Original Research Article

Standardized precipitation index (spi) for extreme droughtAssessment in Harohar-Punpun Basin, Bihar.

Abstract

By definition drought is a long period of unusually low rainfall, especially one that badly affects growing or living conditions. Rainfall is to be believed as a normal, wet and dry condition of the climate. It is one of the most important water associated hazards. It has great impact on agricultural, hydrological, economic, environmental and social systems. Understanding theseimpacts is crucial for drought planning, mitigation, and response. It also helps decision makers identify and reduce vulnerability to drought. A drought index value is a single number, far more valuable than raw numbers for result making. The standardized precipitation index (SPI) has several characteristics that are an upgrading over other indices, with its simplicity and flexibility.

The standardized precipitation index (SPI) method is used for observing and describing drought based on seventy (70) year precipitation data of Harohar-Punpun Basin, Bihar. Finding drought index with 3- month, 6-month,12-month, time scale basis. Positive SPI values point to normal condition to wet condition and negative values indicate normal condition to dry condition. In this work, we computed years of intense drought between 1951 and 2021.We investigated how the effects of extreme drought varied across nine stations.At SPI-3, station-3 has the high extreme drought value, which has found to be -3.78 in 2008 and low extreme drought value has -2.63 in 2011 at station-9.Similar SPI-6 and SPI-12, station-3 has the highest extreme drought, which has found to be -4.20 in 2009, and station-2 has the lowest extreme drought, which was found to be -2.63 in 1966. Station-4 has the highest extreme drought, which has calculated to be -3.39 in 1967, and station-6 has the lowest extreme drought value, which has -2.4 in 2018.Stations 8 and 9 in SPI-3 have a frequency which has same that is 2.12.In comparison to other stations, they have the highest frequency.Station 4 in SPI-6 and SPI-12 has a high frequency of 3.09 and a low frequency of 0.87, while station 4 in SPI-12 has a high frequency of 3.37 and a low frequency of 0.36.

1. Introduction

The most significant climate hazard that has a negative impact on both natural and socioeconomic systems is drought, a common occurrence in the climate[1]. Therefore, understanding drought is essential for managing and planning water supplies [2–4] and to implement strong mitigation strategies, minimize the socioeconomic effects of prolonged drought [5,6]. Droughts are typically divided into four categories: meteorological, agricultural, hydrological, and socio-economic [7]. Lack of precipitation is referred to as a meteorological drought, which is the first event in the emergence and development of drought conditions [8]. The term "hydrological drought" describes a lack of both surface and groundwater resources [9]. Typically, agricultural dryness results in decreased soil moisture and decreased crop output [10]. Lastly, socioeconomic drought is linked to the water resources system's failure to meet human demand. [11].A number of indicators have been presented in recent decades to identify and track drought [12]. The primary aspects of drought, such as severity, duration, and extent, are objectively quantified and compared across locations with different meteorological and hydrologic regimes using drought indices[13].Among the existing indexes, the Standardized Precipitation Index (SPI; [14]) is widely usedworldwide for its simplicity, its applicability at different locations and time scales [12].Furthermore, the main advantage of the SPI lies in the use of precipitation as the only input to assess the drought. Indeed, it requires only rainfall monthly time series and can be computed for different time scales (e.g., usually 3, 6, 12, 24 and 48 months). For the sake of clarity, in this work we shorten the name of the SPI to include the time scale: as an example,SPI3 is the SPI evaluated with a 3-months' time scale. According to the standard procedureproposed by McKee et al. [14], monthly cumulated series of observed precipitation values,at any time scale, are fitted with a Gamma distribution, whose parameters are evaluatedwith the Maximum Likelihood Estimation (MLE) method.

Global economic losses due to droughts areestimated to be as high as 600-800 million dollars per year, which are much greater than those due toother meteorological disasters [15]. Therefore, it is necessary to conduct drought monitoringand assessment globally or in each area in order to determine drought intensity, magnitude, durationand spatial extent and to provide a basis for fighting drought and drought relief. Therefore, it isnecessary to select or develop an index to describe drought.Therefore, drought management in agriculture is a major challenge for Bihar in achieving sustainable agricultural development. To tackle the drought efficiently it is essential to understand the spatial-temporal pattern of drought evolution in Bihar.Drought assessment plays an important role in the planning and management of waterresources. For assessment, some numerical standard is needed so that drought measurescan be compared between regions and can be compared with past drought events [16].

Drought indices use severalhydro-meteorological data such as rainfall, streamflow, reservoir storage, soil moisture,groundwater, and water supply indicators either independently or collectively [17].

Drought is having certain characteristics such as they usually take an elliptic profile. Being of slow start it isdifficult to determine the beginning and end of the drought event. The duration may vary from months to years andthe core area or epicenter changes over time. The impacts are non-structural and not easy to compute. It is a creepingphenomenon. The impacts of drought are increasing and the effects expand when events continue from one season oryear to the next. It does not have a sharp ending.Strong points favoring the use of the SPI are its capacity to be calculated on different time-scales to adapt to the varied response times of typical hydrological variables to precipitation deficits. It allowsdetecting different drought types that affect different systems and regions. Although the SPI hasshown to be useful for drought monitoring and early warning [18], deficiencieshave also been noticed related to its inability to detect drought conditions determined not by a lack of precipitation but by a higher than normal atmospheric evaporative demand.

Developing States including Bihar and developed states Jharkhand of India that tend to share similar sustainable development challenges, including small but growing populations, limited resources, remoteness, susceptibility to natural disasters, vulnerability to external shocks, excessive dependence on international trade, and fragile environments. Their growth and development is also held back by high communication, energy and transportation costs, irregular international transport volumes, disproportionately expensive public administration and infrastructure due to their small size, and little to no opportunity to create economies of scale.

However, GIS based long- term drought monitoring and assessment in Bihar and jharkhand is not common. The objective of the study is to know the spatial and temporal pattern of drought in Bihar using long-term (historic data) data.This study will provide a basis for the projection of future climate extremes over Harohar-Punpun basin under different drought scale. Moreover, the findings of the study will provide potential socio–economic implications for policy–makers to design climate change adaptation and mitigation strategies in the region.

Materials and method

2. Study Area and Data Collection

ThePunpun-Harohar basin is located in the state of Bihar and Jharkhand, India. This basin is situated between latitude 24^0 6’N and 25^0 35’ N and 24^0 10’ N and 25^0 30’N and longitude 84^0 0’E and 85^0 19’E and 84^0 40’E and 86^0 8’E. The total geographical area of Punpun basin is 9025.75sq.Km and Harohar basin is 14296.18 sq.Km. The Punpun basin cover the area of patna district, Jehanabad district, Gaya district, Arungabad district, Palamu District, Nalanda district and Hazaribagh district. The Harohar basin cover the area of Patna district, Nawada district, Jehanabad district, Gaya district, Hazaribagh district, Giridih district, Munger District and Nalanda district. Total 9 sub stations are located in this map. Location map of the study area is shown in Fig.1.

The river Punpun originates from Harihargang block of Palamu District in the Chotanagpur Plateau at the elevation of 442 m. In the head reach it receives the tributaries like Batane, Adari, Madar and Kalan and in the lower reach the river has got two main tributaries known as Morhar and Dardha both running almost parallel to each other and meeting the main stream on the right bank east of Patna-Gaya road. After traversing about 15 Km in north-east direction the river Punpun falls in the river Ganga near Fatuha which is about 20Km east of Patna.

The river Harohar is the principal tributary of the river Kiul having its sub- tributaries like the Dhadhar, the Sakri, the Kaurihari, the Panchane and the Phalgu. The river Phalgu is the united stream of the river Mohane and Lilajan, both having their origins in the hills of Hazaribagh district. The river Paimar rises near village Sichugora in Nawada district and is joind by a branch of river Phalgu and falls into the Dhoa. Dhoa later gets converted into the Harohar.

Average annual rainfall of Punpun basin varies from 99cm near confluence with the Ganga (Patna District) to 134cm in the upper most reach (Palamu District). About 85 to 87 percent of the annual rainfall occurs during monsoon period from June to September. The maximum value of 24Hours rainfall with 50 years frequency is 32cm which occurs in the upper catchment while other portions it is between 24 to 28cm. In Harohar basin, the average annual rainfall varies from 99cm in the lower catchment of the river to 126cm in the hills of Hazaribagh district .About 85 percent of the annual rainfall occurs Seventy years precipitation data has been collected fromIndian Meteorological Department (IMD) for this study from 1951 to 2021. Variations in the yearly precipitation for seventy years from 1951 to 2021 are shown in Fig. 2.

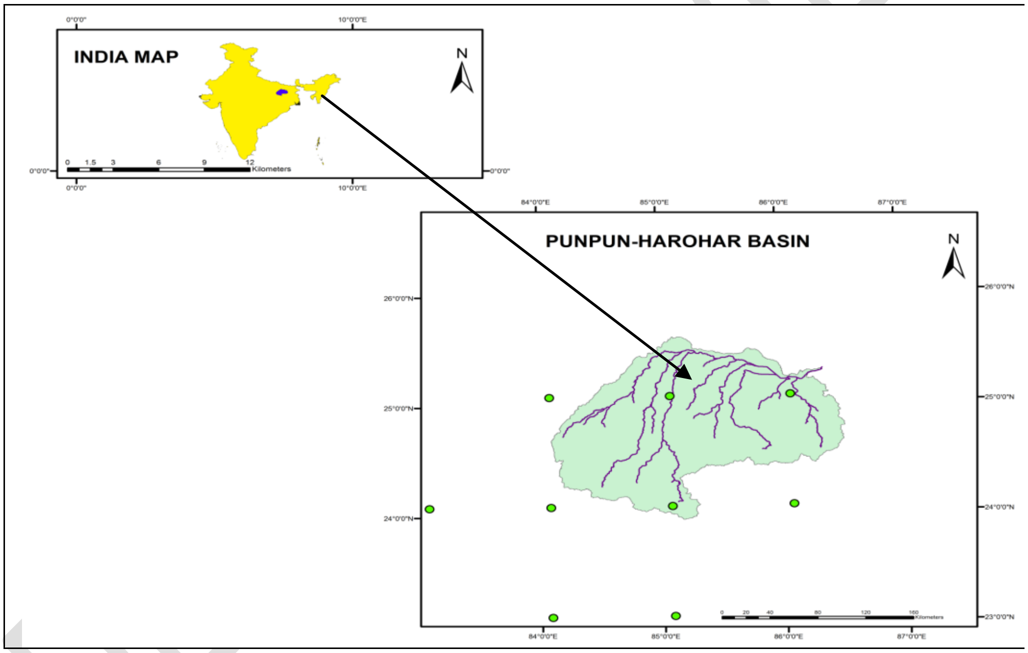

Fig 1: Study Area

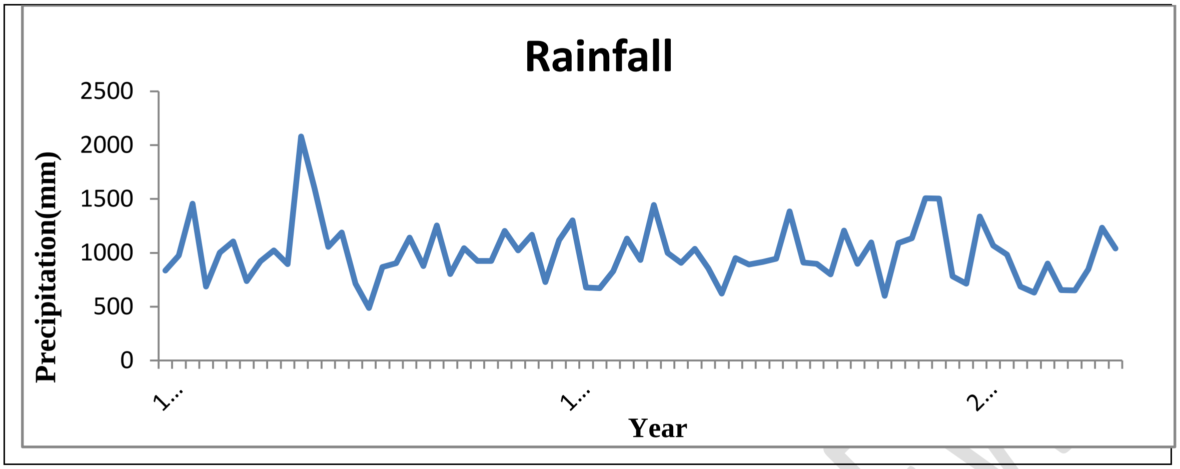

Fig. 2. Yearly precipitation (mm) from 1951 to 2021 for Punpun-Harohar Basin

3. Computation of the Standardized Precipitation Index (SPI)

McKee et al. (1993) developed the Standardized Precipitation Index (SPI) for the purpose of monitoring drought. Thom (1966) found the gamma distribution to fit climatologically precipitation time series well. The gamma distribution is defined by its frequency or probability density function:

$$G(x) = \frac{1}{\beta^{\alpha}\tau^{\alpha}} x^{\alpha-1} e^{\frac{-x}{b}} \qquad (1)$$

Where, α > 0, α is a shape factor. β > 0, β is a scale factor.

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1}\, e^{-y} \qquad (2)$$

Where, Γ (α) is the gamma function.

Computation of the SPI involves fitting a gamma probability density function to a given frequency distributionof precipitation total for a station. From Thom (1966), the maximum likelihood solutions are used to optimallyestimate α and β

$$\acute{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \qquad (3)$$

$$\beta = \frac{x}{\alpha} \tag{4}$$

$$A = l_n x - \frac{\sum \ln (x)}{n} \tag{5}$$

Where, n = number of precipitation observations.

The cumulative probability is given by:

$$G(x) = \frac{1}{\Gamma\ (\alpha)} \int_0^x t^{\alpha - 1}\ e^{-t}\ dt \tag{6}$$

The gamma function is undefined for x=0 and a precipitation distribution may contain zeros, the cumulativeprobability becomes

$$H(x) = q + (1-q)\ G(x) \tag{7}$$

where q is the probability of a zero. If m is the number of zeros in a precipitation time series, Thom (1966) statesthat q can be estimated by m/n. The cumulative probability, H(x), is then transformed to the standard normal randomvariable Z with mean zero and variance of one, which is the value of the SPI.The classification shown in the following table is used to define drought intensities resulting from the SPI computation:

Table 1. Category of Standardized Precipitation Index (SPI) based on range values

SPI Values	Class
>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 to –1.49	Moderately Dry
-1.5 to-1.99	Severely Dry
< -2	Extremely Dry

Table 2. Category of Standardized Precipitation Index (SPI) based on Extreme Draught only for this region

SPI Values	Class
Highly Extreme	<3.5
Moderate Extreme	2.76 to 3.49
Fairly Extreme	2 to 2.75

4. Results and Discussion

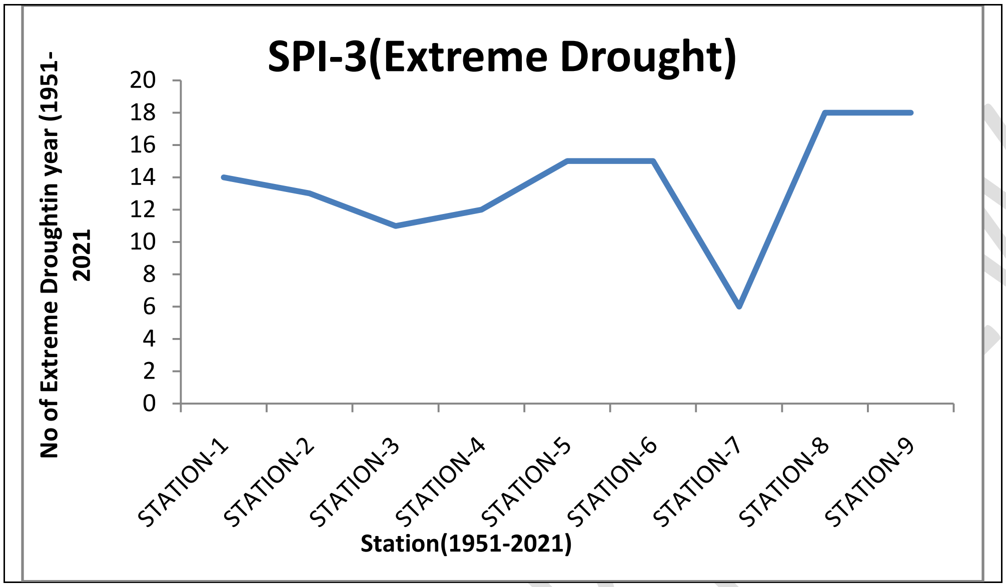

Fig.3 3-month SPI of Extreme Drought for Punpun-Harohar Basin

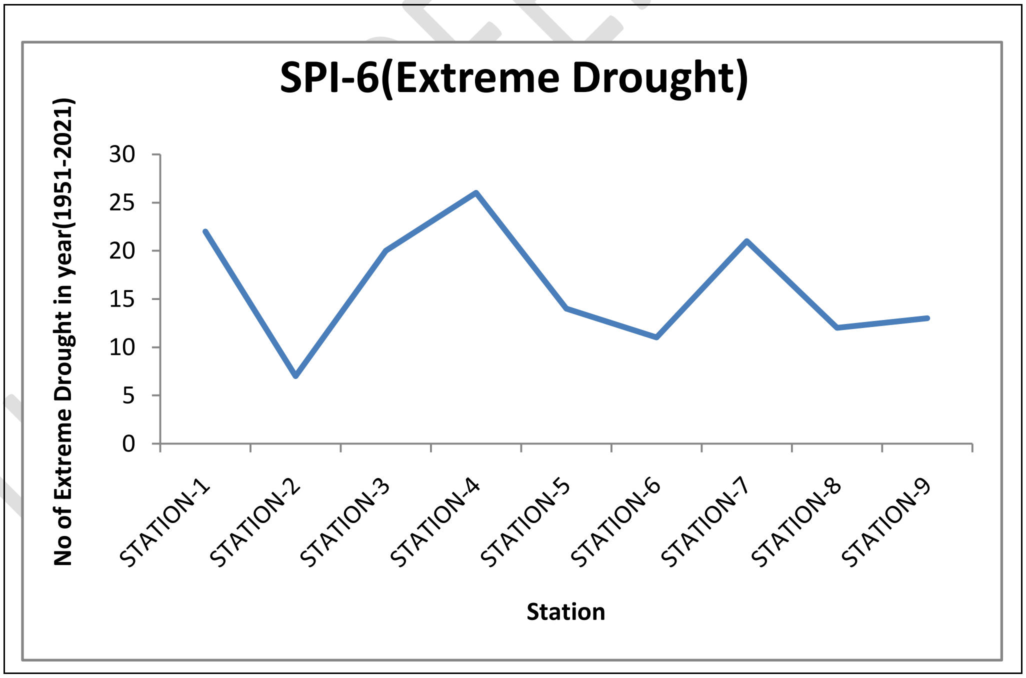

Fig.4 6-month SPI of Extreme Drought for Punpun-Harohar Basin

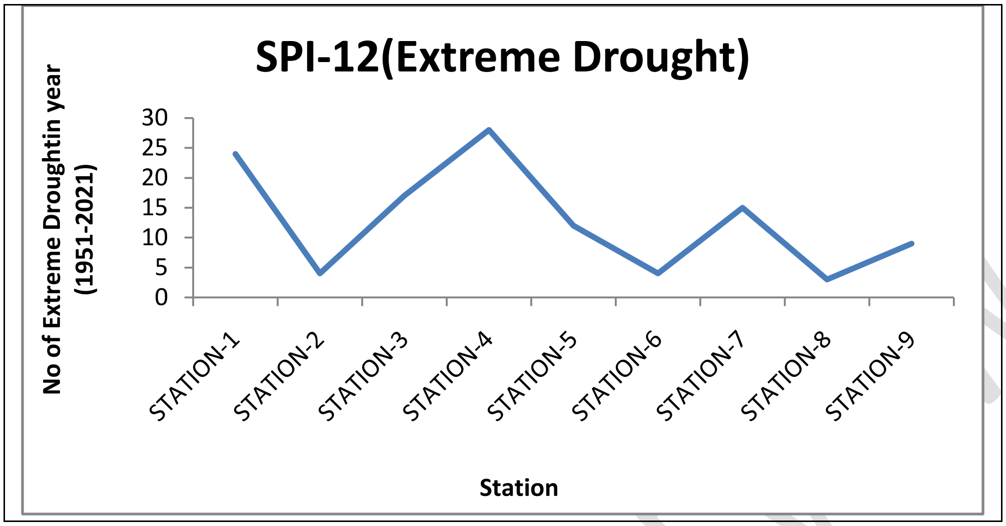

Fig.5 12- month SPI of Extreme Drought for Punpun-Harohar Basin

Table 3. Total number of events of Extreme Drought in Punpun-Harohar Basin

No. of Station	SPI-3	SPI-6	SPI-12
STATION-1	14	22	24
STATION-2	13	7	4
STATION-3	11	20	17
STATION-4	12	26	28
STATION-5	15	14	12
STATION-6	15	11	4
STATION-7	6	21	15
STATION-8	18	12	3
STATION-9	18	13	9

The results for Punpun-Harohar basin were evaluated and found that the results of different station of SPI-3, SPI-6 and SPI-12 have quite different results as per their respective categories.These models were calculated using rainfall data over a 70-year period at nine stations. The extreme drought events for 9 stations of 3, 6 & 12 month SPI in Table 3 are shows.The value of station 8and 9 in SPI-3 is 18 , which is the highest event value of this month and for 6th and 12th month, the maximum number of SPI has come at 4th station whose event value is 26 and 28.

Table 4. Extreme Drought in different Year at SPI-3 and SPI-6

SPI-3				SPI-6			
No. of Station	Year	Month	Extreme Drought	No. of Station	Year	Month	Extreme Drought
1	1972	6	-3.19	1	1989	4	-4.10
2	1972	6	-3.17	2	1966	12	-2.63
3	2008	11	-3.78	3	2009	3	-4.20
4	1988	11	-3.28	4	1999	4	-3.78
5	2008	10	-3.1	5	2009	1	-3.20
6	1966	9	-3.05	6	2001	3	-3.26
7	1982	9	-2.69	7	1995	5	-3.03
8	1966	9	-2.71	8	1982	2	-2.77
9	2011	12	-2.63	9	1972	8	-3.26

Table 5. Extreme Drought in different Year at SPI-12

SPI-12			
No. of Station	Year	Month	Extreme Drought
1	1980	2	-2.92
2	1967	6	-2.99
3	1967	2	-3.18
4	1967	6	-3.39
5	1982	7	-2.53
6	2018	12	-2.4
7	1967	6	-2.99
8	1958	7	-2.86
9	1973	3	-2.44

Table 4 & 5 shows extreme drought in different Year at SPI-3, SPI-6 & SPI-12.Maximum extreme drought was found in 11 months of 1988 in 3 month SPI, whose value is -3.78 at station 3 and lowest value was -2.63 in 2011 at station 9. Similarly in 6 and 12 month of maximum SPI were -4.10 and -3.39 , which has found in year 1989 and 1967 at station 1and 2.In SPI-3, SPI-6 and SPI-12, we see that extreme drought has started since the year 1966. Extreme drought comes once in about 10 years or less.

Fig 6 and 7 shows graphical representation of SPI 3, SPI6 and SPI12of different Extreme Drought for Punpun-Harohar Basin for the basis of Table 2.To know more accurately about the result of Extreme Drought, we have divided the Extreme Drought for this area into three parts.According to spi-3, spi-6 & spi-12, we found that station 3 has shown highly extreme drought.This can be seen in the figure6 and 7.And moderate drought has come 6th time in SPI-3, SPI-6 and SPI-12.Whose highest value is -3.46.

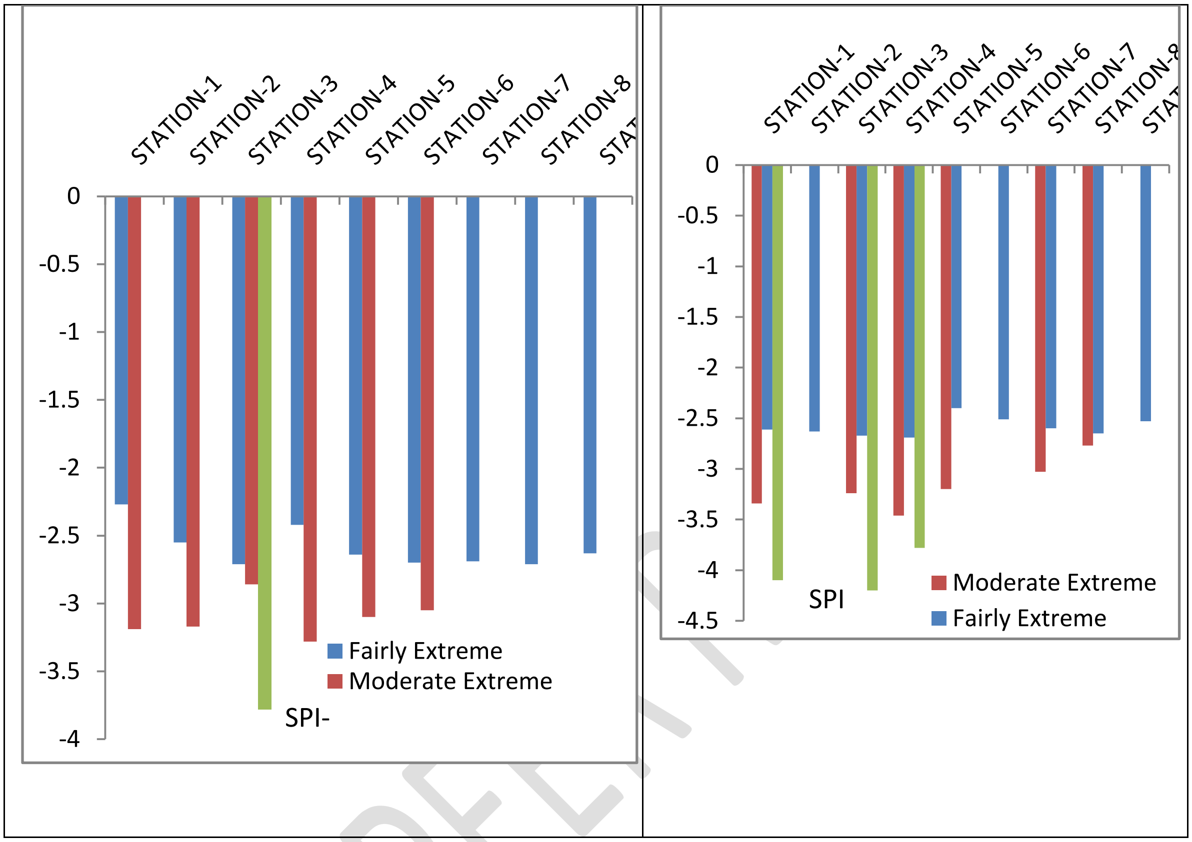

Fig.63 & 6- month SPI of different Extreme Drought for Punpun-Harohar Basin

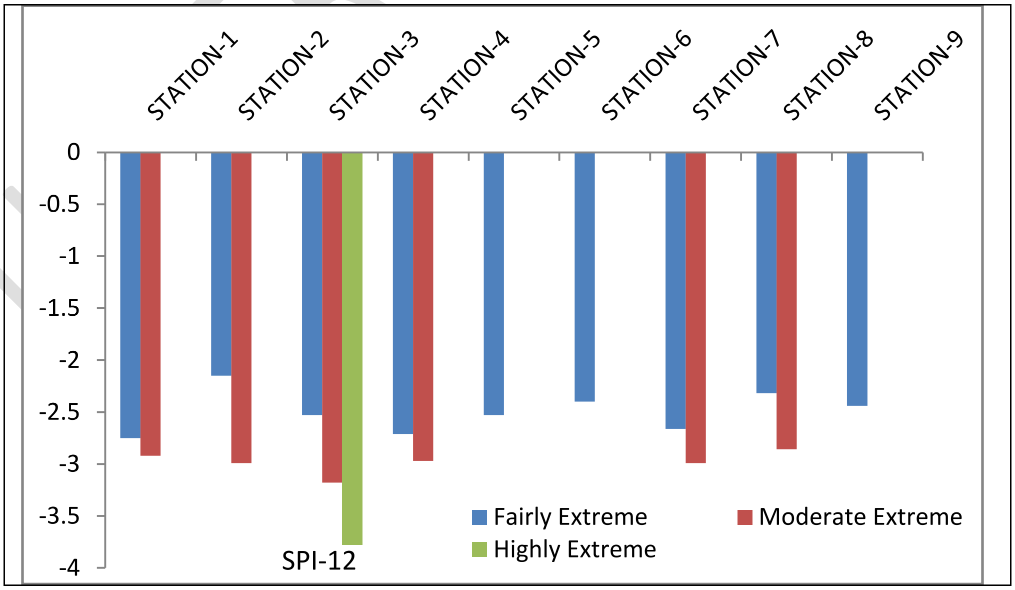

Fig.712- month SPI of different Extreme Drought for Punpun-Harohar Basin

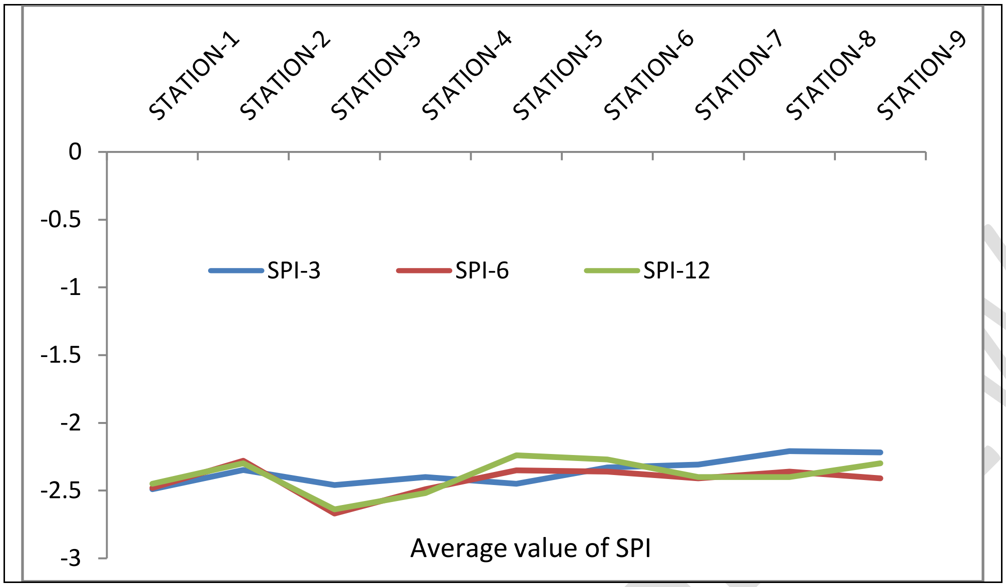

Fig.83, 6 &12- month SPI of Extreme Drought for Punpun-Harohar Basin

Table 6.Average Extreme Drought in different Station at SPI-3 and SPI-6

No. of Station	SPI-3	SPI-6	SPI-12
STATION-1	-2.49	-2.48	-2.45
STATION-2	-2.35	-2.28	-2.3
STATION-3	-2.46	-2.67	-2.64
STATION-4	-2.4	-2.49	-2.52
STATION-5	-2.45	-2.35	-2.24
STATION-6	-2.33	-2.36	-2.27
STATION-7	-2.31	-2.41	-2.4
STATION-8	-2.21	-2.36	-2.4
STATION-9	-2.22	-2.41	-2.3

5. Conclusion

As a result, the primary goal of this study was to evaluate droughts identified in the Punpun-Harohar basin's historical rainfall data using the Standardized Precipitation Index criterion. The analysis of temporal patterns in drought produced a number of intriguing results about the variability in the incidence of drought in the area. The reported rainfall data in this basin showed an increasing trend, indicating that the areas under examination are drought prone. In order to evaluate drought characteristics like frequency and severity, it found that SPI is a useful method. Due to the fact that it employs just precipitation data and provides reliable results, the SPI technique performs best without the use of other environmental parameters such as minimum and maximum temperatures, humidity, potential evapotranspiration (ETo), and sun hours.

Results from the SPI-3, SPI-6, and SPI-12 methods are comparable to those from other extreme drought situations. Because it is straightforward and efficient, this approach is preferable for agricultural applications.

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