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Meteorological Drought Quantification with Standardized Precipitation Index for Jhelum Basin in Kashmir Valley

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ABSTRACT

Droughts are generally identified and characterized using drought indices. The present study deals with the potential of using precipitation-based Standardized Precipitation Index to duplicate observed meteorological droughts in the Jhelum river Basin of Kashmir valley. Historical droughts that occurred from 1980 to 2017 have been examined in the study. The SPI analysis shows a good agreement with the recorded historical drought events. SPI was also used to study the time-based pattern of drought occurrence and its severity. The droughts in the Jhelum basin occurred during the years 1999, 2000, 2001, 2007 and 2016. The intensity of these droughts was found to be severe to extreme. The most prolonged droughts in the basin occurred during three successive years during 1999, 2000 and 2001. The SPI Values were less than -1 for these years on 6-month, 9-month and 12-month time scales. The 12-month SPI values for these years were -2.37, -2.39 and -2.46 respectively. However, the SPI values suggest moderate dryness in place of acute dryness during the years of severe and extreme drought.

Keywords: Drought, Drought Intensity Jhelum, Multi-Scale, Normal, Standardized Precipitation Index

I. INTRODUCTION

Drought is perceived differently by different persons depending upon the individual perceptions; for example, a farmer describes a drought as an extended period of low rainfall which affects the growth and yield of plants. A drought is defined as “a period of abnormally dry weather sufficiently prolonged for the lack of water to cause serious hydrological imbalance in the affected area, on the degree of dryness and the duration of dry spell” [1]. According to the Irrigation Commission of India, drought is a condition that occurs in any area where the annual rainfall is less than 75% of normal rainfall. The National Commission on Agriculture (1976) categorized droughts into three classes- a) Meteorological drought: The situation where there is more than 25% decrease in precipitation from normal over an area; b) Hydrological drought: Meteorological drought, when prolonged, results in hydrological drought with noticeable diminution of surface water and groundwater resulting in drying up of tanks, reservoirs, streams and rivers, cessation of springs and fall in the groundwater level; and c) Agricultural drought: This occurs when the soil moisture and rainfall are insufficient during the growing season to sustain healthy growth of crops to maturity.

Like other extreme events, droughts are a consequence of climate change. According to the Intergovernmental Panel on Climate Change (IPCC), the earth surface temperature has increased by about +0.76°C over the last

100 years [2]. The report further predicts temperature will rise by 2.7-4.3 °C over India by the 2080s. The increase in occurrence of extreme events due to climate change is evident from the fact that 2010 was one of the warmest as well as one of the most disastrous year in the recent past [3].

Drought unlike other natural disasters takes months to erupt. In other words, it creeps up over several seasons in a region [4]. It usually goes unnoticed by the community until impacts from the drought have already occurred [5]. The area and population affected by droughts is generally much more than that of any other natural catastrophe [6,7].

Droughts are effectively monitored using a drought index. A Drought index is a quantitative measure that characterizes drought levels by assimilating data from one or several variables (indicators) such as precipitation and evapotranspiration into a single numerical value [8]. Various drought indices have been developed throughout the world in the past using rainfall as the single variable. These include the commonly used Deciles [9], Standardized Precipitation Index (SPI) [10], and Effective Drought Index (EDI) [11]. Palmer Drought Severity Index (PDSI) [12] is another popular drought index which considers temperature along with rainfall.

As far as the history of Jhelum basin is concerned, the basin is more prone to floods rather than droughts. Droughts do not represent typical extreme events that occur in the basin. Therefore, no substantial studies have been performed drought analysis in the Jhelum Basin. The River Jhelum is however reported to have completely dried up during the severe drought of 1917-1918 [13]. However, frequent spells of drought during recent years suggest the need to study the pattern and severity of droughts in the region. Prolonged dry spell and absence of adequate rainfall resulted in the resulted in the lowering of water level in the River Jhelum during 2016 as wee as 2017. In 2016, the water level in the river was recorded at -6 ft at Sangam, which was the lowest in last 55 years. The situation worsened in 2017 when the level of the river Jhelum plunged to the lowest in 61 years. During September to December 2017 only 5 mm of rainfall was recorded in the valley against a normal of 100 mm. Thus, the present study has been undertaken to study the drought conditions in the Jhelum basin of Jammu and Kashmir state over a period of 38 years. In this study, the SPI drought index has been selected to assess the drought condition in the Jhelum Basin of Kashmir Valley. SPI is the most commonly used drought index because of it is simplicity, the ability to represent drought on multiple time scales and is based on probability. SPI for the basin was calculated on the basis of precipitation data of seven meteorological stations located across the basin.

II. STUDY AREA

The Jhelum River basin lies between 33°25’ N to 34°40’ N latitude and 73°55’ E to 75°35’E longitude. River Jhelum is an important tributary of river Chenab which itself is a tributary of river Indus. The area under study covers the Jhelum basin located in the state of Jammu and Kashmir, India. The area covered by the basin up to the Indo-Pakistan border is about 17622 km^2 and the length of the main channel is 165 km. Monthly precipitation data was obtained for seven stations namely; Srinagar, Shalimar, Qazigund, Pahalgam, Kupwara, Kokernag and Gulmarg from India Meteorological Department. Data for these stations was obtained for the years 1980-2017. The study area and the location of meteorological observatories are shown in Fig. 1.

The Jhelum basin located in the Kashmir valley of Jammu and Kashmir state has a temperate climate but the weather conditions are highly unpredictable. Rainfall varies greatly from region to region within the state. The average annual rainfall of Kashmir valley is 670 mm. Normal annual temperature and precipitation data of the Jhelum Basin is presented in Fig. 2.

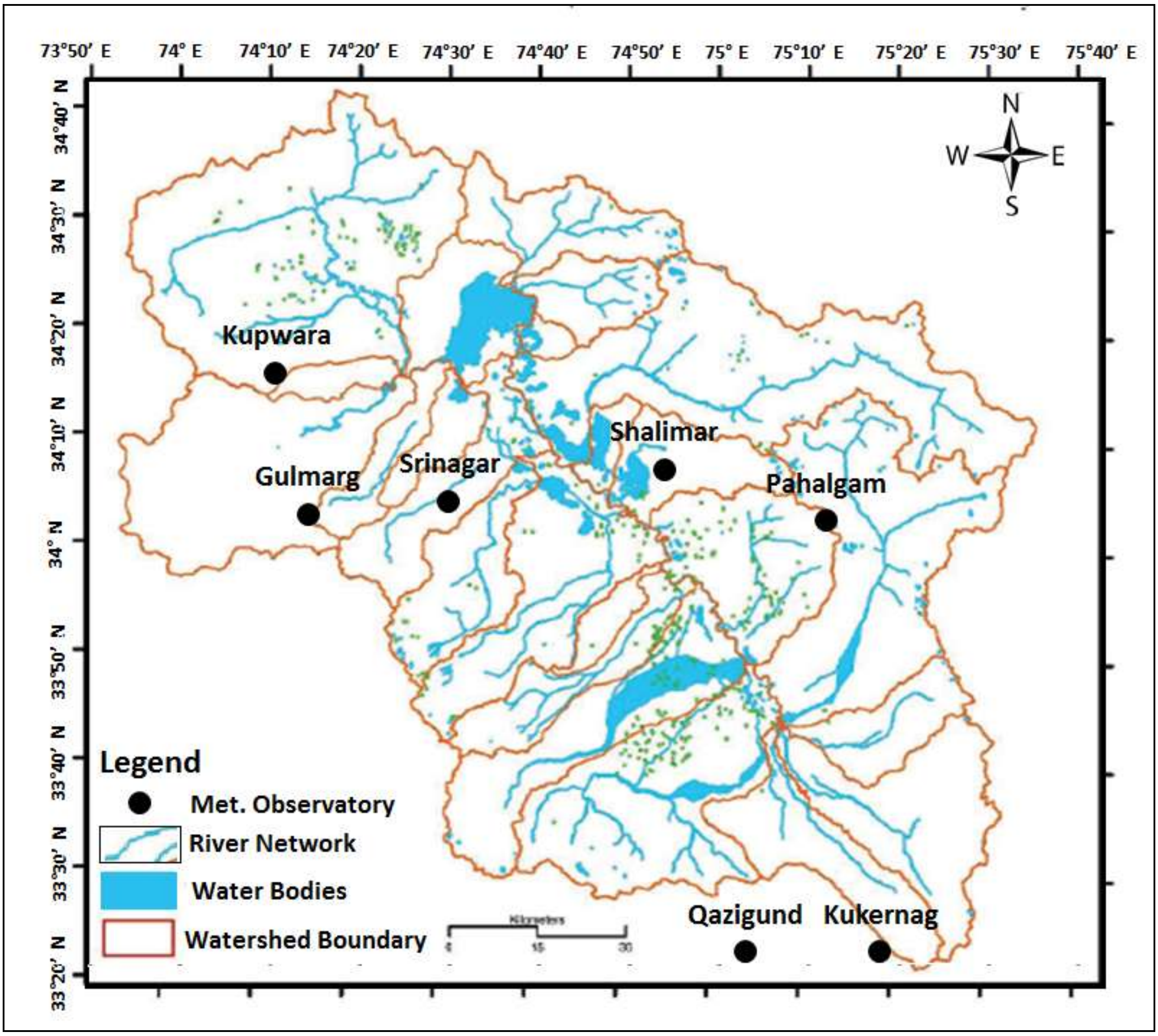

Fig. 1 Map of Study Area Showing Location of Meteorological Stations

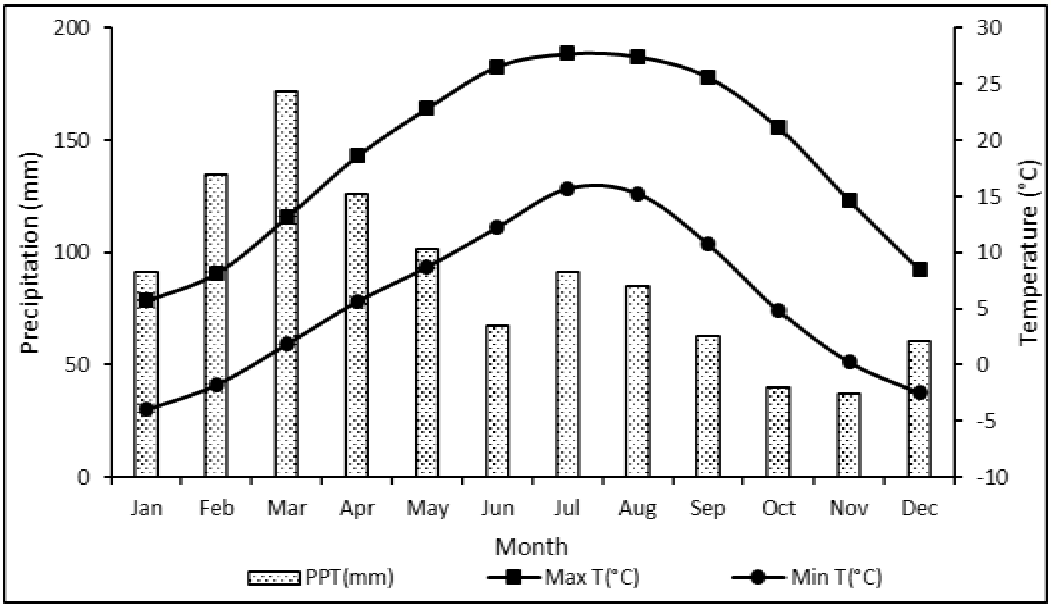

Fig. 2 Monthly normals of precipitation and temperature for Jhelum Basin

III. METHODOLOGY

The monthly rainfall data from the seven meteorological stations was used to compute the average monthly and annual temperature of the entire Jhelum Basin for a period of 38 years. The average precipitation of the basin was calculated using Thiessens polygon method [14] and then used to compute SPI. McKee et al. [10,15] formulated the Standardized Precipitation Index (SPI) for the purpose of monitoring drought. The percent deviation from normal precipitation was also calculated for the given time-series. It is one of the simplest measurements of precipitation value for a location. It is calculated by using equation 1;

$$\%\ deviation = \frac{Actual\ precipitation - Normal\ precipitation}{Actual\ precipitation} \times 100 \quad \ldots (1)$$

The percentage deviation from normal is a very simple index and makes it practical to communicate drought levels to the public [6].

The long-term record of precipitation values is fitted to a probability distribution. The distribution is then transformed into a standard normal distribution. The mean of this standard distribution is 0 while the variance is 1 (Edwards and McKee, 1997). The datasets are most commonly adjusted to the gamma function [16,17]. Some studies have also shown better adjustments to other functions [18]. The statistics for the frequency distribution are figured on the basis of a reference time-scale of minimum 30 years. The SPI output values are in units of standard deviation from long-term medians and offer the corresponding probabilities of occurrence of each drought category relative to the normal probability density function [5].

McKee et al. [10] also set up a criterion for classification of drought conditions based on the SPI (Table 1). The drought intensity is defined by the value of SPI. In general, SPI values greater than zero represent greater than normal precipitation, while SPI values less than zero represent negative values indicate lower than normal precipitation. The SPI can be computed for different time scales and can provide early warning of drought, although it is not a forecasting tool.

Table 1 Classification of drought conditions according to the SPI values

SPI	Classification
≥ 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	Extremely dry

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 [19]. Every drought event/spell ends when SPI becomes positive. Short time scales SPI anomalies reflect the soil moisture condition and long-term time scale reflect streamflow, groundwater recharge and reservoir storage. Based on historical long-term time series data, analyst can tell the impact of these anomalies on aforementioned domains. The duration of drought event/spell may be obtained by counting the months from the beginning to ending of negative SPI values and magnitude by positive summing the SPI values of all months within drought event/spell. SPI for the study area was computed at timescales of 1-month, 3-months, 6-months, 9-months and 12- months.

IV. RESULTS AND DISCUSSIONS

The variation in annual precipitation for the Jhelum Basin over the time period 1980-2017 is shown in Fig. 3. Also, trend analysis of precipitation shows a slight decrease of precipitation in the last 38 years with linear regression equation $y = -2.7552x + 6575.7$ and $R^2 = 0.0215$. The percent deviation of precipitation from normal for the Jhelum Basin is shown in Fig. 4. The figure shows that the Jhelum basin witnessed drought in the years 1999, 2000, 2001, 2007 and 2016. The most severe drought occurred in the year 2000, when the annual rainfall was nearly 40% less than the normal value for the basin.

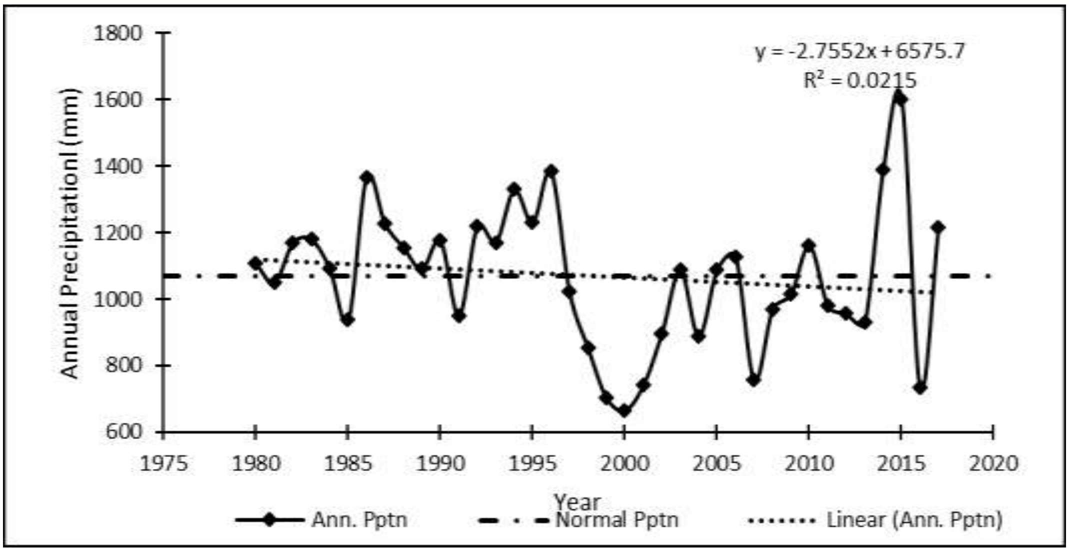

Fig. 3 Yearly precipitation(mm) during 1980-2017 for Jhelum basin

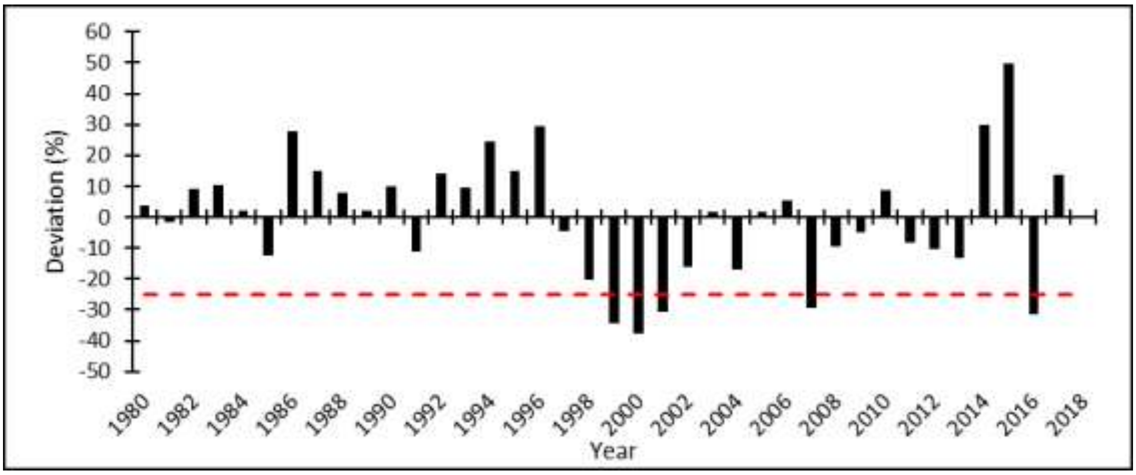

Fig. 4 : Percentage deviation of precipitation from normal for Jhelum Basin during 1980-2017 (lower threshold of drought i.e. 25% in red).

In the present study, SPI was computed at timescales of 1-month, 3-months, 6-months, 9-months and 12-months. The SPI values over different time scales for Jhelum Basin are shown in Fig. 5. The influence of the timescale on the number and duration of detected droughts is clearly apparent. 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 [20].

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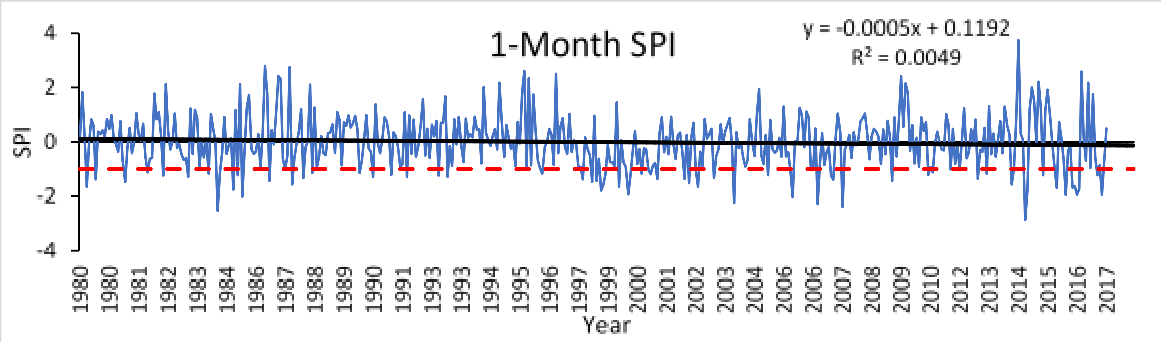

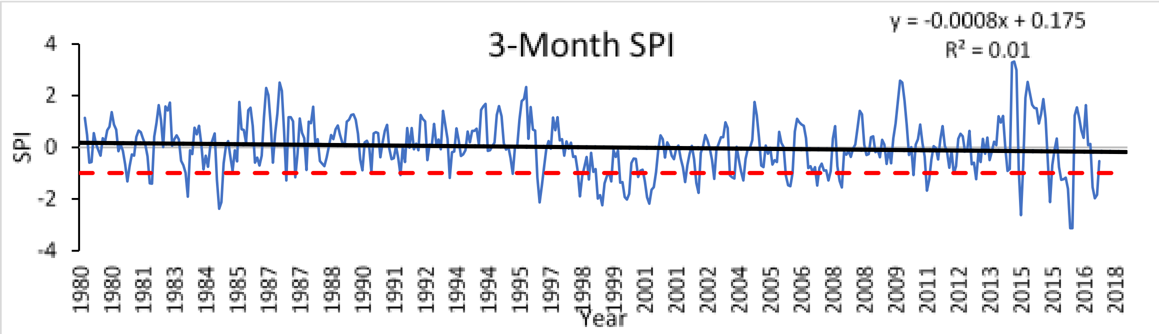

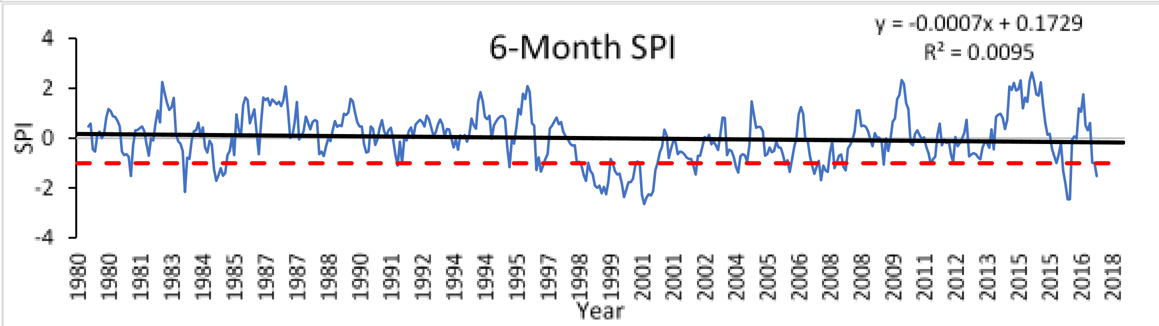

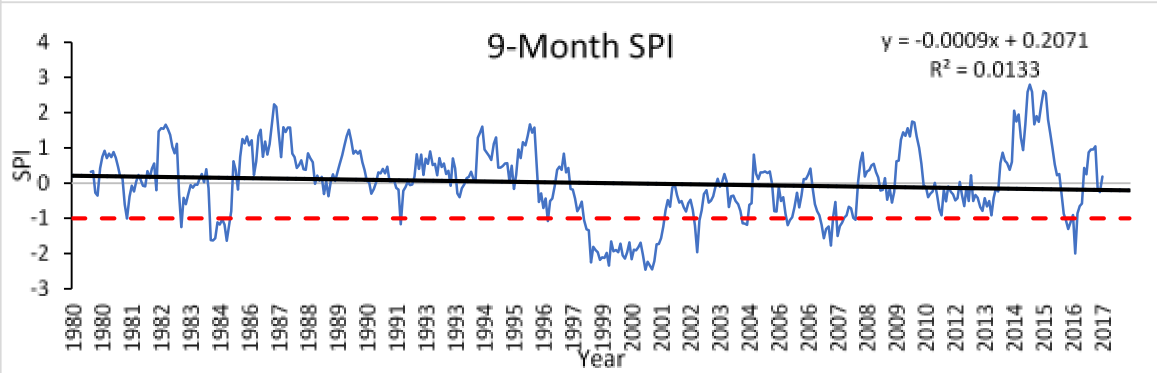

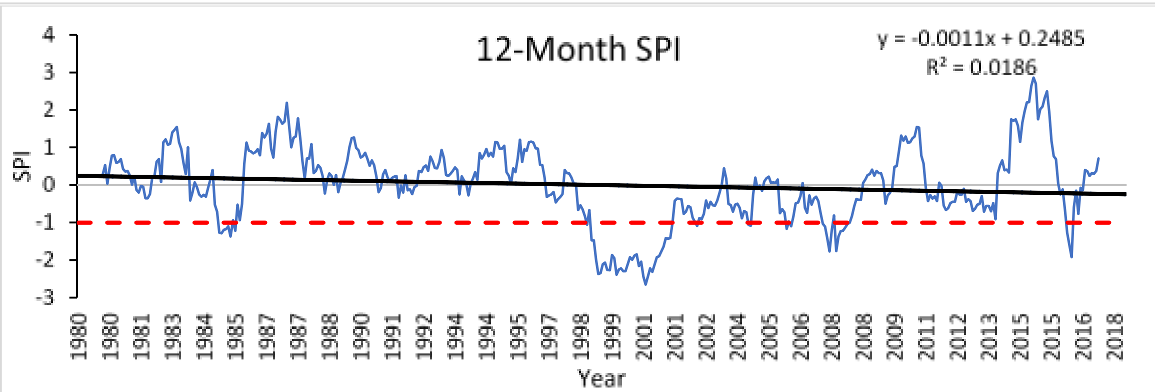

Fig. 5 SPI-1, SPI-3, SPI-6, SPI-12 and SPI-24 series for the Jhelum Basin (lower threshold in red).

Drought events were detected for each time step. 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.1The lowest SPI on 1-month timescale for the Jhelum Basin was -2.87 which occurred during the year 2014. 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. The lowest SPI on 3-month timescale was -3.13 during the year 2016. The 6-month SPI specifies seasonal to medium-term trends in precipitation and is very efficient in showing the precipitation over different seasons. The lowest SPI on 6-month timescale was -2.64 which occurred in the year 2001.

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, an SPI value of -1.5 or below indicates that dryness has a significant impact on agriculture as well as other sectors. The lowest SPI on 9-month timescale was -2.46 which occurred in the year 2001. 12-month SPI values are generally linked to stream-flows, level of reservoirs and even groundwater levels at stretched timescales. The lowest SPI on 12-month timescale was -2.65 which occurred in the year 2001.

The drought index SPI was able to capture the major documented drought events over the basin during 1980-2015. For the study period, only 5 meteorological droughts occurred in 1999, 2000, 2001, 2007 and 2016. All these droughts have occurred during the recent 20 years. The period of study during 1980-1998 have not witnessed a single drought year.

Moreover, the SPI trendlines suggest decreasing nature of SPI on all scales. This implies that the frequency of droughts in the Basin has increased during last two decades. The decreasing trend of precipitation further increases the vulnerability of the basin to droughts. The worst period of drought occurred during 1999-2001, when three consecutive drought-years were observed in the basin. The rainfall deficit during these years was nearly 35% of the normal and the SPI values were less than -2 on all time-scales.

The results indicated that SPI was able to reproduce the drought events that occurred in the Jhelum basin during last 4 decades. The detected drought events (i.e., the forecasts) correspond to the cases when the SPI value exceeds a given threshold, which indicates that a certain area is affected by an event. The SPI values on different time scales show that the droughts experienced in the region were mostly of moderate to severe intensity. The droughts of 1991, 2000 and 2001 were extreme droughts with SPI-12 values of -2.37, -2.39 and -2.46 respectively.

V. CONCLUSIONS

Jhelum Basin of Kashmir valley enjoys a temperate climate, hence most vulnerable to drought hazard risk. SPIs on time scales of 1, 3, 6, 9 and 12 months have been analyzed. The time series of the average1, 3 and 6 months SPI for the basin revealed that short term droughts are not common in the basin throughout the period of record.

Fluctuations in 12 months SPI series have clearly identified short term as well as long-term dry periods. The long-term droughts in the basin varied in intensity from severe to extreme. The study verified that long term droughts of during 1999, 2000 and 2001 had a severe nature. Since meteorological droughts are the first stage in the progression of subsequent agricultural or hydrological droughts, this methodology could be used to activate a management response for a drought event, which starts at a specific threshold value. Additionally, this methodology can be used to complete lacking information on droughts' duration, geographical extension or intensity. The results of the study are also relevant to climate change studies to understand the historic patterns and build future scenarios of drought, occurrences.

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