Drought forecastingUsing Standard Precipitation Index Based on Rainfall of Western Region

Abstract

Drought has always been one of the most dangerous natural disasters for manhood. Due to the continuous global climate change, drought occurrences have become more frequent and severe, affecting human existence and long-term social progress. This work, three different statistical distributions; gamma, normal, and log-normal were used to model the precipitation data in order to calculate the multi-temporal $PI_{Standard}$ values. Therefore, utilising all three of the above-mentioned theoretical probability distributions, the drought index $PI_{Standard}$ has been computed. $PI_{Standard}$range more than 2 (extremely wet) to less than -2 (extremely dry), with 0.99 to - 0.99 considered the near-normal range. $PI_{Standard}$ is calculated at different time scales which can be 1, 3, 6, 12 and 24months, time scales. The temporal trends of SPI at the stations were identified using the Mann-Kendall test.$PI_{Standard}$ were computation at 1, 3, 6, 9, 12 and 24-month time scales. $P_{IStandard}$ provides a better analysis of meteorological drought at multiple different timescales for short- and long-term planning because it uses the running sum of rainfall values at 1 to 24 months and more parameters for the statistical distribution used.For short-term drought monitoring and agricultural crop planning, a 1- to 3-month $PI_{Standard}$ can be utilized; however, long-term hydrological drought monitoring and water management planning require $PI_{Standards}$ of 6 to 9 months and 12 to 24 months, respectively.Drought analysis using $PI_{Standard}$ results can be used to design rainwater harvesting and storage structures in drought-affected areas for appropriate crop planning.

Key words: Rainfall, Standardized Precipitation Index ($PI_{Standard}$), Running Sum

1. Introduction

Drought has always been one of the most dangerous natural disasters for manhood. Due to the continuous global climate change, drought occurrences have become more frequent and severe, affecting human existence and long-term social progress. Between 1950 and 2000, China's average catastrophic area was about 21.14 M ha, or 14.9% of the nations planted area. 6.64 billion dollars in agriculture economic losses resulting from 16.09 M persons having

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difficulty accessing benign water to consume**(Thomas and kumar, 2016; Shekhar and Shapiro, 2019).**

Drought is a natural occurrence in which there is significantly less water or moisture available than is typical or forecast for a particular time(**Ramdas, 1950; Beran and Redier, 1985)**. When it comes to the agro-climatic conditions in any given place for a time period, this condition might be caused by inadequate rainfall, a lack of irrigation facilities, under-exploitation, or a lack of water or moisture availability to meet the usual crop requirements **(Barker *et al.*, 2016; Palmer, 1968)**. The activities causing global climate change are forecast to cause droughts with a significant impact on agriculture all over the worldwide, especially in developing countries, even though these continue to be relatively isolated in their breadth **(Chandra*et al.*, 2018; Ntale and Gan, 2023)**. Droughts can have serious consequences for the environment, agriculture, human health, the economy, and society. Using drought indices like the Standardized Precipitation Index ($PI_{Standard}$) **(Mc Kee *et al.*, 1993)** and the Effective Drought Index (EDI), drought research and assessment is conducted **(Byun & Wilhite, 1999)**. Precipitation data are used as the computation's input in each of these methods**(Gibbs, and Maher, 1967)**. The $PI_{Standard}$ requires less computing than alternatives because it is based on the probability of precipitation during any time period **(Dracup *et al.*, 180a; Sen, 1980).** Long-term precipitation anomalies can have an impact on groundwater level, stream flow, and reservoir storage**(Kumar*et al.*, 2022).**

Another important drought indicator, the effective drought index (EDI), is created using a daily time step **(Byun and Wilhite, 1996); Guttam, 1998; Guttam,1999).** However, its principles can be used similarly with monthly precipitation data**(Kar*et al.*,2004)**. The effective drought index (EDI) determined by the amount of precipitation required to restore normal conditions (PRN). The recovery from the drought's accumulated deficit is dependent on PRN, or precipitation. PRN is effectively determined by monthly effective precipitation (EP) and the variation in EP from the mean for each month. The study's findings could be applied to rainwater collection, crop planning and management, and water resource storage buildings **(kumar, *et al.* 2022)**

The following factors related to the complexity of the influencing factors and physical mechanisms in a region where severe droughts occur frequently: the first is the outdated infrastructure for water conservation projects and insufficient disaster resistance; the second is the ecological over-cutting of forest resources, which seriously damages soil and vegetation and modifies the natural regulation of the water cycle system, particularly the artillery cycle (**Wilhite, *et. al* 2007; Karlina, 2016)**. The specific objectives of this study are; computation of meteorological drought indices, to identify dry, normal and wet conditions on different time and to propose a water management and mitigation of drought **(Wilhiteet al., 2007; Salehnia*et al.*, 2017)**.

2. Material and Methods

2.1 Study area

This study was planned to compute the $PI_{Standard}$ values for different time spans using the rainfall data of Modipuram (Meerut) district in Uttar Pradesh State of IndiaImportant information about the study area and methodologies used are presented in this chapter.The data recording site lies in Plane region district Meerut in the west U.P. The coordinates are 290 01' North latitude, 770 45' East longitude, and 219.75 m above mean sea level. Meerut is also located on the western edge of India's fertile Gangetic plains. Meerut has a subtropical climate with cold winters, mild springs, hot summers, and a typical monsoon. The rainy season begins on June 15th and lasts until September, with average rainfall in July. Summer temperatures range from 46°C to 26°C. Temperatures in the winter range from 25°C to 5.2°C. The relative humidity ranges from 45% in May to 85% in January. May is the driest and January is the coolest month.

2.2 Collection and Analysis of Data

The rainfall data for 30 years (1990 to 2019) of Modiuram (Meerut) district were taken from the IIFSR and SVPUA&T at Modipuram MeerutFig. 1. The daily rainfall data of Modiuram (Meerut) station for 30 years (1990 to 2019).

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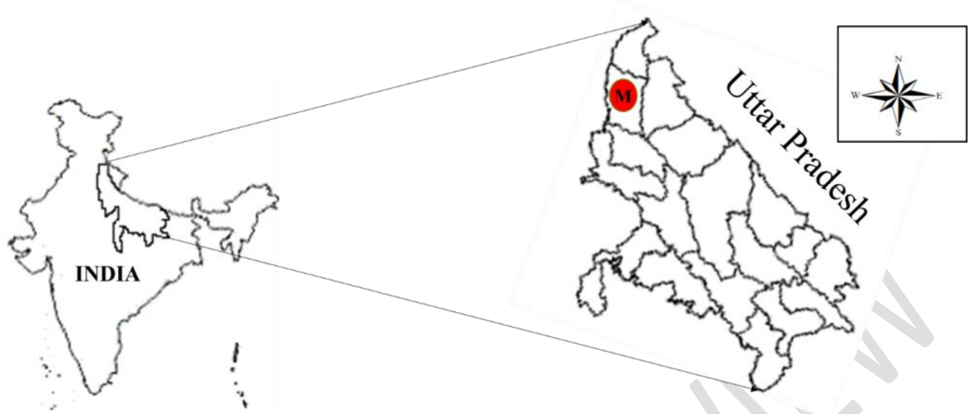


Fig. 1 Location of study area

2.2 Standardized Precipitation Index

Compared to earlier approaches, the $PI_{Standard}$ more accurately captures moisture and dryness. $PI_{Standard}$ is computed over a range of time periods, including 1, 3, 6, 12, 24, and 48 months. Draughts cannot be predicted by the $PI_{Standard}$, but it can depict when wetness and dryness occur. The $PI_{Standard}$ is computed for any desired period at any location using the long-term precipitation record (30 years or more). When the $PI_{Standard}$ value is positive, there was more precipitation than the median; when it is negative, there was less precipitation than the median. The classification scheme for draught intensities resulting from $PI_{Standard}$ estimates is displayed in Table 1.

Table 1 The $PI_{Standard}$ induced drought intensities were categorized using the table below

Particulars	**$PI_{Standard}$(Z) values**
Extremely wet	2 and above
Very wet	1.5 to 1.99
Moderately wet	1.0 to 1.49
Near normal	-0.99 to 0.99
Moderately dry	-1 to -1.49
Severely dry	-1.5 to -1.99

Extremely dry	-2 and less

2.3 $PI_{Standard}$ computation

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.

$$g(X) = \frac{1}{\beta^{\alpha}\Gamma^{\alpha}} X^{\alpha-1} e^{-x/\beta} \quad \text{..... (1)}$$

where, α = shape parameter, $\alpha > 0$, β = scale parameter, $\beta > 0$ and x = precipitation amount (mm), $x > 0$

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy \quad \text{....(2)}$$

where, $\Gamma(\alpha)$= gamma function of α .

Fitting a gamma probability density function (PDF) to a given frequency distribution (FD) of precipitation totals for a station is required to compute the $PI_{Standard}$. To estimate α and β as follows:

$$\bar{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad \text{.... (3)}$$

$$\bar{\beta} = \frac{\bar{X}}{\alpha} \quad \text{.... (4)}$$

$$A = \ln\left(\bar{X}\right) - \frac{\sum \ln(X)}{n} \quad \text{.... (5)}$$

$\bar{x}$= average rainfall in mm of all previous data of same event,n= number of precipitation observations

After calculating the values of α, β and A, the cumulative probability of a observed precipitation event for a given time scale can be found out. Calculated the cumulative probability is done as follows:

$$G(X) = \int_0^{x} g(X) dx \quad \text{.... (6)}$$

$$G(X)=\frac{1}{\beta^{\alpha}\Gamma(\alpha)}\int_0^x X^{\bar{\alpha}-1}e^{-x/\beta}dx \quad \text{…. (7)}$$

Since a precipitation distribution may contain zeros and the gamma function is undefinable for x = 0, the cumulative probability becomes:

$$H(X)=q+(1-q)G(X) \quad \text{.... (8)}$$

where,q= the probability of a zero event

For, $0<H(X)\leq 0.5$

$$SPI(Z)=-\left(t-\frac{(c_0+c_1\times t+c_2\times t^2)}{(1+d_1\times t+d_2\times t^2+d_3\times t^3)}\right). \quad \text{.... (9)}$$

For, $0.5<H(X)\leq 1.0$

$$SPI(Z)=+\left(t-\frac{(c_0+c_1\times t+c_2\times t^2)}{(1+d_1\times t+d_2\times t^2+d_3\times t^3)}\right) \quad \text{.... (10)}$$

where,For, $0<H(X)\leq 0.5$

$$t=\sqrt{\left(\ln\frac{1}{(H(X))^2}\right)} \quad \text{…. (11)}$$

For, $0.5<H(X)\leq 1.0$

$$t=\sqrt{\left(\ln\frac{1}{(1-H(X))^2}\right)} \quad \text{…. (12)}$$

and the coefficients are

$0.5<H(X)\leq 1.0$

$c_0=2.515517$ $c_1=0.802853$ $c_2=0.010328$

$d_1=1.432788$ $d_2=0.189269$ $d_3=0.001308$

The $PI_{Standard}$ values and their corresponding cumulative probability are given in Table 2.

Table 2 $PI_{Standard}$ **and its corresponding cumulative probability**

$PI_{Standard}$	**Cumulative probability**
-3.0	0.0014
-2.5	0.0062
-2.0	0.0228
-1.5	0.0668
-1.0	0.1587
-0.5	0.3085
0.0	0.5000
+0.5	0.6915
+1.0	0.8413
+1.5	0.9332
+2.0	0.9772
+2.5	0.9938
+3.0	0.9986

$PI_{Standard}$ is computed for any month in the record pervious i_{th} months, where i_{th} = 1, 3, …24 depending on the time period of interest. As a result, the $PI_{Standard}$ can be calculated with both a three-month and a 24-month total of precipitation. A short-term or seasonal drought index, an intermediate-term drought index, a long-term drought index, and a long-term drought index are all calculated for the purposes of this study using a 1, 3, 6, and 12 month $PI_{Standard}$, respectively.

3. Result and Discussions

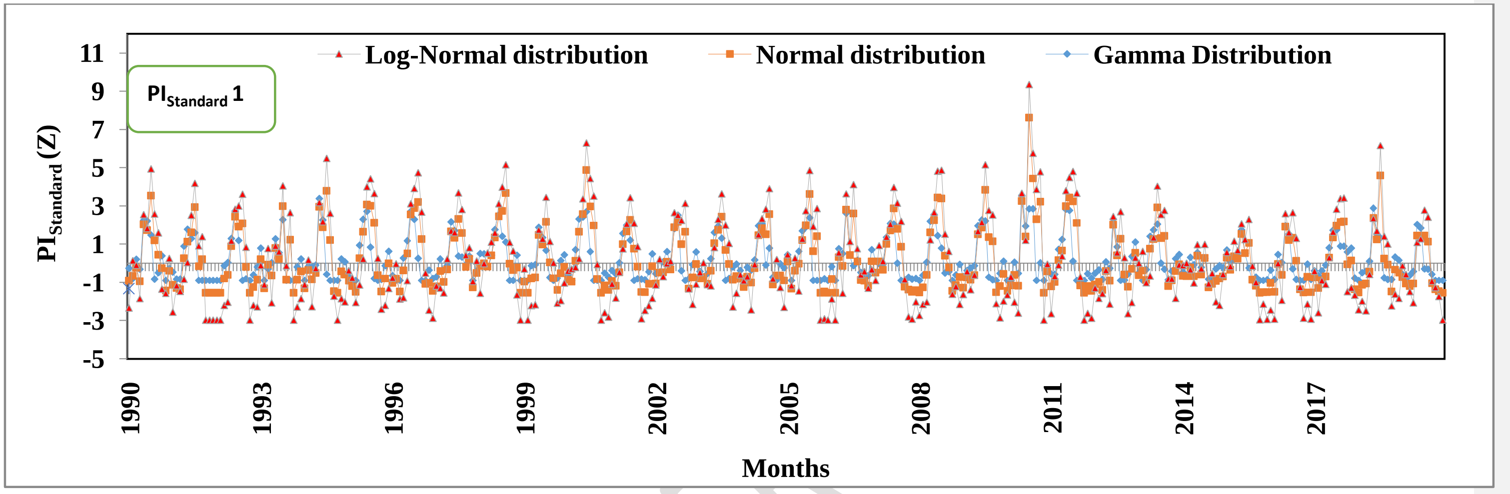
3.1 Standardized Precipitation Index ($PI_{Standard}$) Using Different Density Probability Distributions (i.e. Gamma, Normal and log-normal)

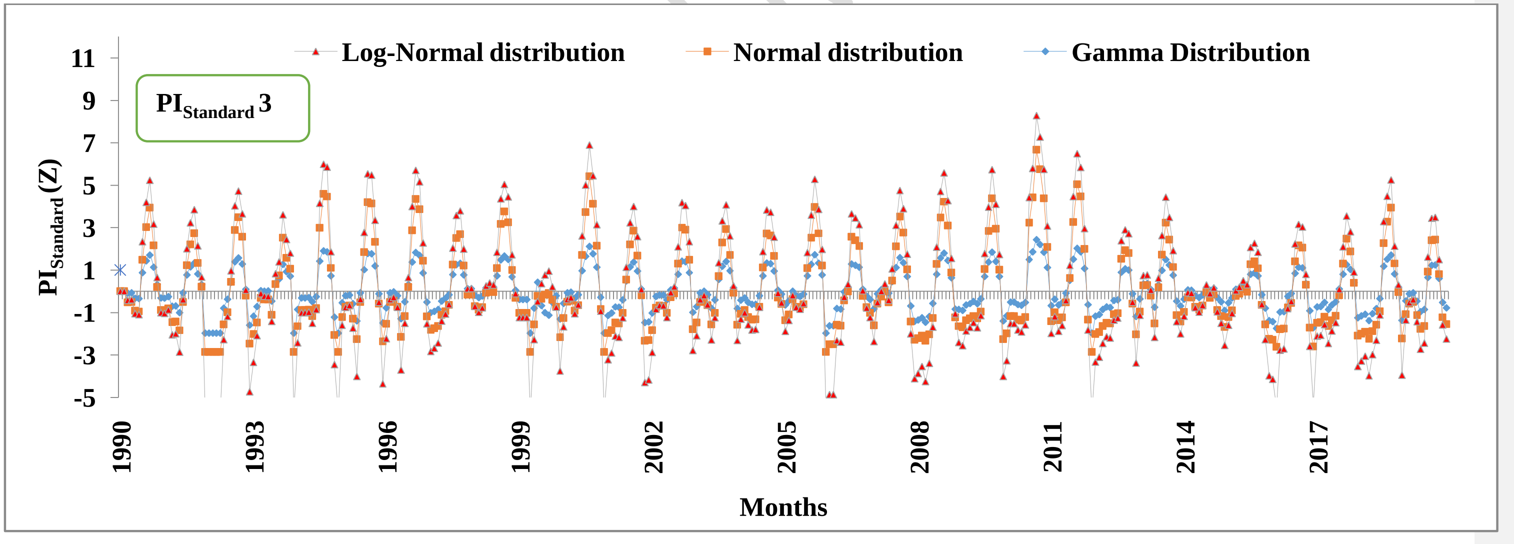
The gamma distribution has been more frequently used to calculate the meteorological data in order to create the drought index $PI_{Standard}$. The study provided previously appears to support this approach. However, it is important to investigate whether the $PI_{Standard}$ at specific time scales, both the normal and log-normal probability distributions, which have the benefits of simplicity, can be described equally well or better. This work, three different statistical distributions; gamma, normal, and log-normal were used to model the precipitation data in order to calculate the multi-temporal $PI_{Standard}$ values. Therefore, utilising all three of the above-mentioned theoretical probability distributions, the drought index $PI_{Standard}$ has been computed.

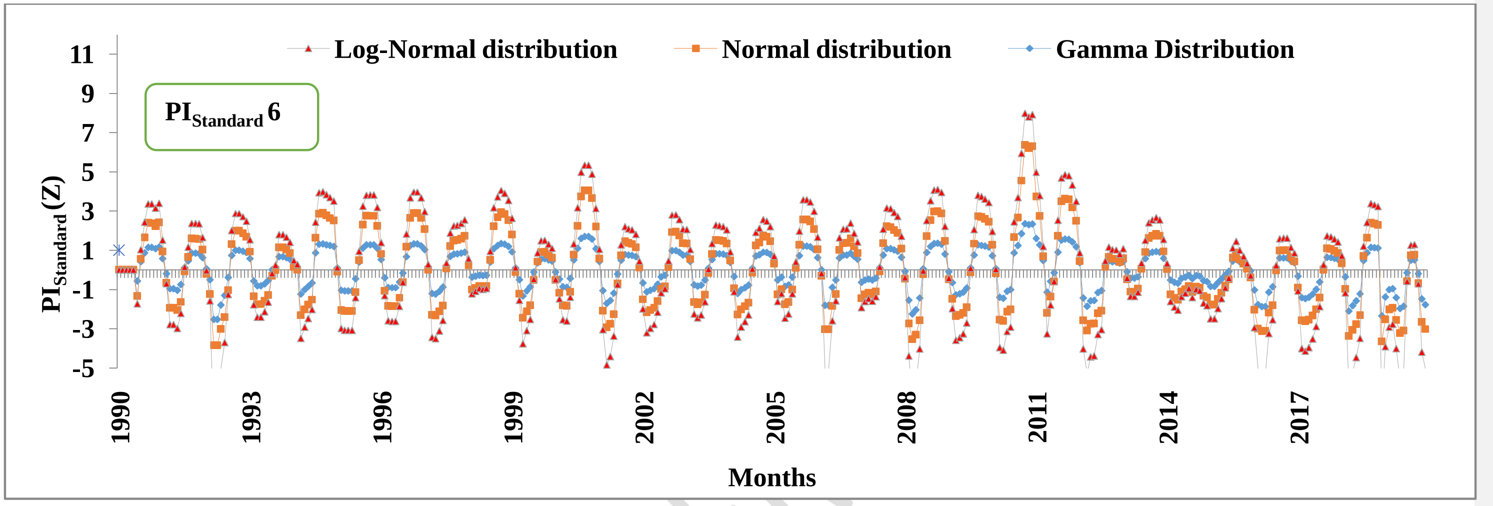
In the current study, rainfall data from the drier regions of western Uttarpradesh, during 30 years (1990-2019) have been analysed to identify the dryness condition at various time scales using $PI_{Standard}$. This rainfall data's analysis using $PI_{Standard}$ illustrates the frequency and severity of droughts at several time scales, including monthly, yearly, pre-monsoon, monsoon, and post-monsoon periods. However, as was already mentioned, values less than 1 signify a meteorological drought situation. All negative $PI_{Standard}$ data is generally a dry condition. The investigation of meteorological drought scenarios in India's western area can be using the $PI_{Standard}$.

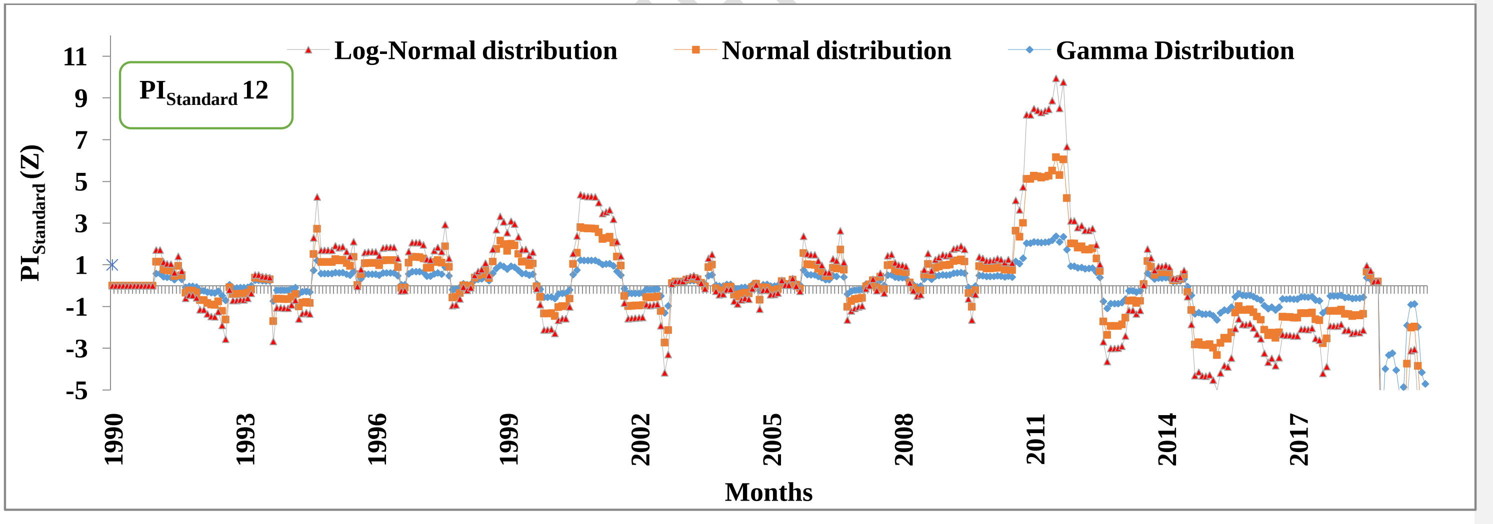
The temporal trends of SPI at the stations were identified using the Mann-Kendall test.$PI_{Standard}$ were computation at 1, 3, 6, 9, 12and 24-month time scales. Fig. 2 shows that the index had variations at short time scales, which decreased as the time scale increased. The three theoretical probability distributions shown in Fig. 2 have been used to create the drought indices $PI_{Standard}$ 6, $PI_{Standard}$ 12, and $PI_{Standard}$ 24 for time series. As can be evident, with the exception of a few extremely dry or extremely wet seasons, the $PI_{Standard}$ 12 coincidence when estimated using the three theoretical probability distribution function is very good. The same figure also shows that the $PI_{Standard}$-24 calculated using the three theoretical probability distributions is extremely similar, with small deviations occurring primarily during exceptionally dry or wet seasons. This happens even though the K-S test indicates that the gamma probability distribution fits for time series the closest. The coincidence is not favourable for the $PI_{Standard}$-6 considering the three theoretical distributions.

The SPI diagram is used to show in Fig. 3are comparable to those in Fig. 2, but in order to save time for time series where the gamma probability distribution best fits the running sum of 12 and 24 months of precipitation, the similar $PI_{Standard}$ diagrams as in Fig. 2 are shown in Fig. 3. As can be seen, the $PI_{Standard}$ 12 and $PI_{Standard}$24 readings, as well as the $PI_{Standard}$6, are extremely close.The SPI values used to show in Fig. 3 are comparable to those in Fig. 2, but in order to save time for time series where the log-normal probability distribution best fits the running sum of 12 and 24 months of precipitation, the similar SPI diagrams as in Fig. 2 are shown in Fig. 3. As can be seen, the $PI_{Standard}$ 12 and $PI_{Standard}$ 24 readings, as well as the $PI_{Standard}$ 6, are extremely close. The same findings can be obtained, which is a time series, where average normal probability distribution fits the running sum of precipitation over 12 and 24 months the best.


Log-Normal distribution
Normal distribution
Gamma Distribution
PIStandard 1
PIStandard (Z)
Months


Log-Normal distribution
Normal distribution
Gamma Distribution
PIStandard 3
PIStandard (Z)
Months


Log-Normal distribution
Normal distribution
Gamma Distribution
PI$_{Standard}$ 6
11
9
7
5
3
1
-1
-3
-5
PI$_{Standard}$(Z)
1990
1993
1996
1999
2002
2005
2008
2011
2014
2017
Months


Log-Normal distribution
Normal distribution
Gamma Distribution
PI$_{Standard}$ 12
11
9
7
5
3
1
-1
-3
-5
PI$_{Standard}$(Z)
1990
1993
1996
1999
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2005
2008
2011
2014
2017
Months

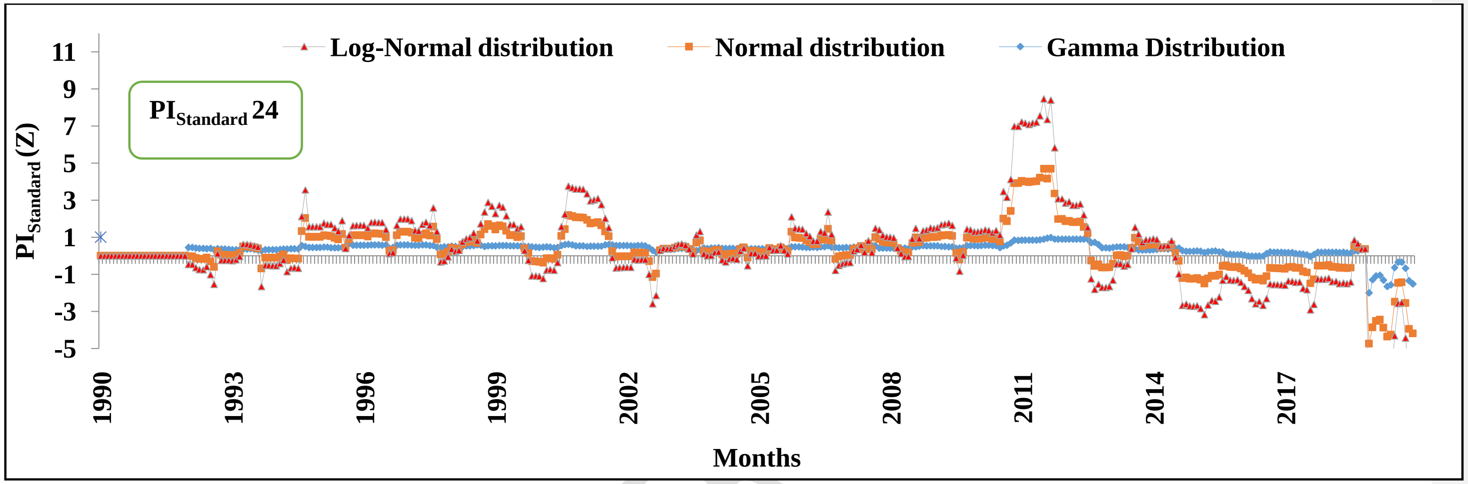
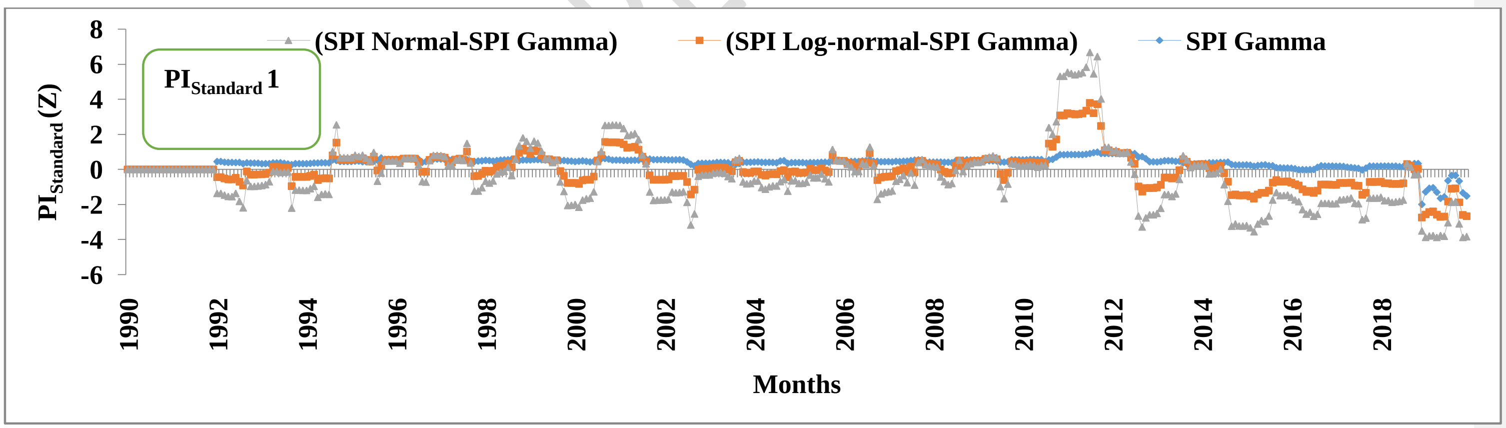
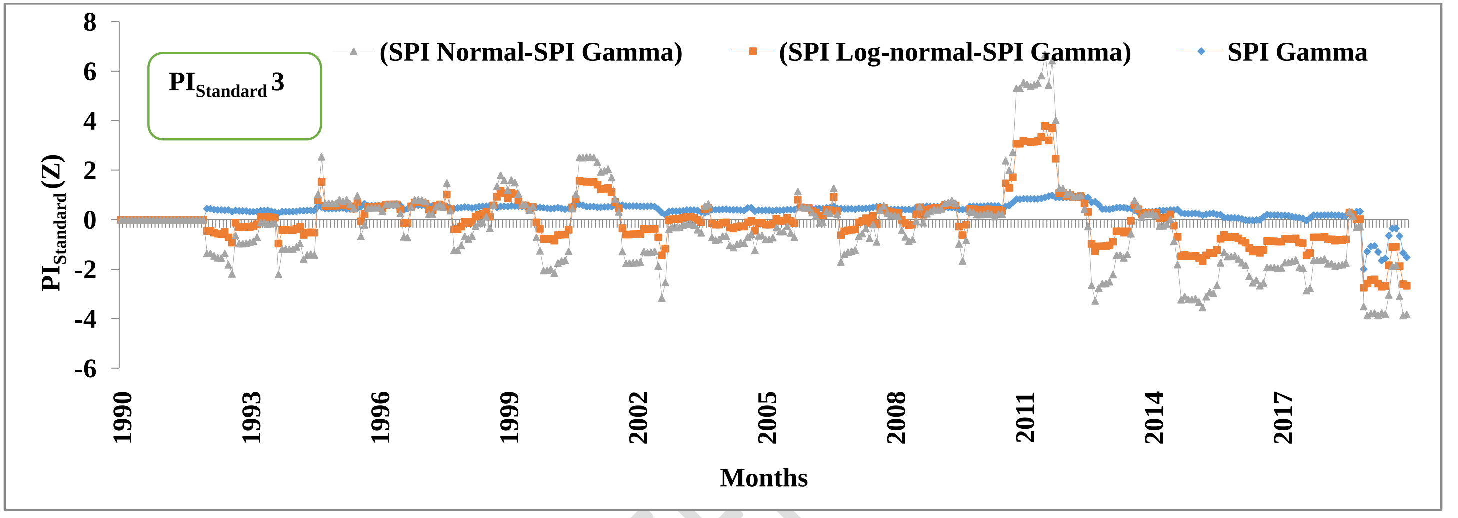
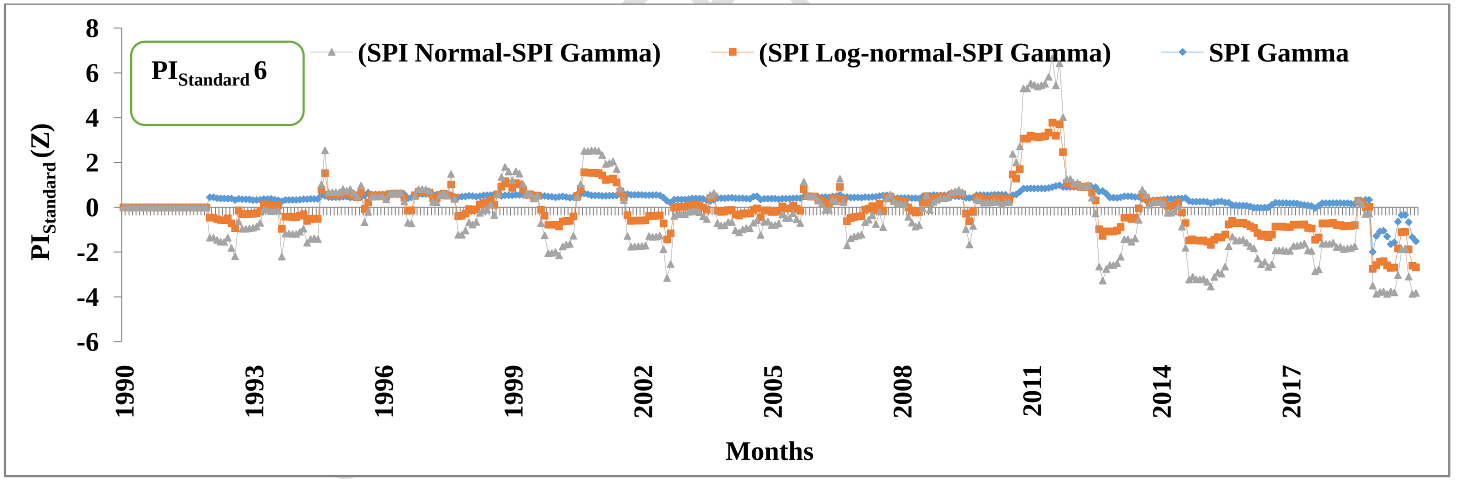


Fig. 2: Drought index of$PI_{Standard}$for time series (1990-2019), modelled by gamma, normal, and log-normal probability distributions, at time scales of 1, 3, 6, 12, and 24 months




PIStandard 3
(SPI Normal-SPI Gamma)
(SPI Log-normal-SPI Gamma)
SPI Gamma
PIStandard(Z)
8
6
4
2
0
-2
-4
-6
1990
1993
1996
1999
2002
2005
2008
2011
2014
2017
Months


PIStandard 6
(SPI Normal-SPI Gamma)
(SPI Log-normal-SPI Gamma)
SPI Gamma
PIStandard(Z)
8
6
4
2
0
-2
-4
-6
1990
1993
1996
1999
2002
2005
2008
2011
2014
2017
Months

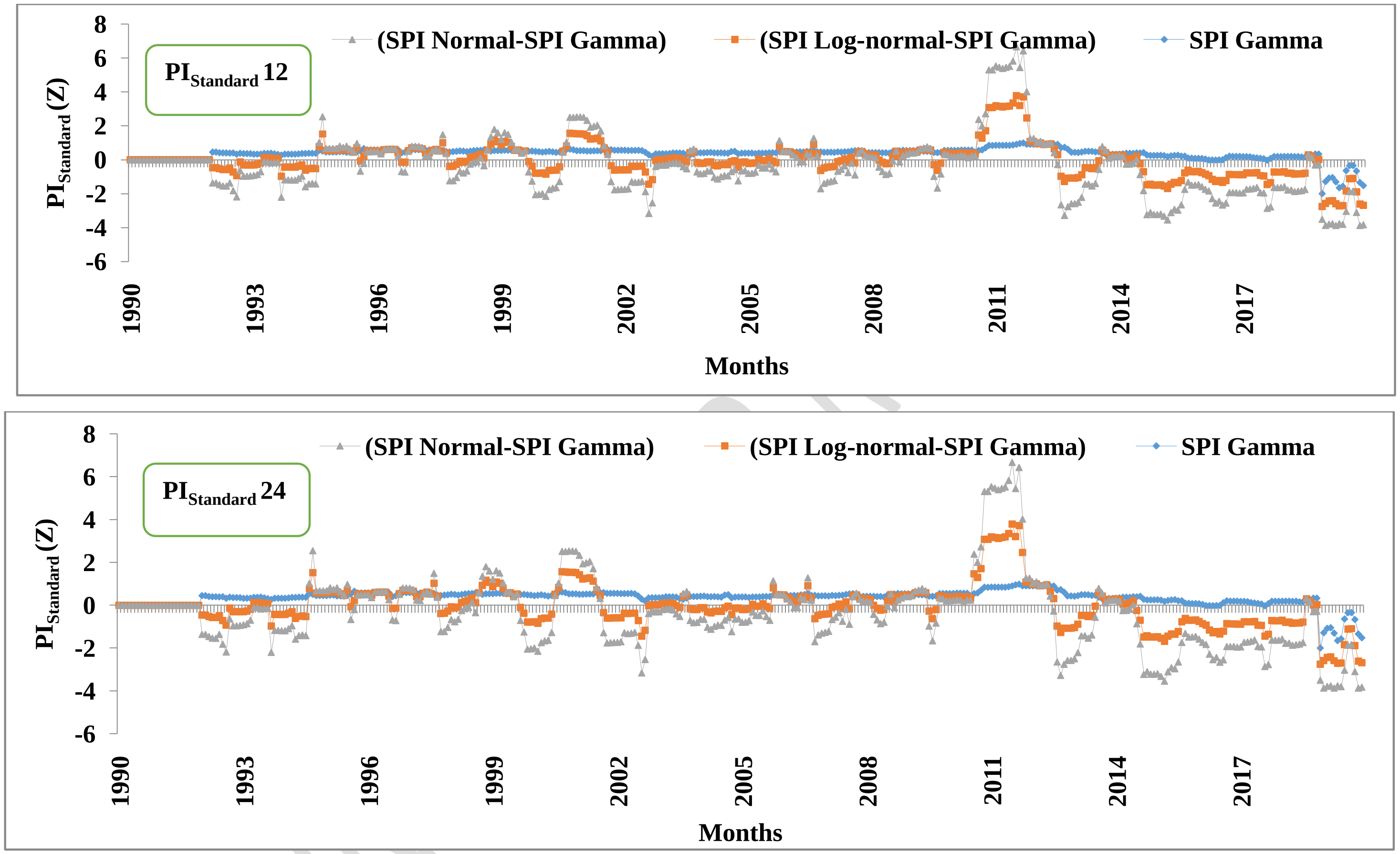


Fig 3: Drought index $PI_{Standard}$ for the time series for rainfall data on (1990–2019), at time scales of 1, 3 6, 12 and 24 months, modeled by gamma probability distribution, and its differences from SPI modeled by normal and log–normalprobability distributions

The $PI_{Standard}$ depending on gamma probability distribution is always somewhere between the SPI depending on normal and the $PI_{Standard}$ depending on log-normal distribution, as can be observed in Figs. 4, and 5 as well as for $PI_{Standard}$ 3 and $PI_{Standard}$ 12. The $PI_{Standard}$ represented by during wet periods with positive $PI_{Standard}$ values compared to $PI_{Standard}$ depending on gamma probability distribution, log-normal distribution always underestimates the extreme wet periods while normal probability distribution always contains a high the wet period in extreme circumstances. At the most extreme dry periods with negative $PI_{Standard}$ values, the exact reverse occurs, yet the $PI_{Standard}$ forecast by gamma always remains between the other two. In comparison to the normal distribution-based SPI, there seem to be a slight upward trend.

According to Figs 4 and 5, the $PI_{Standard}$ could be expected to serve as a suitable reference that corresponds to the amount of rainfall over 3 or 12 months. A 3-month period with less than 100 mm of precipitation, for example, will result in a moderate drought (1.49 $PI_{Standard}$> 1.0), whereas a 3-month period with 1000-1350 mm of precipitation will result in a moderate wet (1.49 $PI_{Standard}$> 1.0). The relationship between the two curves of rainfall and its cumulative probability for $PI_{Standard}$-3 and $PI_{Standard}$-12, which may be used as an under comparable for both short- and long-term predictions for Pantnagar station, should coincide with the relationship between the curve of cumulative probability and $PI_{Standard}$, according to Figs. 6 (a and b). The occurrence of drought or flooding for a specific total rainfall corresponding to a different time period will also be predicted. Find the quantity of rain in Pantnagar over a 3-month or 12-month time period on cross the cumulative probability curve.

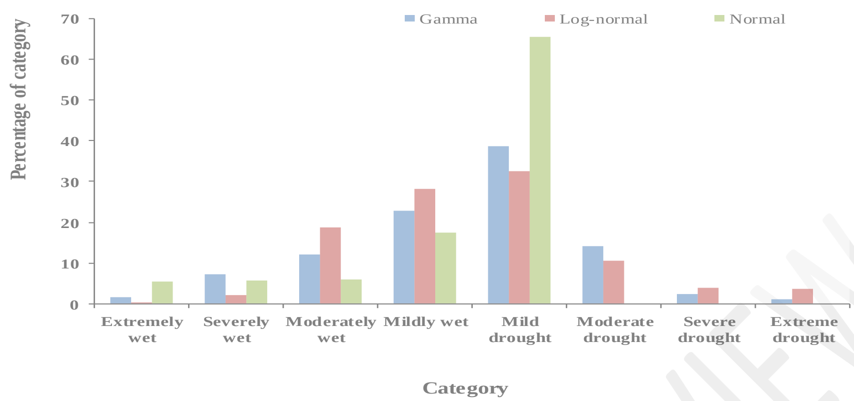


Fig. 4 Droughts found by $PI_{Standard}$ in Modipuram (Meerut)for 3 month (1990–2019)

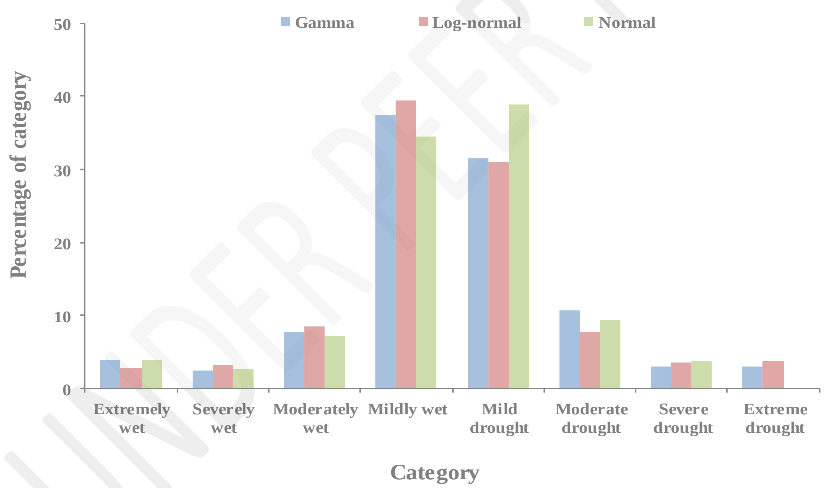


Fig. 5 Droughts found by $PI_{Standard}$ in Modipuram (Meerut)for 12 month (1990–2019)

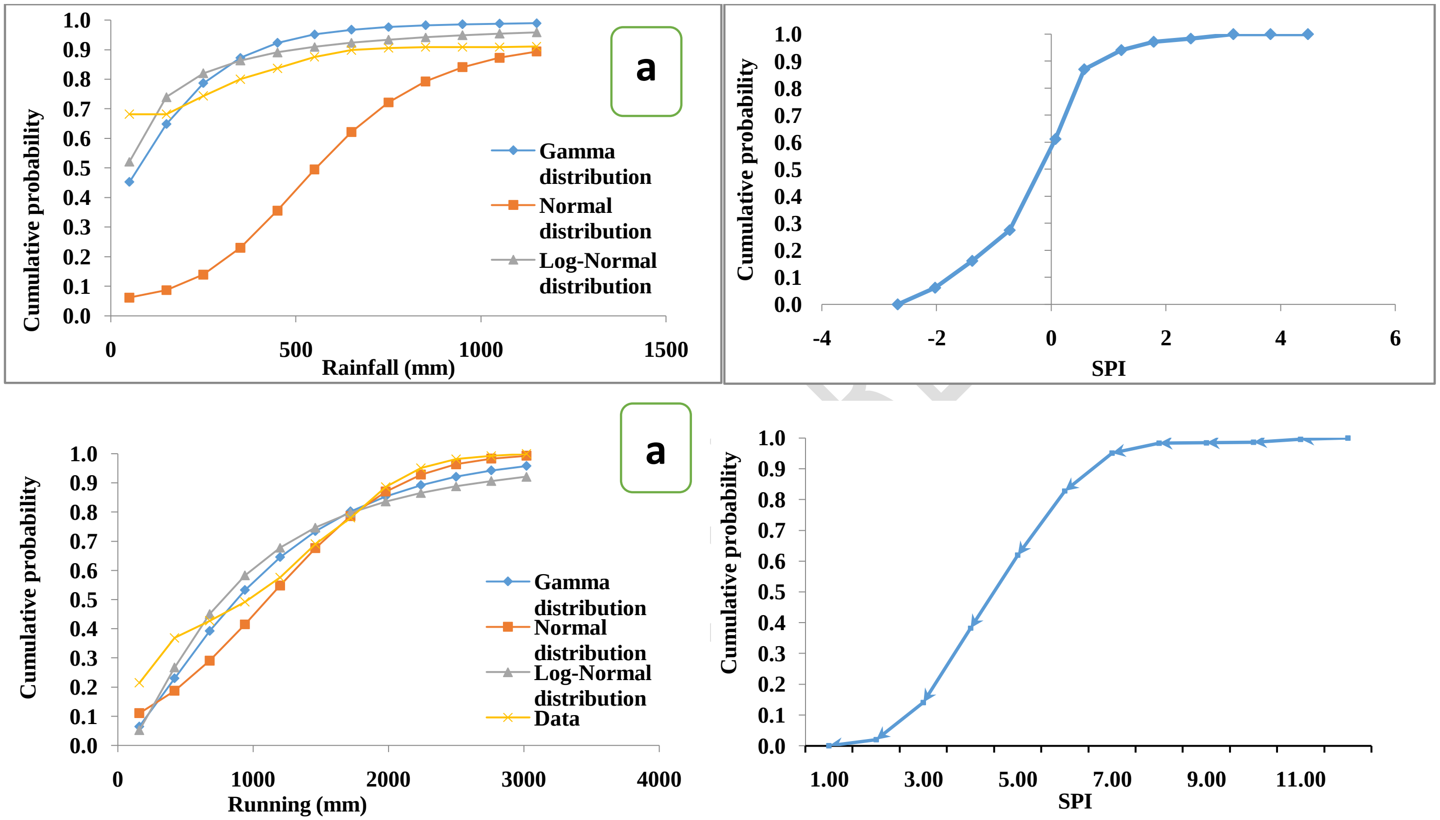


Fig. 6 (a and b):Theoretical and empirical cumulative probability distributions for the cumulative amount of precipitation during 3 and 12 months

Conclusions

As a result, monitoring of meteorological drought is serious for this region. Drought monitoring in the region can be done using the $PI_{Standard}$ at various time scales. The assessment periods under consideration may range from 1 to 24 months, depending on the region's need for short-term or long-term planning. The PIStandard variable time scale enables it to describe drought conditions for a variety of meteorological, agricultural, and hydrological applications. $P_{IStandard}$ provides a better analysis of meteorological drought at multiple different timescales for short- and long-term planning because it uses the running sum of rainfall values at 1 to 24 months and more parameters for the statistical distribution used.For short-term drought monitoring and agricultural crop planning, a 1- to 3-month $PI_{Standard}$ can be utilized; however, long-term hydrological drought monitoring and water management planning require $PI_{Standards}$ of 6 to 9 months and 12 to 24 months, respectively.Drought analysis using $PI_{Standard}$ results can be used to design rainwater harvesting and storage structures in drought-affected areas for appropriate crop planning.

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