Analysis of Historical Rainfall Data for Drought Investigation Using Standard Precipitation Index (SPI) Under Temperate Conditions of Srinagar Kashmir

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Abstract

Drought monitoring is of crucial importance for freshwater planning and management as well as for prediction of the onset and severity of droughts. In this study, temporal pattern of droughts was analyzed in the Shalimar area of Srinagar district of Jammu & Kashmir using SPI approach. Monthly precipitation data from 1985 to 2015 were used to compute Standardized Precipitation Index (SPI) values. The computation of SPI series was done for short as well as intermediate time scales. Analysis of SPI values were done to study the temporal patterns of drought occurrence. The drought severity and duration were also estimated. From the analysis, it was observed that in the years 1989, 1998, 2003 and 2008 moderate droughts occurred where as in the years 2000 and 2001 severe droughts occurred in the Shalimar area. Extreme drought occurred in the year 1999 when the SPI value was -2.243. Also, SPI in the severe and extreme drought years indicate only moderate dryness instead of extreme dryness.

Key Words: Standardized Precipitation Index, Temperate Region, Drought Monitoring

Introduction

Extreme meteorological events such as heat waves, cold waves, droughts, floods etc. have affected this earth since the dawn of time. Extreme weather events are a potential consequence of climate change, and are becoming more frequent, powerful and unpredictable. Minor changes in the averages of many key climate variables can correspond to large changes in weather. Substantial changes in the frequency and intensity of extreme events can result from relatively small fluctuations in the average of a distribution of precipitation, temperatures or other climate variables. According to the Intergovernmental Panel on Climate Change (IPCC) report (Solomon, 2007) temperatures at the surface have risen globally, with significant regional variations. The fact that 2010 was one of the warmest as well as one of the most disastrous year demonstrates that climate change is causing more extreme events. The recent IPCC report warns more changes to weather extremes are expected by the end of 21st century. Among the extreme meteorological events, droughts have the least predictability and affecting more people than any other hazard. Scientists are slightly less certain about changes to drought events in the future. It is likely droughts will become longer or more intense by the end of the century. For this reason, droughts in future pose a threat to climate dependent economic sectors, especially agriculture and have therefore necessitated the assessment and study of past drought trends.

Drought is a naturally occurring event caused due to deficiency in precipitation over an extended period of time. It is a slow-onset, creeping natural hazard that affects continuously all parts of the world. It occurs in all climatic zones such as high as well as low precipitation areas and causes high economic and social losses around the world. Droughts are generally measured in terms of deficiency in the rainfalls or streams flows below a predefined reference level. The magnitude of departure from the reference level during a drought spell is known as the severity of drought. Droughts are occurring in different regions of the world with increased frequency and severity. In India, large parts of the country perennially reel under recurring drought. Around 68 % of the total area is vulnerable to drought and about 35 % of which receives rainfall between 750 mm and 1125 mm is considered drought prone while 33 % that receive less than 750 mm is chronically drought prone. In India, the most drought prone regions are the arid and semi-arid regions (Appa Rao, 1991). The severity and intensity of drought is more in arid to extremely arid region (Adnan

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et.al., 2017).In India, the highly drought prone areas lie in the states of Rajasthan, Uttar Pradesh, Karnataka and Odisha (Gupta et *al.*, 2011).Droughts in these areas occur more frequently. Also, the drought prone areas over the country have been showing a decreasing trend (Sen and Sinha, 1997). Droughts in the country are becoming regional and a general shift of droughts is towards agriculturally important areas of coastal south-India, central Maharashtra, and Indo-Gangetic plains (Malliya et *al.*, 2016).

Droughts in Kashmir Valley of the state of Jammu and Kashmir are not a common occurrence. The parts of the state which are drought prone lie mostly in the Jammu region including Doda, Kathua Udhampur and Jammu Districts. As such no significant studies have been conducted for analysis of drought situations in Kashmir Valley. However, during the severe drought of 1971-1918, the River Jhelum of Kashmir is reported to have dried up completely (Nagarajan, 2003). The present study has been undertaken to study the drought conditions in the Shalimar area of Kashmir valley of Jammu and Kashmir state over a period of 31 years. Standard Precipitation Index (SPI) was used in the current study.

Study Area

The site Shalimar weather station from which data has been collected lies slightly away from Shalimar Ghat (34° 08' 30.5" N and 74° 51' 42.0" E) in the vicinity of Dal Lake catchment. Shalimar is located in Kashmir, Himalayas, India between the geographical coordinates of 34° 02' - 34° 13' N latitude and 74° 50' – 75° 09' E longitude. The location of the Shalimar weather station and Srinagar district is shown in Figure 1.

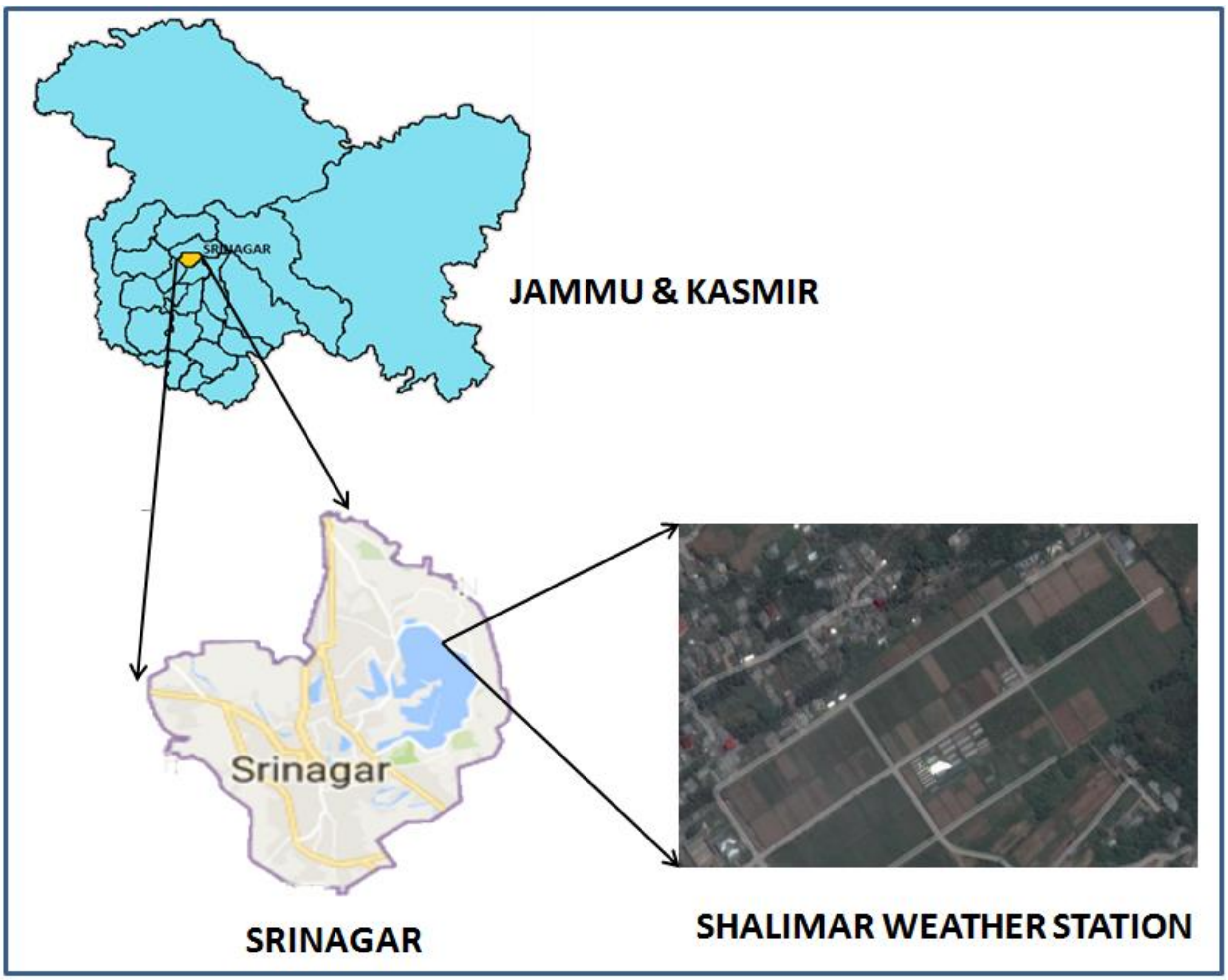

Figure 1: Location of Srinagar District and Shalimar weather station**.**

Kashmir Valley has a moderate climate, which is largely defined by its geographic location, with the towering Karakoram Range in the north, Pir Panjal Range in the south and west and Zanskar Range in the east. It can be generally described as cool in the spring and autumn, mild in the summer and cold in the winter. As a large valley with significant differences in geo-location among various districts, the weather is often cooler in the hilly areas compared to the flat lower part. Compared with other plain parts of India, Kashmir valley enjoys a more moderate climate but weather conditions are unpredictable. Rainfall in the different regions of the state also varies to a great extent. The average annual rainfall of Kashmir valley is 670 mm whereas for Leh and Jammu region it is 70 mm and 1251 mm respectively. Annual Temperature and precipitation data of Srinagar District for the study period is presented in Figure 2.

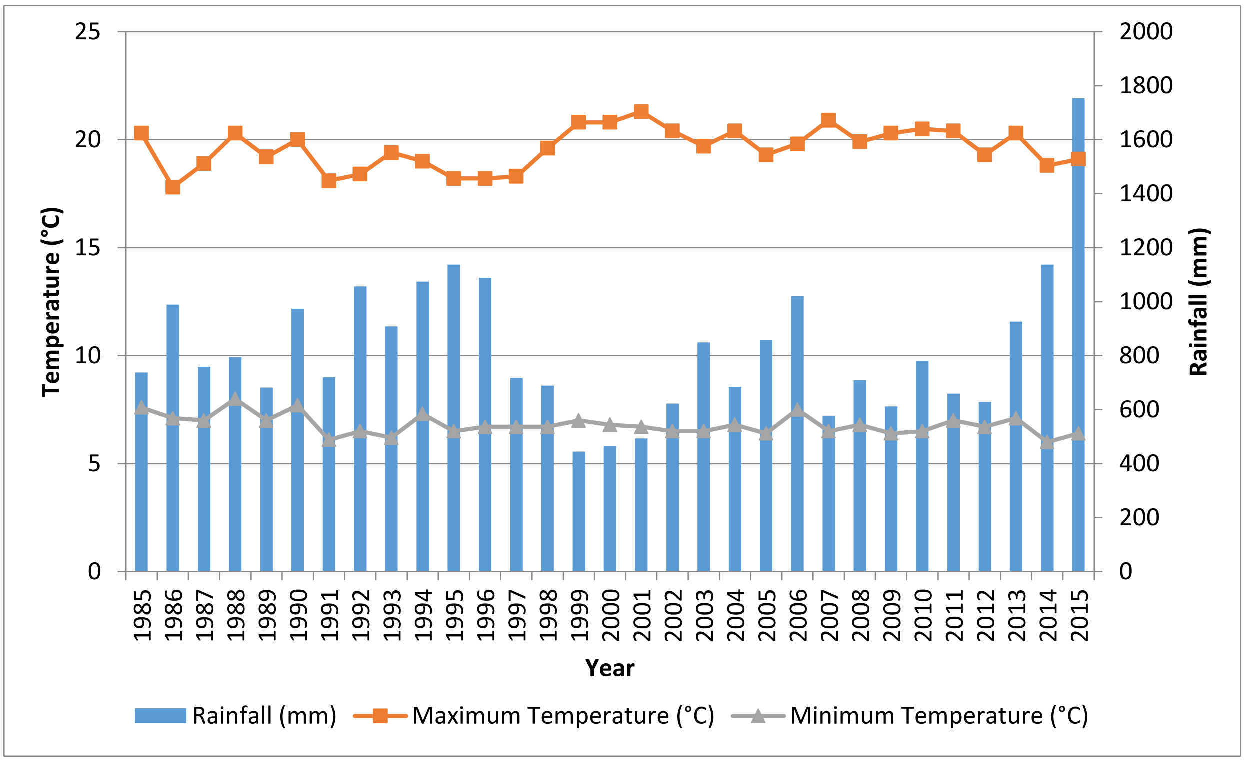

Figure 2: Annual Temperature and precipitation data of Srinagar District for 31 years (1985-2015).

Data and Methodology

Drought characteristics such as magnitude, duration, severity and spatial extent usually explained by drought indicators or drought indices. Drought indices integrate huge amount of data on rainfall, snowpack, stream-flow, and other water supply indicators into a comprehensible big picture and are used to investigate occurrence and extent of drought events. A drought index value is typically a single number, far more useful than raw data for decision making. A number of different drought indices have been developed to detect and monitor droughts which include Palmer drought severity index (Palmer 1965), standardized precipitation index (SPI; McKee et *al.*, 1993, 1995), rainfall anomaly index (van Rooy, 1965), deciles (Gibbs and Maher, 1967), crop moisture index (Palmer, 1968), Bhalme and Mooly drought index (Bhalme and Mooley, 1980), surface water supply index (Shafer and Dezman, 1982), national rainfall index (Gommes and Petrassi, 1994), and reclamation drought index (Weghorst, 1996).An evaluation of different drought indices by Keyantash and Dracup (2002) showed that SPI is the second highest ranked drought index. This evaluation was based on six different criteria, i.e. robustness, tractability, transparency, sophistication, extendibility and dimensionality. On that account, SPI has been used quite extensively for drought-related study.

Standardized Precipitation Index

Over the years several indices have been proposed to detect and monitor droughts each have its own its strengths and weaknesses. The most widely accepted index is Standardized Precipitation Index (SPI) which is based on probability concept. The SPI was designed by researchers at Colorado State University (McKee et *al.*, 2013) to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of a drought on the availability of the different water resources. SPIs for short timescales are indicators for immediate impacts such as reduced soil moisture, snowpack, and flow in smaller creeks whereas SPIs for longer timescales indicate reduced stream flow, reservoir and groundwater recharge. The different timescale helps to identify the types of drought from meteorological to hydrological drought (Adnan et.al., 2015).

The following classification was used to define drought intensities resulting from the SPI.

2.0+	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

Computation of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation totals for a station or grid point and then transforming the gamma distribution to a normal distribution with mean of zero and variance of one. The statistics for the frequency distribution are calculated on the basis of a reference period of at least 30 years. The SPI output values are in units of standard deviation from long-term medians and provide the corresponding probabilities of occurrence of each drought category relative to the normal probability density function (Khan et*al.*,2013)

Daily precipitation data for the period of 30 years (1985 – 2015) was obtained from AMFU Shalimar station (Division of Agronomy, SKUAST-K). The daily precipitation data was tabulated into monthly precipitation data which was used as input for the calculation of SPI. The data was then started to analyze. The data was prepared in excel program while as the statistical analyses was done using standardized precipitation index (SPI) software. Computation of SPI was carried out at various timescales.

The monthly soil moisture data for the present study was produced using the Leaky Bucket Model of Climate Prediction Center (CPC). The soil moisture data set of CPC is available from the year 1931-present. It plays a very important role in monitoring droughts at different timescales and spatial resolutions (Svoboda et al., 2002).

Results and Discussion

Rainfall data was subjected to annual rainfall departure analysis for identification of drought years and the extent of deficit of annual rainfall. A year is considered as drought year if the total amount of annual rainfall over an area is deficient by more than 25% of its normal value. The percentage annual rainfall departures in Shalimar region is shown in Figure 1. From the analysis it was observed that in years 1999, 2000, 2001, 2007 drought occurred in the area. Also it is evident from the graph that the region experienced severe drought in the year of 1999 when the rainfall deficit was 43.85 %. Also, trend analysis of precipitation showed a slight decrease of precipitation in the last 30 years with linear regression equation $y = 0.491x + 14.45$ and $R^2 = 0.012$.

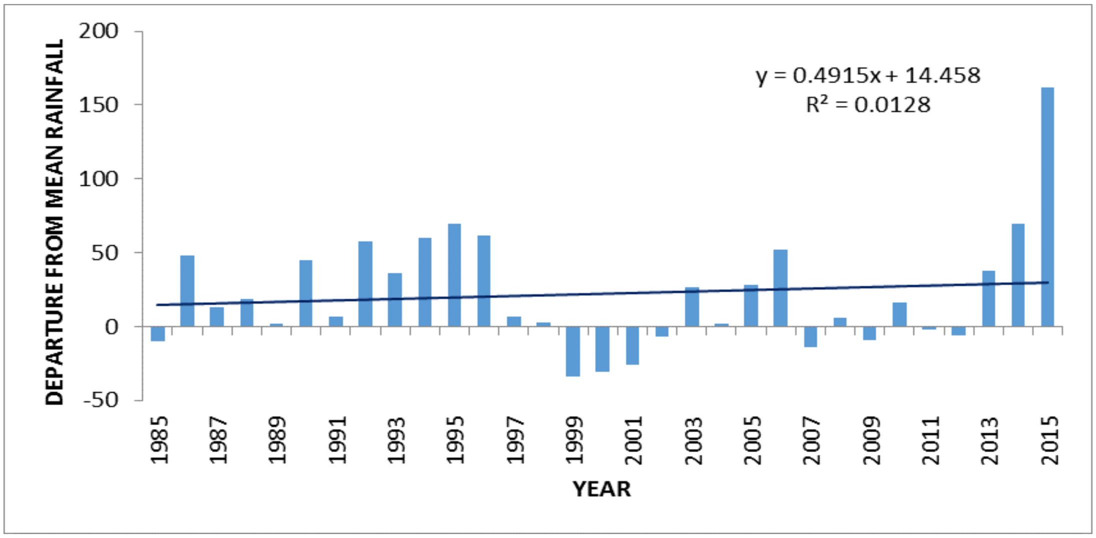

Figure 3: Percentage annual rainfall departures in Shalimar region for the period 1985-2015**.**

The annual SPI for Shalimar from 1985 to 2015 was calculated to demonstrate the frequency of occurrence of dry and wet conditions. The SPI based drought classification proposed by McKee et *al*. (McKee et *al*., 1993) was adopted in this study. The value of the SPI gives a measure of the severity of a wet or dry event. A drought event occurs if the SPI value is -1.0 or less and the event ends when the index becomes positive (Bordi et *al.* 2001). SPI was computed at timescales of 1-month, 3-months, 6-months, 9-months and 12-months.It was observed that on smaller scales such as SPI-1 and SPI-3 series, the drought intensities are highly variable and become less than −1.0 and greater than 1.0 on several occasions. However, on longer timescales; SPI-6, SPI-9 and SPI-12 drought intensity decreases. This variation is due to a seasonal component found in the rainfall data since SPI is relative to the rainfall characteristics of that area.

1-month SPI indicates short-term conditions and it can be closely associated to meteorological drought. It is also useful for assessing soil moisture and crop stress, particularly during the growth season of the crops.1 month SPI for the period 1985-2015 at Shalimar weather station is shown in Figure 4. The lowest SPI on 1-month timescale was -3.45 which occurred in the year 2007.

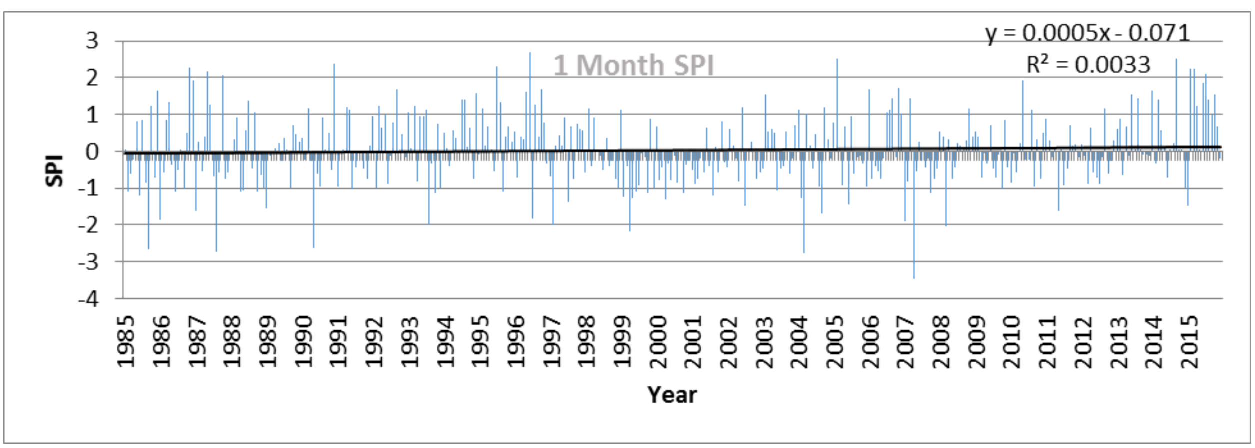

Figure 4: 1-Month SPI calculated for Shalimar Weather Station (1985-2015).

3-month SPI specifies short-term as well as medium-term moisture conditions and offers an estimate of seasonal precipitation. A 3-month SPI is more helpful in emphasizing existing moisture conditions of major agricultural regions than many other hydrological indices. 3-month SPI for the period 1985-2015 at Shalimar weather station is shown in Figure 5. The lowest SPI on 3-month timescale was -2.84 which occurred in the year 1989.

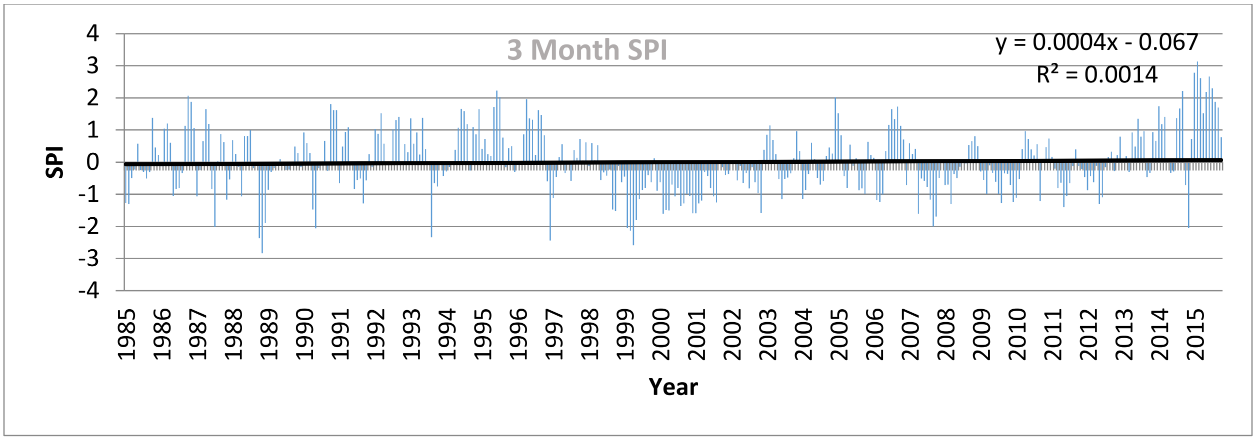

Figure 5: 3-Month SPI calculated for Shalimar Weather Station (1985-2015).

The 6-month SPI specifies seasonal to medium-term trends in precipitation and is very efficient in showing the precipitation over different seasons. 6-month SPI for the period 1985-2015 at Shalimar weather station is shown in Figure 6. The lowest SPI on 6-month timescale was -2.43 which occurred in the year 1995.

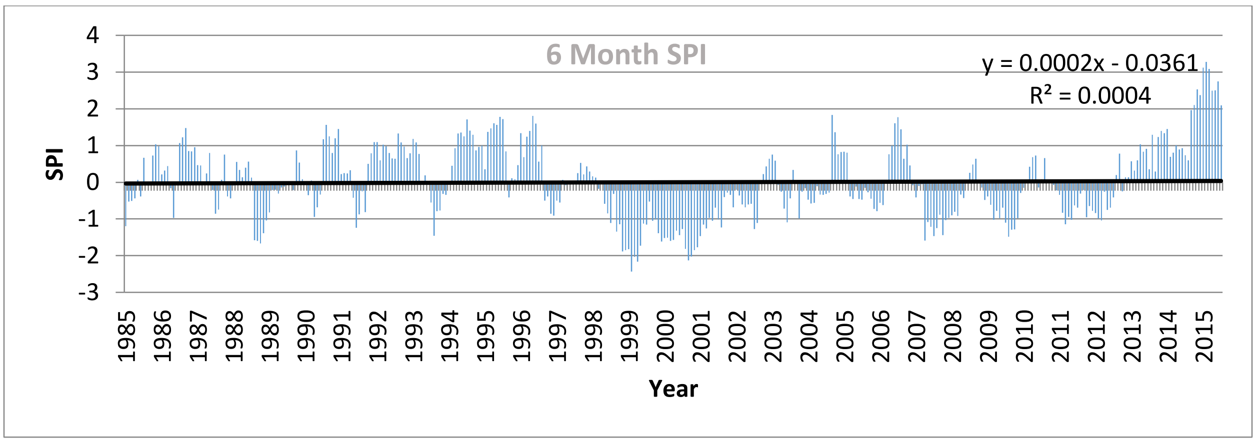

Figure 6: 6-Month SPI calculated for Shalimar Weather Station (1985-2015).

The 9-month SPI provides an insight of inter-seasonal precipitation patterns over a time-scale of medium interval. For droughts to develop, generally a season or more is required. For a 9-month time scale,

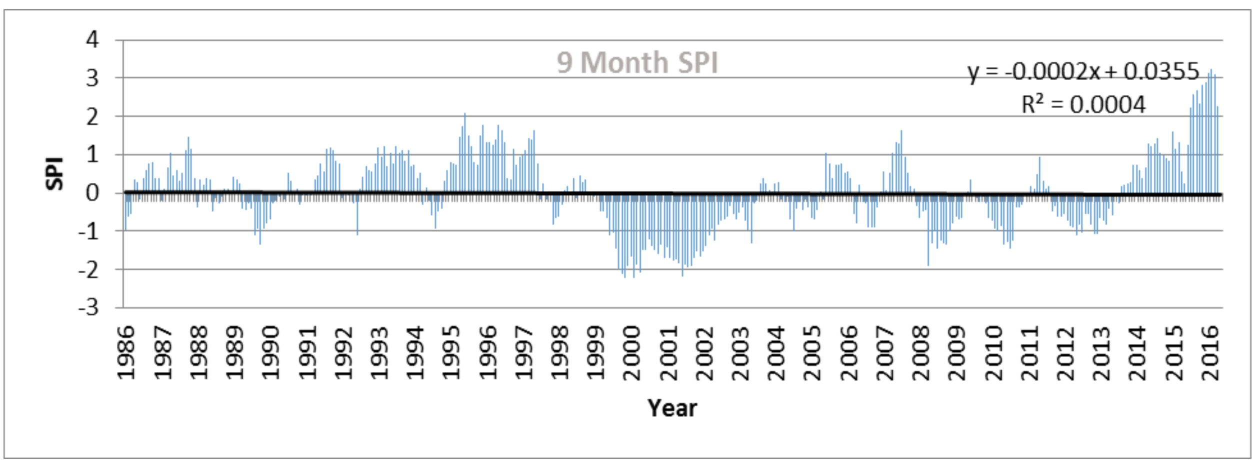

Figure 7: 9-Month SPI calculated for Shalimar Weather Station (1985-2015).

an SPI value of -1.5 or below indicates that dryness has a significant impact on agriculture as well as other sectors. 9-month SPI for the period 1985-2015 at Shalimar weather station is shown in Figure 7.The lowest SPI on 9-month timescale was -2.22 which occurred in the year 1999.

12-month SPI values are generally linked to stream-flows, level of reservoirs and even groundwater levels at stretched timescales. 12-month SPI for the period 1985-2015 at Shalimar weather station is shown in Figure 8. The lowest SPI on 12-month timescale was -2.35 which occurred in the year 2001.

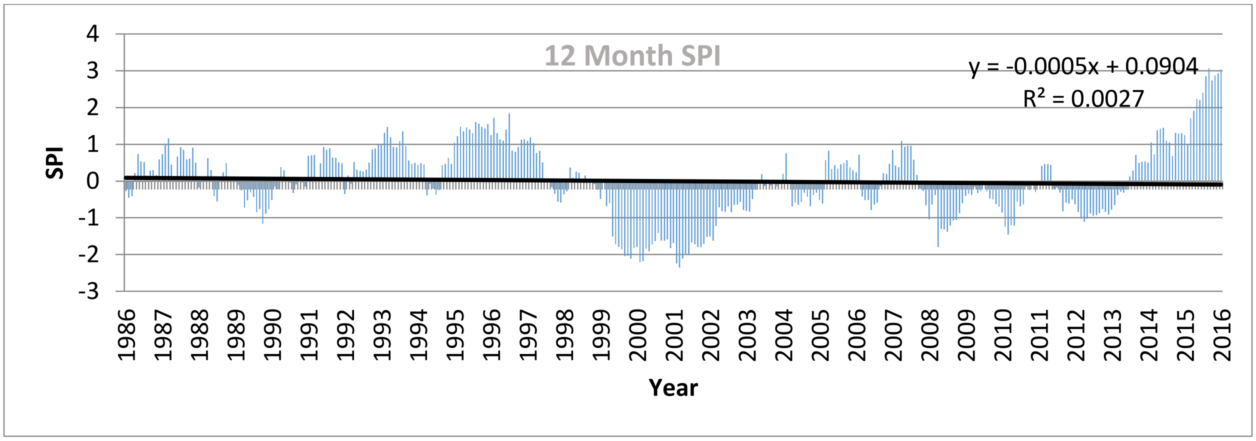

Figure 8: 12-Month SPI calculated for Shalimar Weather Station (1985-2015).

Since there are two main cropping seasons in India; Kharif and Rabi, therefore the analysis of dry and wet conditions during these seasons is of crucial importance in drought prediction and preparedness. However, the main agricultural season in Kashmir is Kharif season which extends from June to October and depends largely on rainfall. The main crops grown in this season are paddy, maize and soybean. Since June represents the peak sowing period therefore rainfall during this month is essential to trigger sowing of seeds. August represents the active growing period of crops and September represents the maximum vegetative phase or early reproductive phase of crops. Harvesting is mostly done in October or November. Therefore, keeping in view the crop phenology and crop calendar, rainfall during June, July, August and September play a vital role in crop production. The SPI Values for Kharif season are shown in Figure 9.

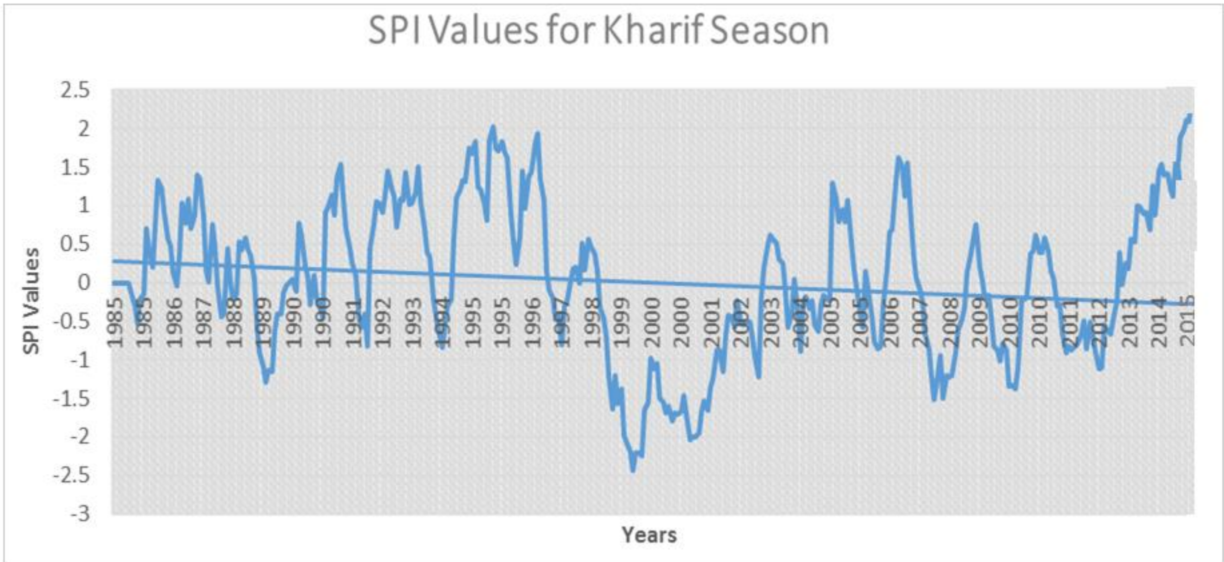

Figure 9: SPI calculated for Kharif season at Shalimar Weather Station (1985-2015).

SPI values for Rabi Season are shown in Figure 10. Results show for Kharif season show that moderate drought occurred in the years 1989, 2002, 2004, 2010 and 2012; severe drought occurred in the years 2000, 2001 and 2008; whereas extreme drought occurred only in the year 1999. For Rabi season, moderate drought occurred in the years 1989, 2002, 2004, 2010 and 2012; severe drought occurred in the years 2000, 2001 and 2008; whereas extreme drought occurred in the years 1999 and 2001. Thus, the most critical drought year in the area was 1999.

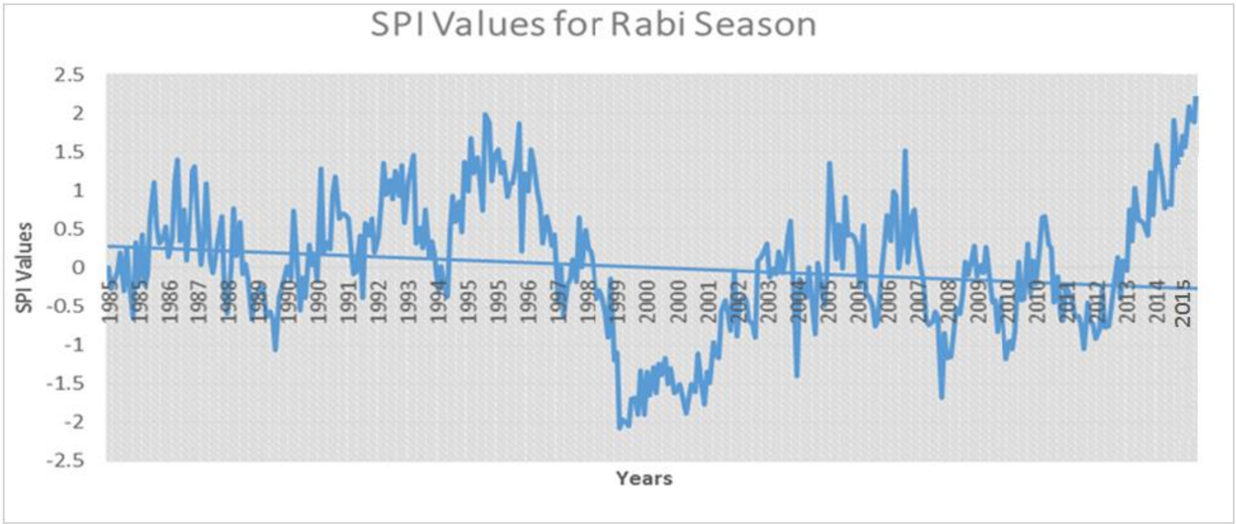

Figure 10: SPI calculated for Rabi season at Shalimar Weather Station (1985-2015).

SPI and Soil Moisture

The correlation between 12-month SPI and soil moisture departure, soil moisture departure and annual rainfall departure and annual rainfall departure and 12-month SPI is shown in Figure 11.

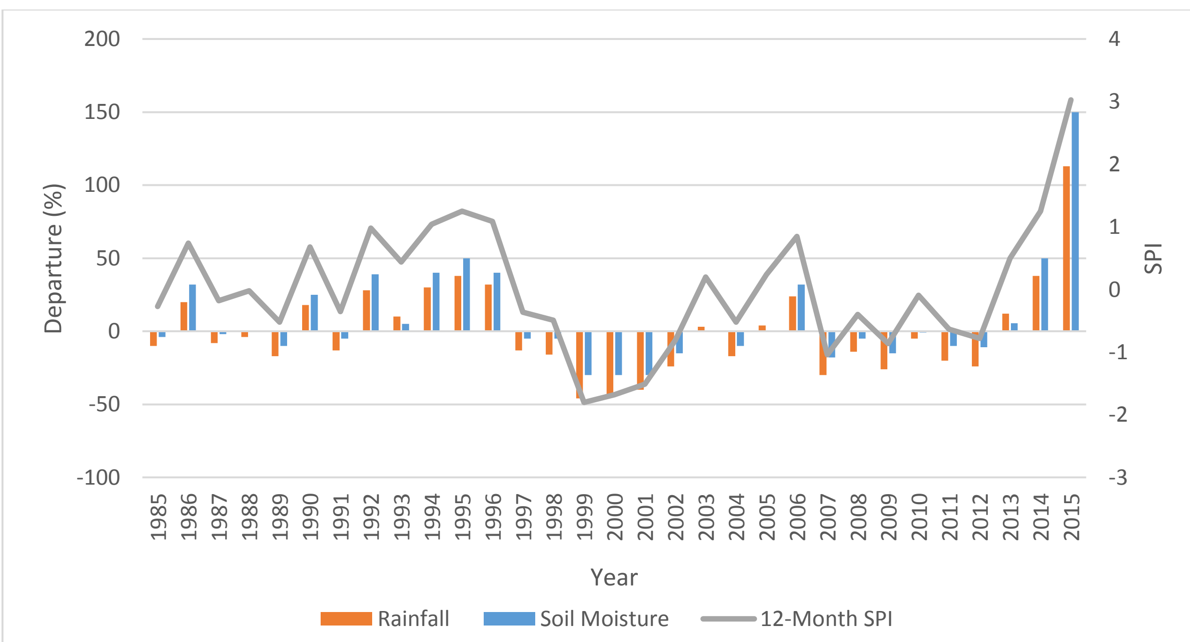

Figure 11: Comparison among 12-month SPI and percentage departure of soil moisture and annual rainfall at Shalimar Weather Station during 1985–2015.

A strong correlation was observed between 12-month SPI and soil moisture departure (r = 0.78), soil moisture departure and annual rainfall departure (r = 0.85) as well as annual rainfall departure and 12-month SPI (r = 0.91). The values of correlation coefficient indicate that rainfall departure can be used for the estimation of SPI and soil moisture departure and can also serve as a good indicator for drought monitoring (Narendra, 2008).

Conclusion

The main aim of this study was to assess droughts observed in the temperate environment of Shalimar, Kashmir by using the Standardized Precipitation Index criterion. Temporal drought patterns were examined which revealed many interesting results on the variability in the occurrence of drought in the region. An increasing trend was observed in the area for the given rainfall data which indicates that the area under consideration is not drought prone. Temporal SPI graphs show that the maximum SPI value (extreme drought) occurred in the year 2001. In that year, the SPI value was -2.35.In addition to this, SPI values in the severe and extreme drought years indicated only moderate dryness instead of extreme dryness with SPI values never falling below -2.5. It was found that SPI is a valuable tool for assessing drought characteristics like frequency and severity. The SPI values were also correlated with rainfall and soil moisture departure values. Rainfall departure was observed to be a good predictor for soil moisture departure and SPI values. The results of the study are also relevant to climate change studies to understand the historic patterns and build future scenarios of drought, occurances.

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