



# Use of meteorological data for identification of agricultural drought in Kumaon region of Uttarakhand

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Agriculture in hill and mountain ecosystems is predominantly rainfed with common occurrence of moisture stress. It is a natural disaster which evolves in time and its impacts last for a long time. In the present investigation, long-term monthly precipitation data for 40 years (1980–2019) were used for characterizing agricultural drought in Almora and Nainital districts of Uttarakhand in India. Different drought indices based on meteorological data like standard precipitation index (SPI), percentage of departure ( $P_d$ ) and percent of normal ( $P_n$ ) were used. Percentage of departure is calculated from deviation of monthly precipitation from the long-term average monthly precipitation. Percent of normal is calculated by dividing the precipitation by normal precipitation for time being considered. SPI values were calculated based on gamma distribution of long-term monthly precipitation data. The Pearson's correlation coefficient between monthly percentage of departure and different SPI time scales (1, 3 and 6 months) were analyzed. SPI-1 (July and August) for both the stations showed very strong correlation with the corresponding monthly percentage of departure ( $r > 0.97$ ) than SPI-3 and SPI-6. Therefore, it is suggested that SPI as a stand-alone indicator should not be interpreted to identify drought in a hilly region.

**Keywords.** Hilly region; precipitation; remote sensing; standard precipitation index (SPI).

## 1. Introduction

Generally, drought can be defined as a temporary meteorological event that originates from deficiency of precipitation over a long period of time (Mishra and Singh 2010). It plays a pivotal role in the agrarian economy-based country like India where the main occupation of people is agriculture. Mostly drought-prone areas of the country lie in western and peninsular India especially arid, semi-arid, and sub-humid regions (Dutta *et al.* 2013). Overall impact of drought is a function of its duration, severity, frequency and spatial extent. In

context to mountain ecosystem, farming is the main livelihood of the people in the Himalayan states of India accounting to 53.8 m ha land under cultivation and contributing 45% of total regional income. The frequency and extent of drought are a function of erratic precipitation and topological differences. This microclimate specificity makes the drought problem location-specific. The irrevocable climate change in the form of unstable monsoons, long dry spells etc., directly affects the two most important agricultural inputs, viz., water and temperature ultimately affecting productivity. The agricultural field becomes less productive for whole

year and it leads to harsh and uncomfortable weather condition both for human being and livestock population (Siddiqui 2004). One of the worst droughts faced by India was in the year 2002–2003 (Patel *et al.* 2012; Dutta *et al.* 2013). About 32% of the total geographical area of India is under different levels of water stress and drought situation (Subramanya 2005). Similar to other natural event, drought evolve slowly and its impact lasts for a long period. Hence, there is an urgent need for integrated monitoring of drought events with different time scales (Rathore 2004; Srivastava *et al.* 2020). An organised approach for combating and proper strategic approach can help the policy makers to alleviate the impact of drought. In order to understand the deficiency of precipitation on different hydrological parameters, several drought indices were evaluated and tested both at different temporal and spatial scales world-wide by various researchers (Pashiardis and Michaelides 2008; Raziei *et al.* 2009; Pandey *et al.* 2010; Tabrizi *et al.* 2010; Karavitis *et al.* 2011; Pai *et al.* 2011; Santos *et al.* 2011; Angelidis *et al.* 2012; Bonsal *et al.* 2013; Dogan *et al.* 2012; Zin *et al.* 2013). In the present context, monitoring of the start of drought, time span and severity has become prime factors for reducing post-drought impact. Based on the previous studies, the standardized precipitation index (SPI) is the most popular tool for monitoring meteorological drought which is mainly based on precipitation data only. Based on SPI scale, Mckee *et al.* (1993) have classified the drought at different scales ranging from near normal ( $-0.99$ ) to extreme drought condition ( $<-2.0$ ). Several studies suggested its utility to assess meteorological drought at different time scales (Guttman 1998; Patel *et al.* 2007; Kumar *et al.* 2009, 2012; Quiring and Ganesh 2010; Poonia and Rao 2012; Dutta *et al.* 2013; Zhang and Jia 2013; Belayneh *et al.* 2014). The various advantage of SPI over different drought indices like China Z Index (CZI), Z-score Index, modified CZI, percent of normal and effective drought index because of its simplicity, temporally flexible, identification of emerging drought months sooner have proved by various researcher across the globe (Guttman 1998; Hayes *et al.* 1999, 2000; Szalai and Szinell 2000; Morid *et al.* 2006; Patel *et al.* 2007; Pandey *et al.* 2008; Jain *et al.* 2009; Mishra and Singh 2009; Edossa *et al.* 2010; Roudier and Mahe 2010; Zhai *et al.* 2010; Karavitis *et al.* 2011; Dutta *et al.* 2013; Srivastava *et al.* 2017, 2018). However, the applicability and accuracy parameter of drought indices may vary

spatially (Jain *et al.* 2015). Edwards (1997) found that due to wide applicability in different climate condition, SPI is popularly adopted in India.

The advantage of SPI over drought indices is that it requires only precipitation as input and at different temporal scales. It is less complicated, flexible and considered as universal drought index by World Meteorological Organisation (WMO). It can provide early warning and can be used to assess the severity of drought. It can be calculated with missing data in the input.

Hence, this has been employed in the present study for drought identification in the mid and high hilly region of Uttarakhand. Along with SPI (1, 3 and 6 months), percentage of departure and percent of normal indices have been used to evaluate the result and hence to assess the applicability of SPI in the hilly region of Uttarakhand.

## 2. Study area

Uttarakhand is the 27th state in India lies between  $28^{\circ}44'-31^{\circ}28'N$  latitude and  $77^{\circ}35'-81^{\circ}01'E$  longitude covering an area of  $53,483\text{ km}^2$ . The terrain and topography of the state is mostly hilly with a large area under snow cover and steep slopes. Two districts of Uttarakhand state, India under Kumaon region, namely, Almora and Nainital were selected (figure 1) for the present study. The total geographical area of Almora district is  $3083\text{ km}^2$  and that of Nainital district is  $3860\text{ km}^2$ . As of 2011 census, the population of Almora district is 621,972 with population density 202 persons per  $\text{km}^2$  and that of Nainital district is 955,128 with population density 247 persons per  $\text{km}^2$ . The climate of Almora is humid subtropical and that of Nainital is subtropical highland according to Köppen climate classification. The normal annual precipitation of the state is 1500 mm. The important crops harvested in both the districts are finger millet, rice, black soyabean, barnyard millet, horse gram (Kharif), wheat, barley and lentil (Rabi). Finger millet, rice, wheat and lentil are the major crops harvested in the study area.

## 3. Data collection

Observed monthly precipitation data for 40 years (1980–2019) were acquired from India Meteorological Department (IMD, Dehradun) and ICAR-VPKAS, Almora (table 1). The monthly observed precipitations were arranged to seasonal, viz.,

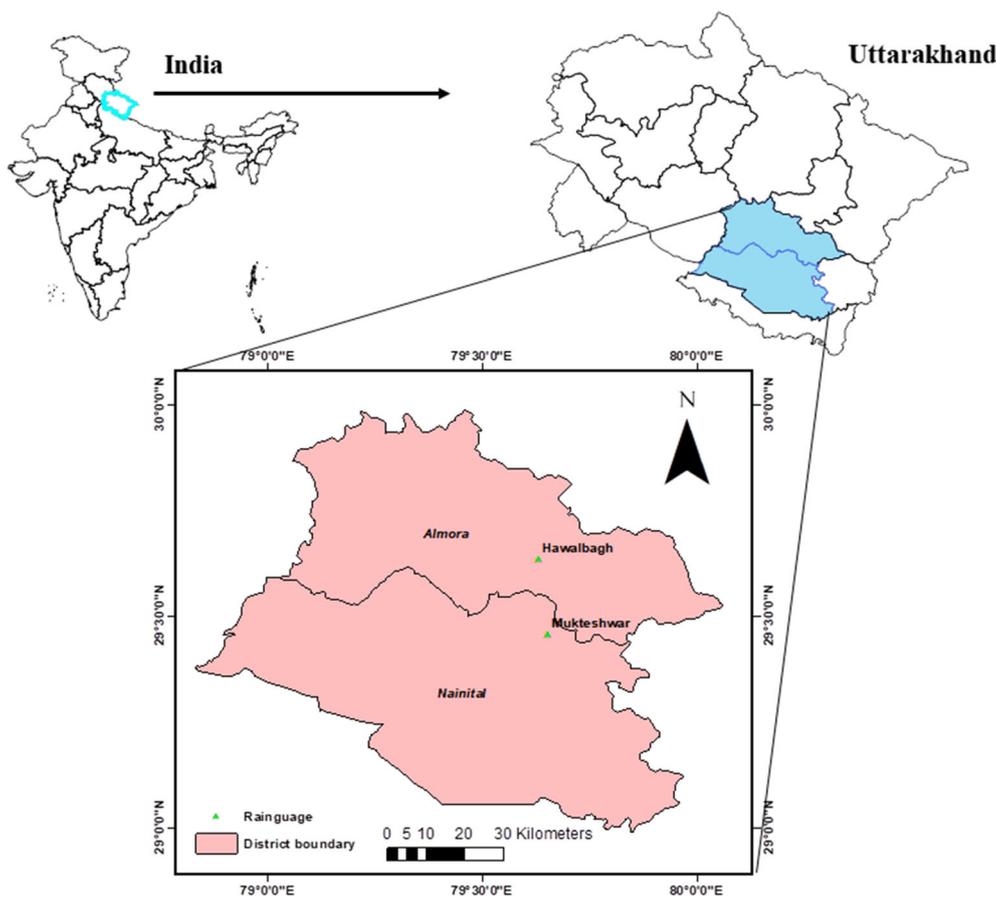


Figure 1. Location of the study area and rainguage.

Table 1. Data used to estimate SPI and percentage of departure.

Station	Location		Period	Elevation (m)
	Latitude	Longitude		
Hawalbagh (ICAR-VPKAS)	29°37'11.4"N	79°37'48.1"E	1980–2019	1250
Mukteshwar (IMD)	29°27'25.4"N	79°39'16.2"E	1980–2019	2286

pre-monsoon (MAM), monsoon (JJAS), post-monsoon (ON), and winter (DJF) according to the classification of Basistha *et al.* (2009) and Singh and Mal (2014). The descriptive statistics of seasonal and annual precipitation (1980–2019) for both the surface observatory are shown in table 2 (Hawalbagh, Almora) and table 3 (Mukteshwar, Nainital). The average annual precipitation observed in the highest elevation surface observatory (Mukteshwar) was more than the Hawalbagh which is located at lower elevation. In addition to this, we have used SPEIbase, which offers long-time, robust information about drought conditions at the global scale, with a 0.5° spatial resolution and a monthly time resolution. It has a multi-scale character, providing SPEI time-scales between 1

and 48 months. Currently, it covers the period between January 1901 and December 2018. The SPEIbase is based on monthly precipitation and potential evapotranspiration.

#### 4. Methodology

##### 4.1 Estimation of standardized precipitation index

SPI is defined as the precipitation values as a standard deviation with respect to precipitation probability function. It is based on precipitation value alone and identified as potential drought index in the recent years. It is calculated in

Table 2. Seasonal and annual rainfall statistics at Hawalbagh, Almora.

Parameter	MAM	JJAS	ON	DJF	Annual
Mean	145.6	691.91	31.69	119.41	988.61
Standard deviation	75.27	159.26	42.65	63	207.49
Minimum	29	424.2	39.25	13	667.9
Maximum	369.5	1156.5	210.4	261.1	1415.1
Coefficient of variation	0.52	0.23	1.35	0.53	0.21

Table 3. Seasonal and annual rainfall statistics at Mukteshwar, Nainital.

Parameter	MAM	JJAS	ON	DJF	Annual
Mean	157.19	947.51	44.2	127.89	1276.79
Standard deviation	70.98	274.46	65.57	73.54	291.49
Minimum	50.4	570.2	0	23	718.3
Maximum	335.4	1816.7	308.3	306.6	2070.8
Coefficient of variation	0.45	0.29	1.48	0.58	0.23

Table 4. Classification of drought based on SPI (McKee et al. 1993).

SPI range	Classification
Greater than 2	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to 0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 to less	Extremely dry

different time scales (SPI 1, SPI 2, SPI 3, SPI 6, SPI 9, SPI 12, SPI 24, SPI 48 months). In the present study, 1-, 3- and 6-month time scale of SPI for the period 1980–2019 of monthly precipitation is used to identify the drought for both the stations. We have adopted the drought classes proposed by McKee et al. (1993) (table 4). The computation of SPI involves fitting a gamma probability density function (PDF) to a given frequency distribution of total precipitation of a station. The gamma distribution is defined by its PDF as:

$$G(x) = \frac{1}{\beta^\alpha} \int_0^x x^{\alpha-1} e^{-\frac{x}{\beta}} dx, \quad (1)$$

where  $\alpha$  and  $\beta$  are defined as shape factor and scale factor, respectively. The value of both the parameters should be greater than zero.

#### 4.2 Estimation of percentage of departure ( $P_d$ )

The percentage of departure from normal is simple drought index defined as the actual precipitation as

percentage deviation from normal. It represents both drought and non-drought conditions (Jain et al. 2015). It was calculated using equation (2). The classification of drought based on  $P_d$  is given in table 2. This drought index can be estimated as:

$$P_d = \frac{(P_i - \bar{P})}{\bar{P}} \times 100, \quad (2)$$

where  $P_i$  is the actual precipitation in the present year and  $\bar{P}$  For calculation is average precipitation for the long-term precipitation.

#### 4.3 Estimation of percent of normal

It is an easy and simple drought index which represents the deficiency of precipitation from wet season to dry season or vice versa as precipitation fluctuates from the normal annual precipitation. It is the most common drought monitoring tool which is widely used by news reporters and common people (Morid et al. 2006). For calculation of percent of normal, at least 30 years mean past precipitation data are used, but for more accuracy 40-year (1980–2019) monthly precipitation data are used in the present study. It can be computed at different time scales such as daily, weekly, monthly, seasonal and annually based on user needs. Because of its simplicity and easy calculation, it is favourable to communicate drought levels to the society (Keyantash and Dracup 2002). There is no specific boundary condition to classify drought levels for this index. A lower value of percent of normal less than 100% indicates drought condition. It is obtained using equation (3).

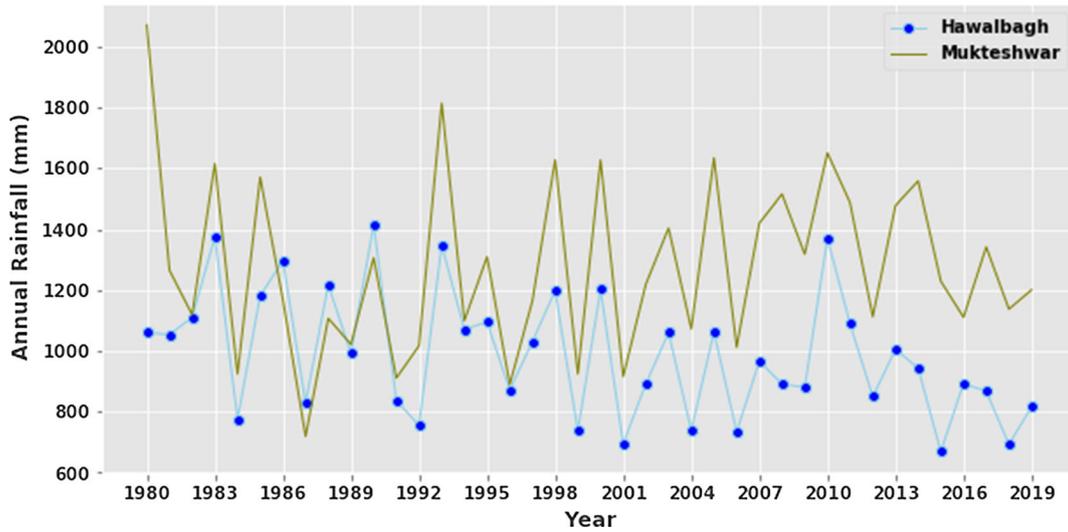


Figure 2. Annual rainfall variation at Hawalbagh and Mukteshwar.

$$P_{ni} = \frac{P}{P_{30}} \times 100, \quad (3)$$

where  $P_{ni}$  is the percent of normal index,  $P$  is the annual precipitation and  $P_{30}$  is the average annual precipitation for the past 30 years.

## 5. Results and discussion

### 5.1 Precipitation variation at the study area

The long-term (1980–2019) monthly precipitation variation of two stations located in the study area is shown in figure 2. The normal annual precipitation for Hawalbagh (Almora) and Mukteshwar (Nainital) based on long-term precipitation data is 988 and 1276 mm, respectively. Both the surface observatories experienced decreasing precipitation trend having  $Z$  value  $-2.82$  and  $-1.56$  for Hawalbagh and Mukteshwar, respectively. The profile of precipitation with respect to elevation was generated using precipitation data from three stations. The precipitation profile was found to be linear with elevation as shown in figure 3.

### 5.2 SPI value

The SPI 1-, 3- and 6-monthly value is computed for the location as shown in figures 4 and 5 for years 1980–2019 for both the stations. The SPI-1 values for the study location are shown in figures 4 and 5 for the years 1980–2019. From figure 4, based on SPI values criteria it can be inferred that 12 years

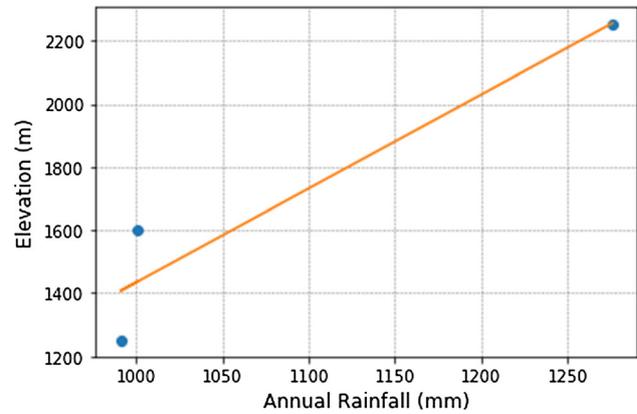


Figure 3. Precipitation profile vs. elevation in the study area.

can be characterized as drought years in the monsoon season (July–September) and the remaining years can be identified as non-drought years in the monsoon season. Because of 1-month time scale of SPI, the years which are identified as drought years can be designated as agricultural drought years. The 1-month SPI reflected short-term conditions, its application can be related closely to meteorological types of drought along with short-term soil moisture and crop stress, especially during the growing season. According to standardized precipitation index user guide of World Meteorological Organisation (WMO), one may want to look at a 1- or 2-month SPI for meteorological drought, anywhere from 1-month to 6-month SPI for agricultural drought, and something like 6-month up to 24-month SPI or more for hydrological drought analyses and applications. For Mukteshwar station, from figure 4 it can be inferred that 11 years can be characterized as drought years and the

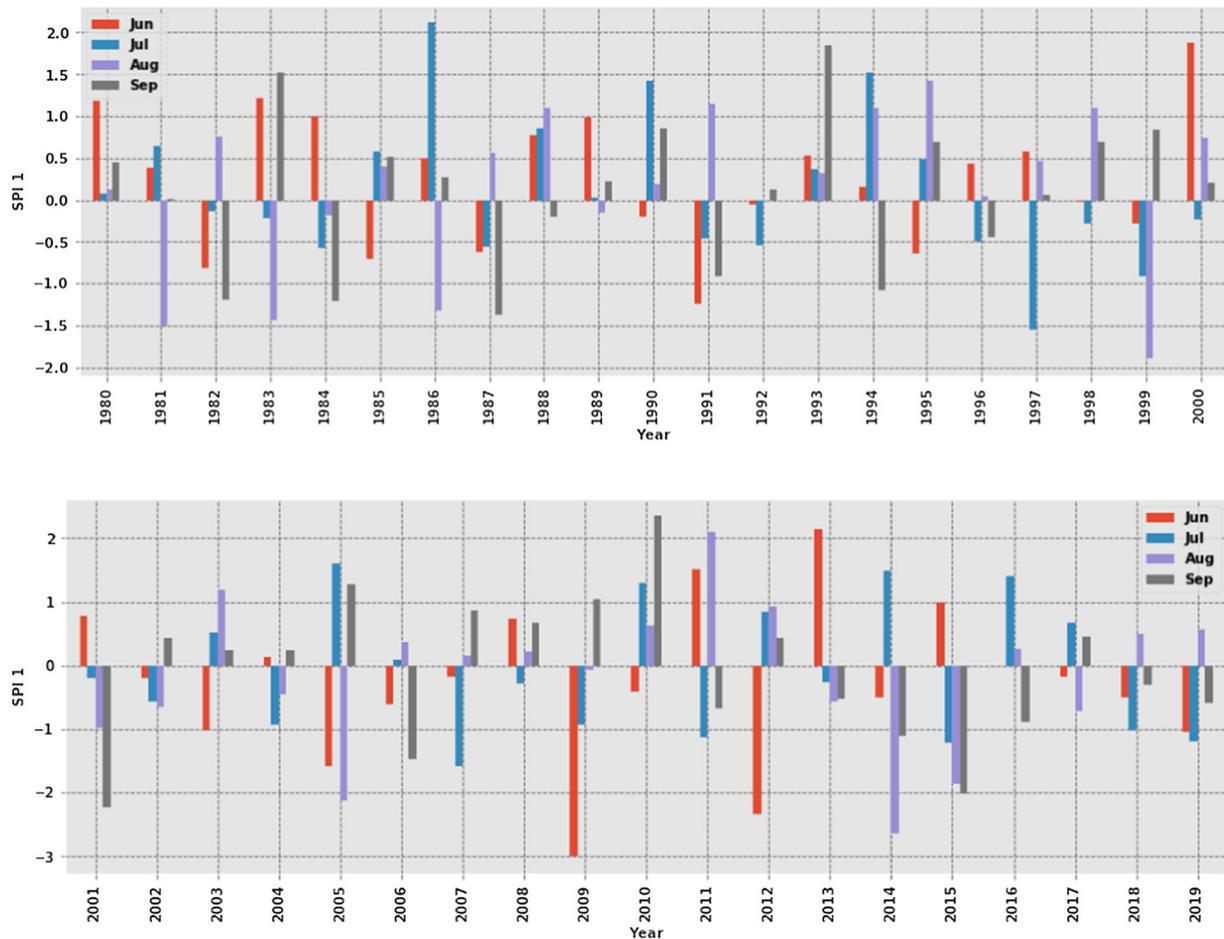


Figure 4. Time series of SPI plot for Hawalbagh.

remaining were identified as non-drought years. Monthly SPI may be resembled to conditions represented by the crop moisture index. Result of this study is found in accordance with Kumar *et al.* (2017) who has noted that 1987, 1991 and 2001 as drought years for Uttarakhand. It is noteworthy that the years 1987, 2002, 2009, 2014 and 2015 are major drought years in the context of India. The results of the present study were in accordance with the findings of previous study conducted (Sahu *et al.* 2018; Kamble *et al.* 2019). Kamble *et al.* (2019) demonstrated the capability of linear regression to identify drought using the relationship between SPI and the vegetation condition index.

Drought is classified based on the condition given in table 5, on the basis of percentage of departure value. Since in recent years drought frequency is increasing, therefore in the present study we have taken decadal time scale to capture drought at finer time scale. Decadal frequency of drought for Hawalbagh and Mukteshwar is shown in tables 6 and 7, respectively.

The result of percentage of departure (figure 6, Hawalbagh) showed that 20 years are agricultural drought years, while the rest years are non-drought years. Mukteshwar (figure 7) showed that 22 years are agricultural drought years, while the remaining years are non-drought years. The same result is conveyed by percent of normal index analysis (figure 8, Hawalbagh) and (figure 9, Mukteshwar).

## 6. SPI vs. percentage of departure

In order to compare the validity of different SPI time scale (1-, 3- and 6-month), the  $P_d$  of July and August was compared with same month of different SPI time scale.  $P_d$  includes both positive (present precipitation is greater than normal) and negative (present precipitation is less than normal) values. July and August are vital from a rainfed agriculture point of view. July is important for sowing different crops, August is critical for crop growth. The occurrence of precipitation in these two months is important for an agricultural

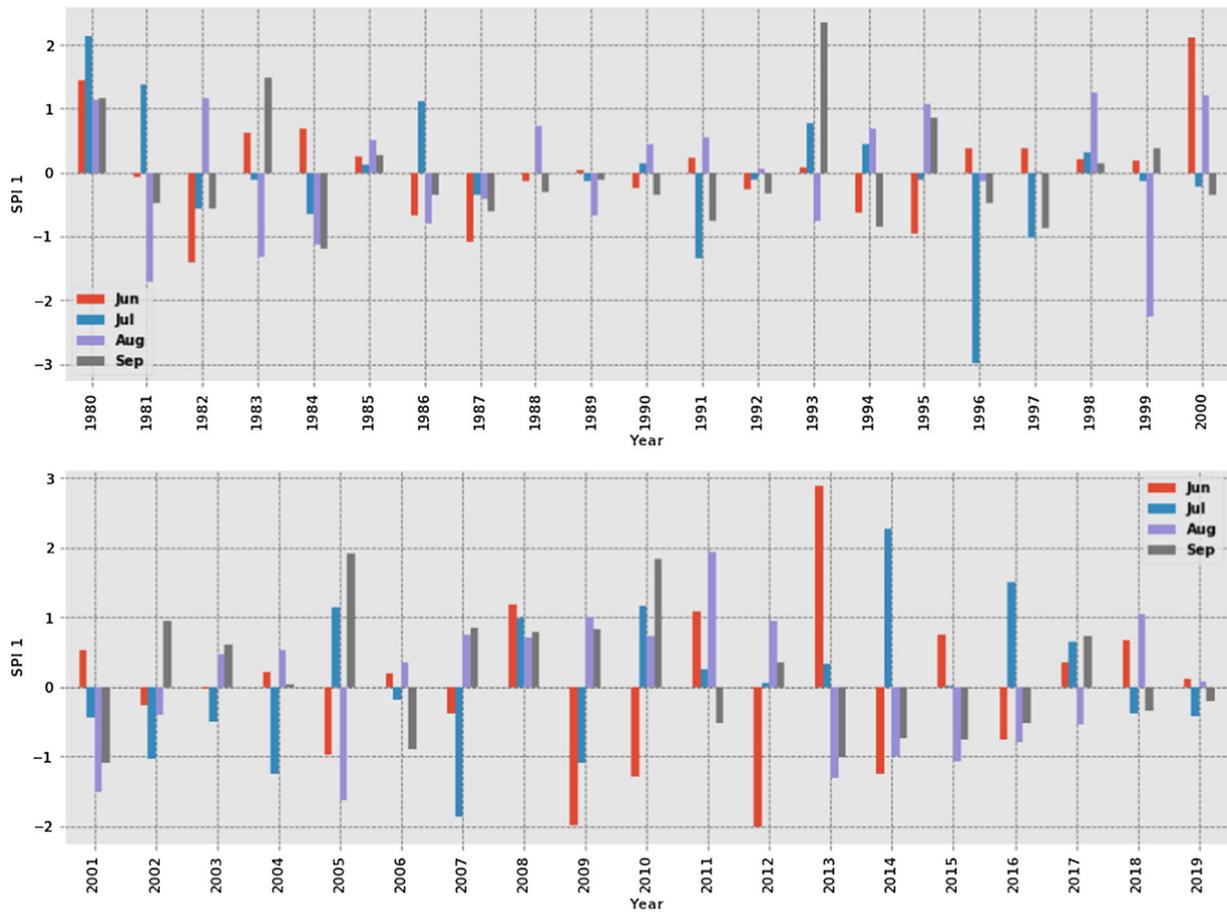


Figure 5. Time series of SPI plot for Mukteshwar.

Table 5. Classification of drought based on percentage of departure (Meshram et al. 2014).

Percentage of departure	Classification
$\geq 0$	No drought
0 to -25	Mild drought
-26 to -50	Moderate drought
$\leq -50$	Severe drought

drought. Pearson’s correlation analysis indicated that monthly percentage of departure was strongly correlated with 1-month time scale for both July and August (table 8). The comparison of different time scales, 1-, 3- and 6-month SPI for July and August with corresponding monthly percentage of departure for both the stations were carried out using scatter plots (figures 10 and 11). The range of monthly percentage of departure and SPI was found to be more for Hawalbagh than Mukteshwar as depicted from the scatter plot. The SPI values were 0 and below for monthly percentage of departure less than 150% (Hawalbagh, figure 10),

whereas the SPI values were 0 and below for monthly percentage of departure less than 150% (Mukteshwar, figure 11). The performance of SPI 1 was found to be better as compared to longer time scale, 3- and 6- month for identifying agricultural drought in the hilly region of Uttarakhand.

### 7. SPI of drought and normal year

The intensity of drought is observed from the statistics published by Government of India which shows that the yield of rice Kharif in 2002–2003 was 0.67 tonnes/hectare and 1.03 tonnes/hectare in Kharif 2010–2011 (Almora). The value of SPI 1 in the drought year 2015 varies from -1.5 to 0 in most of the months. For Hawalbagh, SPI was lowest at -2 in the month of September, around -1.75 in August and -1.25 in July (figure 12). For Mukteshwar, SPI was lowest at -1 in the month of August, around -0.65 in September and 0.02 in the month of July (figure 12). The SPI variation for normal year is shown in figure 13.

Table 6. Decadal variability of drought events at Hawalbagh, Almora.

Decade	No drought	Mild drought	Moderate drought	Severe drought
1980–1989	8	2	0	0
1990–1999	6	4	0	0
2000–2009	3	4	3	0
2010–2019	3	5	2	0

Table 7. Decadal variability of drought events at Mukteshwar, Nainital.

Decade	No drought	Mild drought	Moderate drought	Severe drought
1980–1989	3	5	2	0
1990–1999	4	3	3	0
2000–2009	6	3	1	0
2010–2019	5	5	0	0

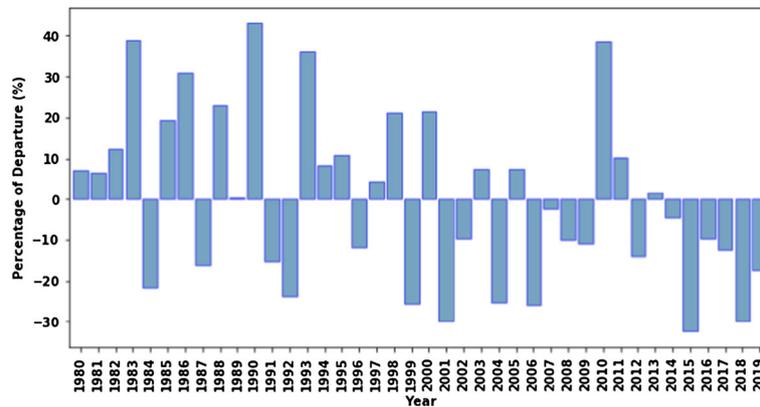


Figure 6. Identification of wet and dry years at Hawalbagh, Almora.

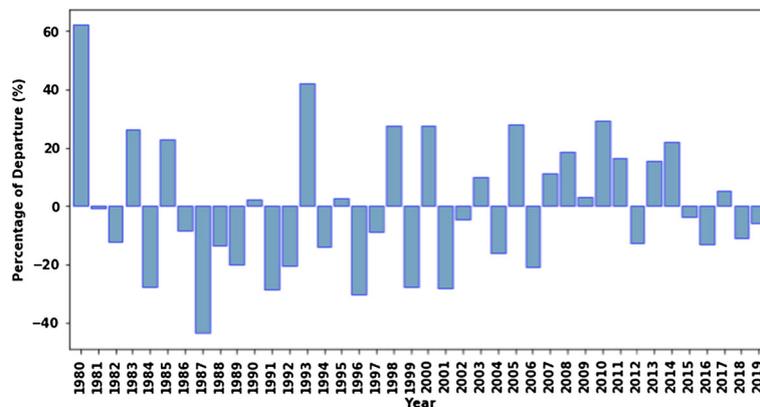


Figure 7. Occurrence of wet and dry years at Mukteshwar, Nainital.

## 8. SPEI of drought and normal year and SPEI vs. SPI

The satellite SPEI for drought year 2015 and normal year 2010 during monsoon period (JJAS) is presented in figures 12 and 13, respectively. As

the spatial resolution of global SPEI database is 0.5 degree, we have taken a point (29.25,79.25) nearest to both of our districts as the representative of SPEI of the place. SPEI in drought year 2015 decreases from 1 in June to  $-1$  in September approximately. However, SPEI shows

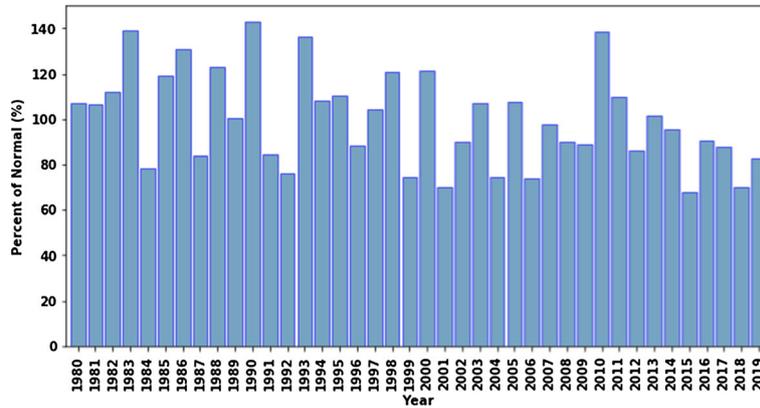


Figure 8. Identification of drought and non-drought years using percent of normal at Hawalbagh.

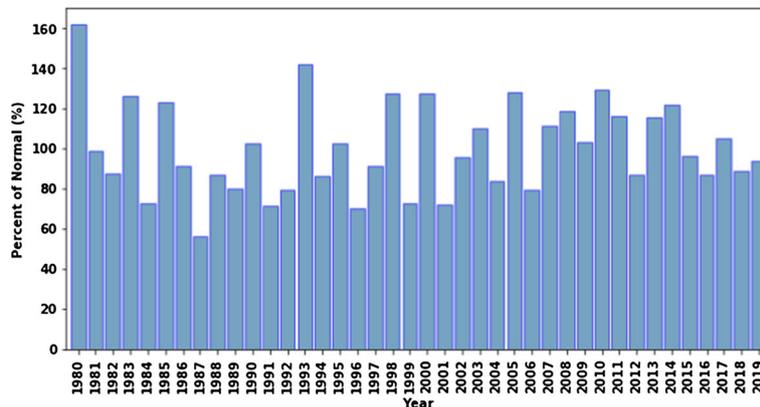


Figure 9. Identification of drought and non-drought years using percent of normal at Mukteshwar.

Table 8. The Pearson’s correlation analysis between percentage of departure and SPI.

Station	$P_d$ vs. SPI	July (1980–2019)		August (1980–2019)	
		Pearson’s $r$	$p$ -value	Pearson’s $r$	$p$ -value
Hawalbagh	SPI-1	0.98	<0.01	0.98	<0.01
	SPI-3	0.32	0.04	0.25	0.11
	SPI-6	0.59	<0.01	0.39	0.01
Mukteshwar	SPI-1	0.96	<0.01	0.98	<0.01
	SPI-3	0.77	<0.01	0.42	0.13
	SPI-6	0.65	<0.01	0.37	0.01

continuous increasing trend during normal year 2010 with  $-1.6$  in June to  $1.1$  in September approximately. Both SPI and SPEI show quite similar pattern, with a rising trend in 2010 and decreasing trend in 2015. It is evident from this that satellite SPEI can differentiate between the normal and drought year. We also computed the Pearson’s correlation analysis between SPEI and SPI to identify their relationship. We performed

the correlation analysis for different time scales 1-, 3- and 6- month SPEI for July and August with the corresponding time scale of SPI. All the correlation is positive (table 9) which reflects that both follows the similar pattern. Moreover, the performance of SPEI 6 was found to be more closely correlated with the corresponding month SPI as compared to other time scales, 1- and 3-months.

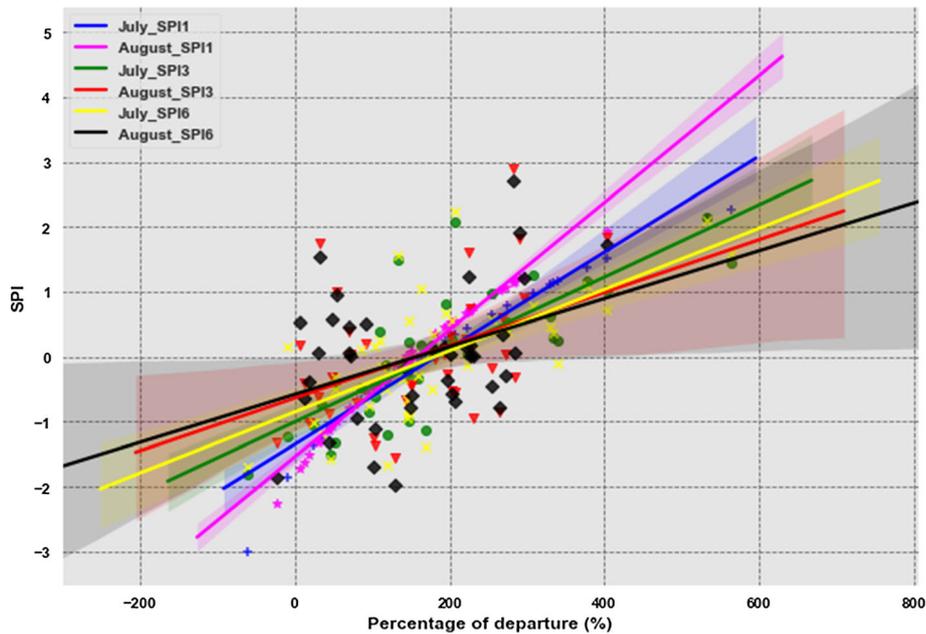


Figure 10. Monthly percentage of departure *vs.* SPI (1, 3, 6) for July and August at Hawalbagh, Almora.

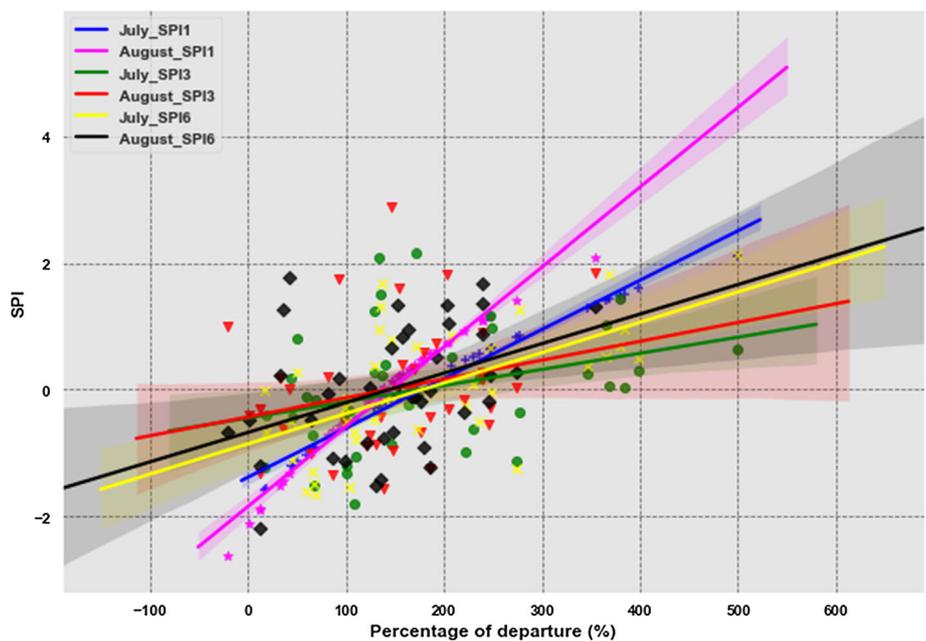


Figure 11. Monthly percentage of departure *vs.* SPI (1, 3, 6) for July and August at Mukteshwar, Nainital.

## 9. Conclusion

In the study, after calculating the SPI at 1-, 3-, 6-month timescales at two meteorological stations in Kumaon region of Uttarakhand from 1980 to 2019, we compared and analyzed the performance of the SPI with respect to percent of departure and percent of normal in drought monitoring for

different time scales. The present study was aimed to utilize meteorological data along with climatic variables for drought identification using three different drought indices. Out of various indices available for identification of drought, the standardized precipitation index, percentage of departure and percent of normal can be used as a guiding tool for drought management. The rainwater

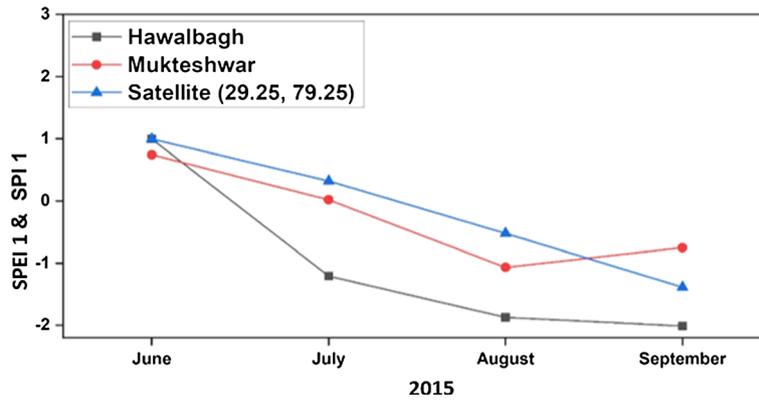


Figure 12. Variation of SPI 1 and SPEI 1 for drought year (2015) for June to October.

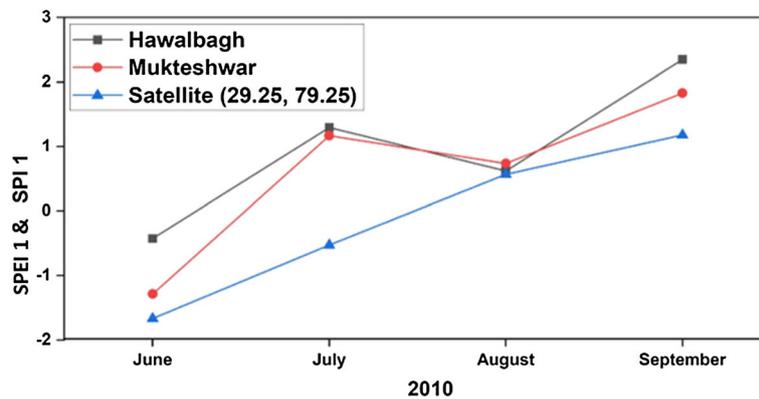


Figure 13. Variation of SPI 1 and SPEI 1 for non-drought year (2010) for June to October.

Table 9. The Pearson’s correlation analysis between SPEI and SPI.

Station	SPEI vs. SPI	July (1980–2019)		August (1980–2019)	
		Pearson’s <i>r</i>	<i>p</i> -value	Pearson’s <i>r</i>	<i>p</i> -value
Hawalbagh	SPI-1	0.49	<0.001	0.61	<0.0001
	SPI-3	0.57	0.0001	0.57	0.0001
	SPI-6	0.59	0.0001	0.67	<0.0001
Mukteshwar	SPI-1	0.49	<0.001	0.59	<0.0001
	SPI-3	0.57	0.0001	0.57	0.0001
	SPI-6	0.62	<0.0001	0.55	0.0002

harvesting technique during monsoon season should be implemented for combating drought situation. Further, this study can be used to identify present and future drought years. Furthermore, spatial and temporal variation of precipitation in Himalayan region is responsible for frequent drought spells. The limitation of the present study is that we have tried to use three drought indices with limited data availability in the hilly region. Therefore, In future, research work should be undertaken with integrated approach with robust datasets.

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### Author statement

UK did the modelling exercise with the help of SS, and prepared the manuscript with contributions

from all the co-authors. UK along with SS performed the research, literature survey, result interpretation, and manuscript revision during peer-review process. UK and SS conceptualized and supervised the entire research and arranged the necessary data and resources. JKB and LK reviewed the first draft and provided inputs for improvement.

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