

# Chapter 5

## Meteorological Drought Assessment in the Bharathapuzha River Basin



M. A. Jincy Rose and N. R. Chithra

**Abstract** Drought is a creeping yet devastating phenomenon that affects nearly half of the population on the earth. Bharathapuzha river, the largest and second-longest of the rivers in Kerala, which was once a perennial river is now on the verge of its death. The river basin faces acute water shortage especially in the summer months of the year. The paper examines and explains the meteorological drought occurrence in the river basin with the help of a highly recommended indicator for drought, the SPI, and a simple and well-renowned rainfall trend detection technique, the non-parametric Mann–Kendall test, and Sen’s slope method for its magnitude. This study also forecasts the temporal drought behaviour in the catchment for RCP 4.5 and RCP 8.5 future climate change scenarios using the simulated precipitation data of CORDEX. Gridded daily precipitation data of IMD (Indian meteorological department) of 0.5-degree resolution was used to study the drought pattern of the river basin in the period of 1971–2005. This historical record analysis was performed to understand the variations in drought events during each of the timescales such as 1 month, 3 months, 6 months, 9 months and 12 months denoted as SPI-1, SPI-3, SPI-6, SPI-9 and SPI-12, respectively. The results indicate the presence of meteorological drought in the historic period as well as in the future scenarios. The Mann–Kendall trend test was done for rainfall over a period of 35 years and could find that the Mann–Kendall statistic  $S$  gives a decreasing trend with time. Sen’s slope gives a decrease in the magnitude of 14.3 mm/year. Thus, the results of the Mann–Kendall trend tests also support the statement of drought in the catchment. The analysis of RCP scenarios also indicates the presence of drought in the river basin with moderate to extreme drought where the frequency of the drought condition increases in the river basin up to 2039 and beyond which it reduces.

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M. A. J. Rose (✉) · N. R. Chithra  
Department of Civil Engineering, National Institute of Technology, Calicut, Kozhikode 673601,  
India  
e-mail: [jincyrose\\_p170004ce@nitc.ac.in](mailto:jincyrose_p170004ce@nitc.ac.in)

## 5.1 Introduction

Drought is a grievous natural phenomenon that is least understood and complex in nature that affects more lives than any other natural hazard. This obviously has paved the way for more researches to define drought (Sheffield and Wood 2012; Mishra and Singh 2010; Tallaksen and Van Lanen 2004; Wilhite 2000; Wilhite and Glantz 1985). Most of the studies are extended in concern with the global scenarios where a regional approach is least prioritized and almost neglected. On a regional scale, drought is reflected in terms of reduction in rainfall, low flow in streams and rivers, declining groundwater levels, wilting of crops and collapsed economy leading to a disturbed societal status. Thus, drought is broadly classified into four, upon the variables involved in the analysis namely meteorological, hydrological, agricultural and socio-economic droughts (Tallaksen and Van Lanen 2004). Among these, hydrological drought analysis can be said to be a little complicated as it involves both climate as well as catchment characteristics. According to Palmer (1965) and Beran and Rodier (1985), drought is stated to be a meteorological phenomenon. The study in the river basin, thus, leads to an investigation of the meteorological drought analysis with the perspective that it being the most fundamental requirement of any drought study. As it is a creeping phenomenon, timely analysis, planning and management would help reduce the severity of the condition to an extent.

Indian Meteorological Department (IMD) classifies drought upon the rainfall deviations which accounts for the total of the season's actual rainfall with respect to the mean of long-term rainfall. As per the IMD, a drought event is said to occur when the total rainfall of a place for a particular season is 75% less compared to the mean of its long-term rainfall. A severe drought is declared if there is a 25% decrease in a season's rainfall compared to its long-term mean (<http://imd.gov.in/section/nhac/wxfaq.pdf>). Though the drought declaring deviation criteria varies spatially, many of the studies follow the deviation of rainfall as the drought intensity indicator due to its easiness. Since this indicator is strongly dependent on its mean, and as the mean rainfall values differ spatially, the distribution of deviation in rainfall cannot be applied uniformly. The Standardized Precipitation Index (SPI), thus, overcomes this situation where a probability distribution function is fitted to the actual rainfall to get a standardized departure. The supremacy of using SPI is that only rainfall data is needed for its computation and can also be compared across regions of different climatic zones.

In the past couple of decades, it is observed to have great anomalies in the general rainfall of the Bharathapuzha region. The river basin is also reported to have a serious water shortfall leading to drought conditions in recent years (Raj and Azeez 2010). Recently, a few studies in the Bharathapuzha river basin have been reported in context with the trend analysis (Raj and Azeez 2012; Jagadeesh and Anupama 2014; Varughese et al. 2017), temperature rise (Raj and Azeez 2010), decision-making process for managing environmental flows (Padikkal and Rema 2013), morphometric analysis using geographical information system environment (Magesh et al. 2013; Raj and Azeez 2012) and land use land cover changes (Raj

and Azeez 2010). As no study on the investigation of drought has been reported in the Bharathapuzha river basin, this paper investigates the occurrence of the meteorological drought assessment of the river basin with the Standardized Precipitation Index (SPI) recommended by the World Meteorological Organization (WMO) due to its spatial consistency. A simple rainfall trend analysis over the catchment uses the non-parametric Mann–Kendall test for trend detection and Sen’s slope method for its magnitude. The study also forecasts the temporal drought behaviour using simulated precipitation data of CORDEX (Coordinated downscaling regional experiment), for RCP 4.5 and RCP 8.5, the two different future climate scenarios.

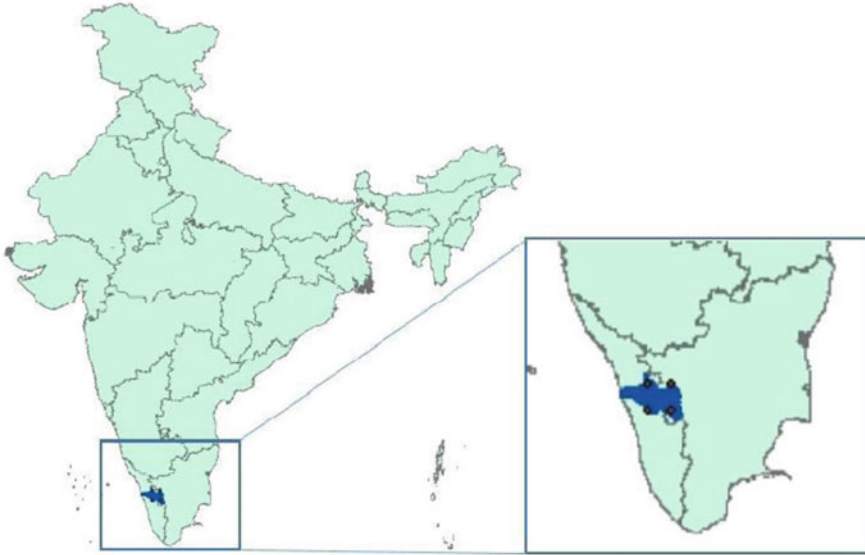
## 5.2 Study Area and Data

### 5.2.1 Study Area

Bharathapuzha is the largest and second-longest of the 44 rivers in Kerala located at  $10^{\circ}25'N$  to  $11^{\circ}15'N$  and  $75^{\circ}50'E$  to  $76^{\circ}55'E$ . It is one among the four medium-sized rivers in Kerala which is 209 km long with a watershed of 6,186 km<sup>2</sup> in which 4400 km<sup>2</sup>, the majority area, falls within the state Kerala and the rest of the portion in Tamil Nadu. It was once a perennial river that originates in the Anamalai hills of Tamil Nadu and debouches into the Arabian Sea at Ponnani in Kerala. The basin receives about an average annual rainfall of 2060 mm. Seven reservoirs were constructed in this river by Kerala Government and four reservoirs by Tamil Nadu Government. Bharathapuzha river basin is having a unique physiographic feature. This region is divided into three prominent physiographic zones; high land with an altitude greater than 76 m, midland with an altitude ranging between 7.6 and 76 m and lowland where the altitude is less than 7.6 m. The river serves as a lifeline to three administrative districts in Kerala and two in Tamil Nadu and also supports the agricultural production system of the Kerala state, especially “the rice bowl of Kerala” in Palakkad. Thus, the river has a pivotal role in the societal, economic and agricultural aspects of the state. The location map of the study area is shown in Fig. 5.1.

### 5.2.2 Data Collection and Pre-processing

$0.5 \times 0.5$ -degree gridded daily precipitation data from the Indian meteorological department for the period of 1971–2005 (35 years) is used for the study. To forecast the SPI index, the freely downloadable ([http://cccr.tropmet.res.in/home/ftp\\_data.jsp](http://cccr.tropmet.res.in/home/ftp_data.jsp)) simulated precipitation data of CORDEX (Coordinated downscaling regional experiment), for two different future climate scenarios (RCP 4.5 and RCP 8.5) for a period of 2006–2099 (94 years), was used. The RCM used is the Conformal-Cubic



**Fig. 5.1** The study area location

Atmospheric Model (CCAM; McGregor and Dix 2001) by Commonwealth Scientific and Industrial Research Organization (CSIRO), and the driving GCMs used are ACCESS1.0 and CCSM4. A Linear Scaling (LS) bias correction was also applied for the data before the drought index calculation.

### 5.3 Methodology

Out of the several indices available, Standardized Precipitation Index (SPI) is the most recommended by the World Meteorological Organization (WMO) and widely accepted and used index, it requires only monthly or daily precipitation data, it can be compared across regions making it consistent in different climates, SPI determines the oddity of a current drought by the standardization of the index, it can be obtained for various time scales ranging from 1 to 48 months in general and hence was used to assess the meteorological drought of the area. The following is the outline of the works done for the drought assessment. (1) Delineation of the river basin in ArcGIS using ASTER Dem, which helps find the location of the grids chosen. (2) Extraction of the rainfall data from IMD (Indian Meteorological Department) for 35 years (1971–2005). (3) Trend detection using the Mann–Kendall test and its magnitude using Sen’s slope method. (4) SPI index calculation for time scales SPI-1, SPI-3, SPI-6, SPI-9 and SPI-12 with the aid of SPI\_SL\_6.exe calculator of the National Drought Mitigation Centre (NDMC), University of Nebraska. (5) Forecasted the

temporal drought behaviour using the simulated precipitation data from CORDEX for RCP 4.5 and RCP 8.5, the future climate scenarios chosen.

### 5.3.1 Delineation of the River Basin

Watershed delineation is done to demarcate the boundary of the area that contributes to the outlet of a river. The river basin was delineated with the help of ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) DEM (Digital Elevation Model) obtained from USGS Earth Explorer (<http://earthexplorer.usgs.gov>) that was freely downloadable. The ASTER DEM helps analyse the changes in the global environment such as warming, mineral research, desertification, acid rain and destruction of the ozone layer. The DEM also aids the geological research and natural resource exploitation and performs mission operations which reflect user requests regarding the data acquisition of the ASTER sensor. The ArcGIS 10.2.1 is aided with the delineation of the river basin. Four grid points of  $0.5 \times 0.5$ -degree resolution are selected on the catchment. The latitude and longitude of each grid chosen are  $(10.5^\circ, 76.5^\circ)$ ;  $(11^\circ, 76.5^\circ)$ ;  $(10.5^\circ, 77^\circ)$  and  $(11^\circ, 77^\circ)$ . The location of the grids on the map is given in Fig. 5.2.

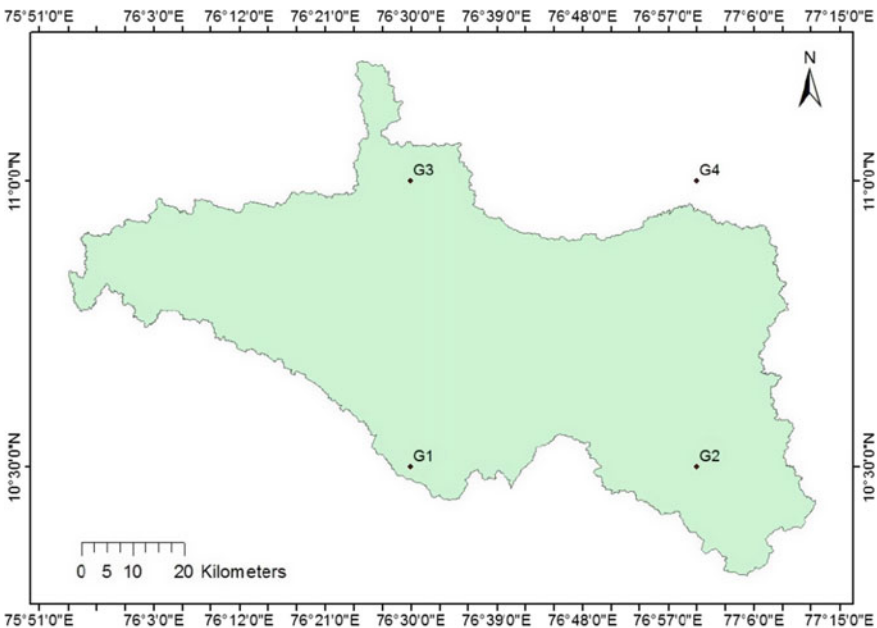


Fig. 5.2 Location of selected grid points

### 5.3.2 Trend Analysis

The rank-based Mann–Kendall test is a non-parametric test recently well used by the research community in order to detect trends in rainfall data (Mann 1945; Kendall 1975; de la Casa and Nasello 2010; Krishnakumar et al. 2009). The test statistic  $S$  is defined as follows:

$$S = \sum_{l=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i) \quad (5.1)$$

The data set length is indicated using  $n$ , and  $x_j$  denotes values of the sequential data.

$$\text{sgn}(y) = \begin{cases} 1 \dots \text{if}(y > 0) \\ 0 \dots \text{if}(y = 0) \\ -1 \dots \text{if}(y < 0) \end{cases} \quad (5.2)$$

When  $n \geq 8$ , the studies say that the test statistic  $S$  is approximately normally distributed with the mean  $E(S) = 0$  and variance as follows:

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^m t_i(t_i-1)(2t_i+5)}{18} \quad (5.3)$$

Here,  $m$  represents the number of tied groups and  $t_i$  is the size of the  $i$ th tied group. The standardized test statistic  $Z$  is computed by

$$\text{ZMK} = \begin{cases} \frac{S-1}{\sqrt{\text{var}(S)}} & \text{when } s > 0 \\ 0 & \text{when } s = 0 \\ \frac{S+1}{\sqrt{\text{var}(S)}} & \text{when } s < 0 \end{cases} \quad (5.4)$$

### 5.3.3 Standardized Precipitation Index for Drought Analysis

In the recent years, the Standardized Precipitation Index (SPI) has gained more prominence as an effective drought indicator highly recommended by the World Meteorological Organization (WMO) that can be compared spatially and temporally. This is because that the actual time series data of rainfall is first fitted to a probability distribution function to get a standardized departure that makes it spatially compatible. SPI calculation necessitates a long-term precipitation data that usually follows a gamma probability distribution function which is then converted into a normal distribution with its mean zero and standard deviations one. Edwards and McKee (1997) explained that the standard deviations with greater than median precipitation

imply a positive SPI value and less than median precipitation implies a negative SPI value. SPI can be computed for different time steps (1 month, 3 months, 6 months, 9 months, 12 months, 24 months, 48 months, etc.). These time steps denote the effect of deficit in precipitation upon various components in water resources namely soil moisture, streamflow, groundwater, etc. The severity of the drought event is decided upon the negative deviations. A severe drought event is said to occur with a higher magnitude. Thus, as the magnitude of negative deviation increases, the severity of drought is also said to increase. The onset of a drought event is indicated with the SPI value  $-1$  and the condition persists until the SPI values become positive again. Therefore, the severity of drought condition is explained within an SPI range where the condition is said to be moderately dry if the SPI value ranges between  $-1$  and  $-1.49$ , the condition is severely dry if the SPI falls between  $-1.5$  and  $-1.99$  and an SPI value less than  $-2.0$  being an extremely dry condition (McKee et al. 1993).

## 5.4 Results and Discussions

### 5.4.1 Trend Analysis

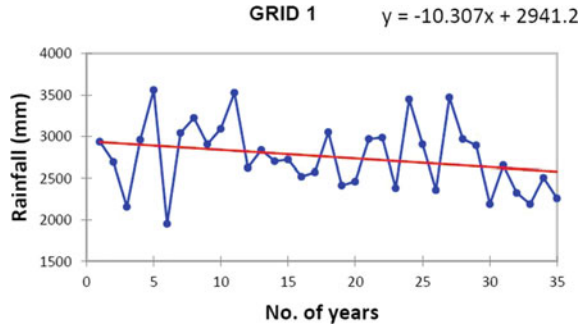
Trend analysis was done for the gridded rainfall data of IMD. The non-parametric Mann- Kendall test was done for the trend detection and Sen’s slope method for its magnitude. The Mann–Kendall test statistic  $S$  measures the trend in the data. The positive test statistic values indicate an increasing trend and negative values indicate a decrease in value over time. The magnitude of  $S$  will be commensurate with the strength of the trend (i.e., larger magnitudes indicate a stronger trend). Table 5.1 provides the information on the existence of a trend in the data. As the  $S$  value obtained for all the grids namely G1, G2, G3 and G4 are negative values, it can be stated that all the grids of the study area show a negative trend. A time series plot of grid 1 is shown in Fig. 5.3.

The defined threshold in the study is 5% with the null hypothesis that states there is no trend. As the trend is judged based on these thresholds, a trend was detected only for grids 1 and 4 at a 5% significance level. As there would be a trend in the data behind the selected threshold, the  $p$ -value calculated that is given in Table 5.1 explains

**Table 5.1** Results of the Mann–Kendall trend test and Sen’s slope estimator

Grid	Location		Mann–Kendall statistic ( $S$ )	$p$ -value (Two-tailed)	Sen’s slope value (mm/year)
	Latitude	Longitude			
G1	10.5	76.5	$-143.000$	0.044	$-14.905$
G2	10.5	77	$-107.000$	0.132	$-15.445$
G3	11	76.5	$-139.000$	0.280	$-16.45$
G4	11	77	$-77.000$	0.049	$-10.152$

Fig. 5.3 MK test for grid 1



the significance level that corresponds to the trend of the respective grids. Thus, grids 2 and 3 show a significant result at a threshold of 14, 29 and 6%, respectively. On an average, there is a decline in 14.3 mm of rainfall per year according to Sen's slope estimator.

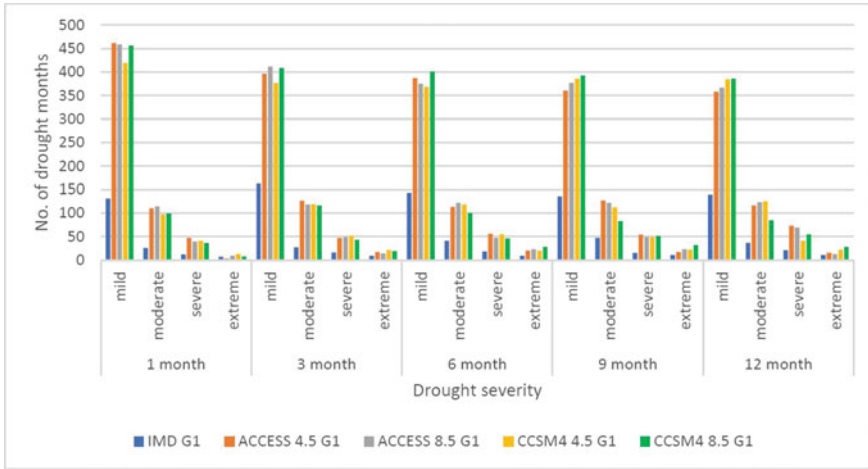
The grids G1 and G4 have a lower  $p$ -value which can reject the null hypothesis even for a larger  $\alpha$ -value. They would be statistically significant at both 95% as well as 90% level of confidence. Thereby, we can conclude both the grids are not only statistically significant but also practically significant. Though grids G2 and G3 are not statically significant and differ by a greater margin when compared to  $\alpha$ -value of 0.05 and 0.1, still the magnitude of the trend which is quantified by Sen's slope is not too high when compared to statistically significant grid G1 ( $-14.905$ ), whereas G2 and G3 have values  $-15.445$  and  $-16.45$ , respectively.

#### 5.4.2 Standardized Precipitation Index (SPI)

The various time steps considered in the analysis are 1 month, 3 months, 6 months, 9 months and 12 months. The SPI values at a time step of 1 month are an indication of the soil moisture for a shorter time span as well as the crop stress. The seasonal precipitation estimates are obtained with the SPI of 3 months that includes short-to medium-term moisture conditions. A visible trend in precipitation from seasonal to medium term could be obtained on a time scale of 6 months. The long-term precipitation patterns as well an indication of inter-seasonal precipitation patterns are well rendered at a duration of the medium time scale of the 9-month SPI. A significant impact of dryness over the agricultural as well as the other sectors are alarmed at an SPI value less than  $-1.5$  at these time scales. The groundwater levels, stream flows and reservoir levels are usually explained by a time scale of 12 months SPI because in the case of longer time scales, the SPI values drift towards the value zero if there is no remarkable wetness or dryness experienced in the area unlike the shorter time scales (Pramudya and Onishi 2018).

Figure 5.4 gives the number of drought months that had affected grid 1 of the study area as per the IMD historic data (1971–2005) and the projected future climate





**Fig. 5.4** Number of drought months for grid 1

scenarios for a time period of (2006–2099) using GCM ACCESS 1.0 and CCSM4 for RCP 4.5 and RCP 8.5. The bar chart also compares the severity condition namely mild drought where the SPI value is within ( $0 > SPI > -0.99$ ), moderate dry ( $-1 > SPI > -1.49$ ), severely dry ( $-1.5 > SPI > -1.99$ ) and extremely dry ( $SPI < -2.0$ ) (McKee et al. 1993). The results show that the drought conditions would persist in the future with an increase in the number of drought months under mild and moderate drought events whereas a decrease in the severe and extreme drought months could be observed with time.

Figure 5.5 depicts the SPI drought index for the 12-month time scale of grid 1 for both the observed IMD gridded rainfall data set as well as the projected future climate scenarios. The GCMs chosen along with the two RCP scenarios are represented graphically. From the analysis, it is found that there was a decreasing trend in the SPI values indicating the drought condition of the basin whereas a wet period in the long run increases or that there is a positive trend. It can also be inferred that the frequency of drought with a higher severity would occur in the basin up to 2039 and beyond which the severity reduces. Though severe drought conditions are experienced in near future as per the analysis, a reduction in the severe and extreme drought events could be observed with time. The standard deviation among the two GCMs adopted was also found to be minimal and, thus, it justifies the data sets chosen.

### 5.5 Summary and Conclusions

The study was done on a once perennial tropical medium river basin of Kerala, the Bharathapuzha river basin, which in the recent decades becomes barely a trickle immediately after the monsoon. The objective of the study was to account for the

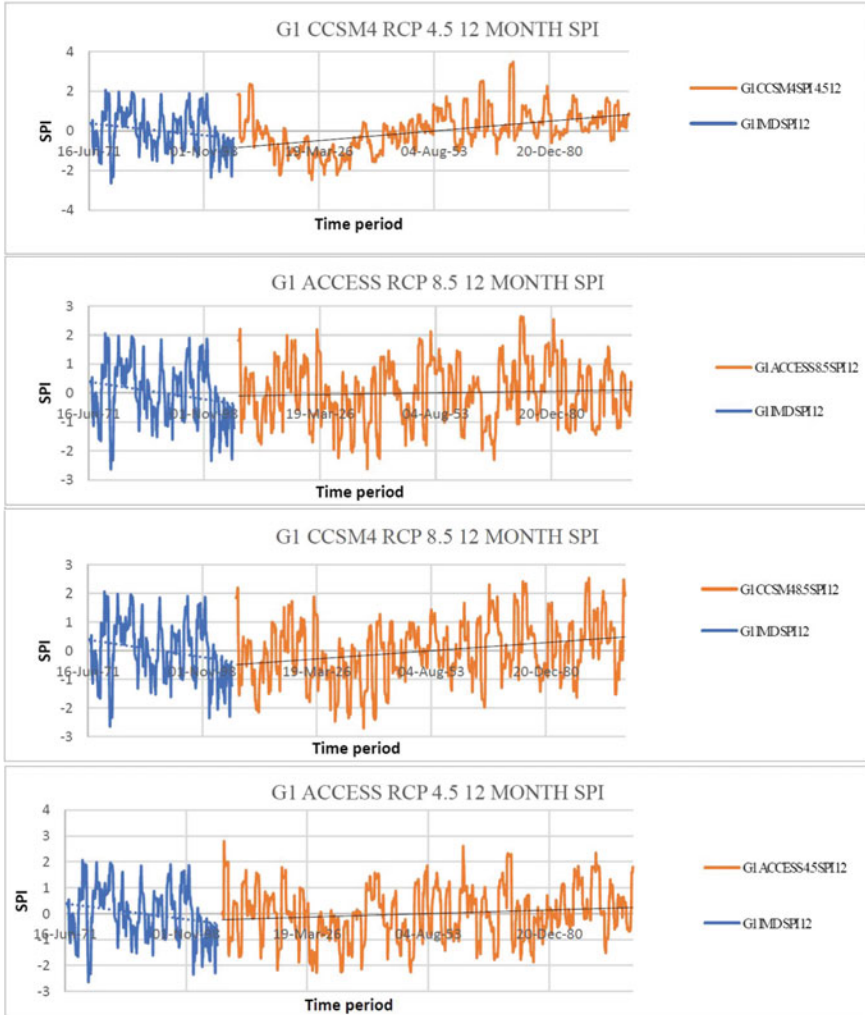


Fig. 5.5 AA12-month SPI for grid 1

presence of meteorological drought existence in the basin. An investigation on the observed IMD gridded rainfall data for 35 years reveals the drought existence that ranges from mild to extreme drought events for all the time scales (1, 3, 6, 9 and 12 months) where the decreasing trend of precipitation in the Mann-Kendall trend test along with Sen’s slope estimator also supports the drought condition experienced in the basin. The SPI values of the projected future climate scenario also explain that the river basin would experience a higher number of meteorological drought events in the future but with a reduction in the level of its severity. It was also noted that the severity of the drought condition as well the frequency of the drought events will be

more pronounced up to 2039 and beyond which a greater number of wetness periods are obtained.

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