whereas there was a peak during 2007 (normal year). There was two demarcable dips in the SPI graph during 2003 and 2011-2012 which represents mild to moderate drought event in site 2 (Fig. 2b).

The following pattern of SPI depends on the rainfall status over the region. The maximum part of the Bundelkhand region (90%) was affected by meteorological drought except some part of Chitrakoot and Sagar districts during the years, 2003 and 2012. The area experienced mild to moderate meteorological drought in both August and September months. On the other hand, in 2007 there was no meteorological drought condition. The following graphs show the trend of SPI based drought scenario in August and September months (Fig. 2a & 2b).

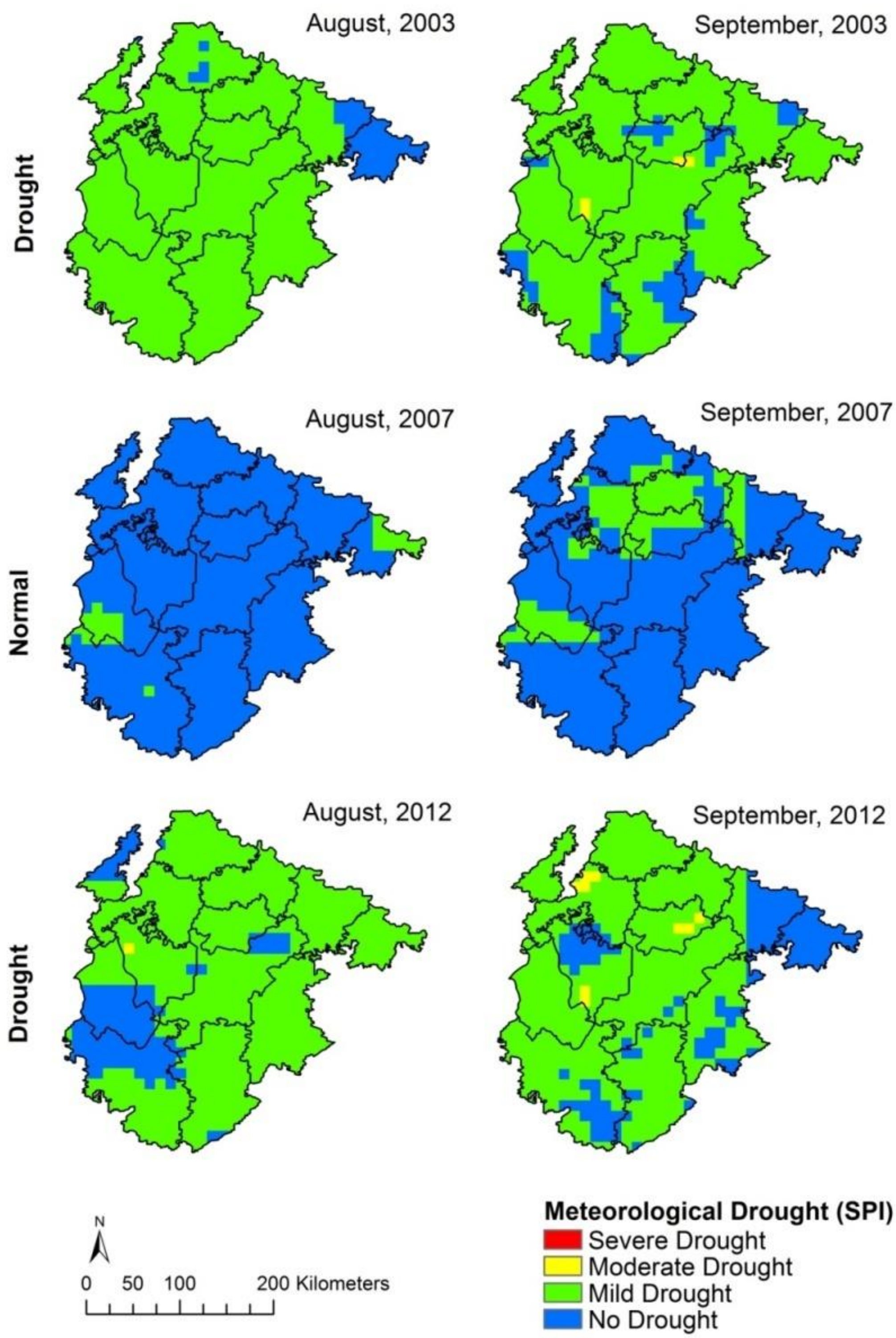

Figure 1 Spatial pattern of SPI for drought and normal year (August and September)

Table 1 Classification of SPI by Mckee et al. (1993)

SPI values	Intensity
> 2.0	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
< -2	Extremely dry

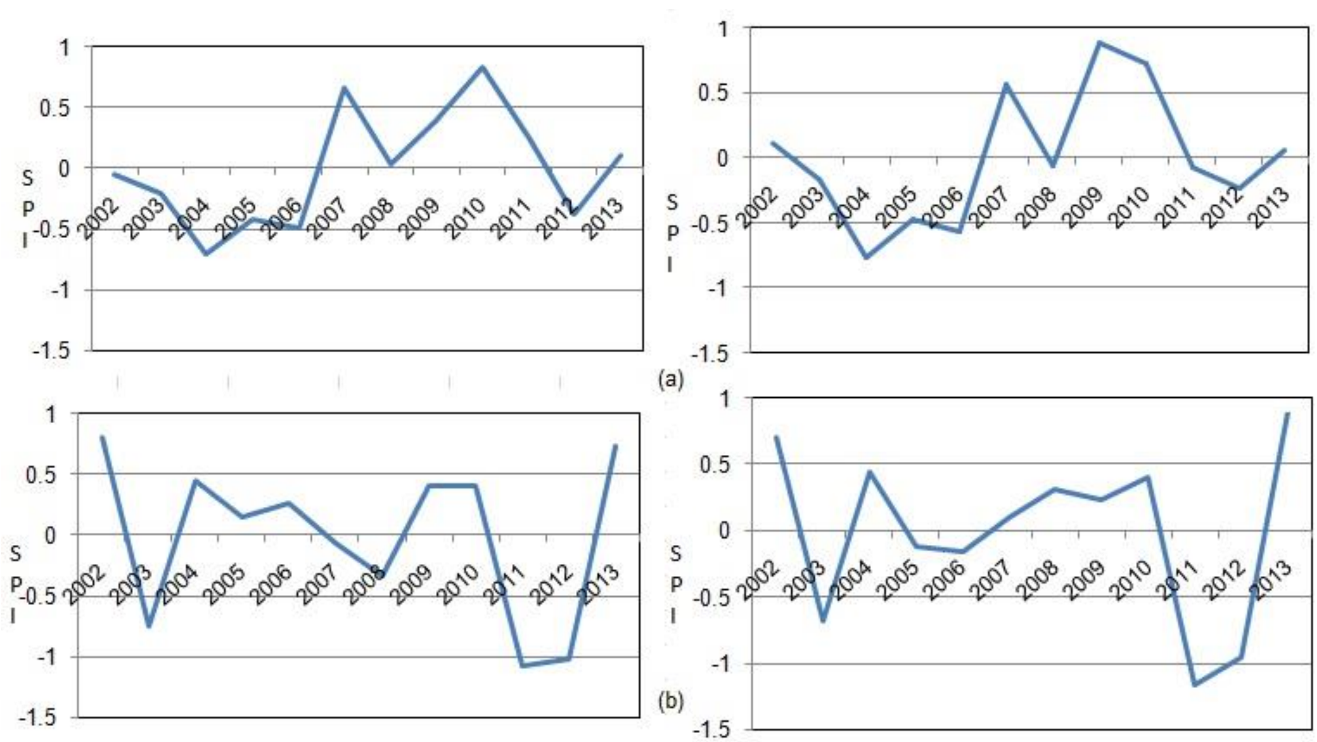

Figure 2 SPI characteristics in the month of (a) August and (b) September for drought and normal year

5. CONCLUSIONS

A systematic and comprehensive meteorological drought analysis has been carried out in Bundelkhand region and the spatio-temporal characteristics of meteorological drought have been evaluated. The meteorology based Standardized Precipitation Index (SPI) has successfully revealed the drought scenario during August and September months. Bundelkhand region is known for prolonged and recurring drought features, and this study also agrees with this fact that the area experienced successive drought events during the last decades. The SPI with geospatial techniques proves to be a robust technique for identifying the spatio-temporal drought stress over the region.

ACKNOWLEDGEMENT

The authors would like to acknowledge NOAA/Climate Prediction Center (CPC) for providing the daily rainfall data to fulfill this study.

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