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ASSESSMENT OF NAGINA AREA OF DISTT. BIJNOR U.P. ON THE BASIS OF STANDARD PRECIPITATION INDEX (SPI) FOR DROUGHT INTENSITY

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ABSTRACT

Drought is a natural and worldwide phenomenon, usually defined by periods of less than normal water availability, and is one of the major weather related hazards. Droughts have been dramatically increased in number and intensity in many parts of the world. Drought is a decrease of water availability in a particular period and over a particular area. Based on the drought analysis using the SPI criteria, appropriate crop planning and design of rainwater harvesting and storage structures in the drought affected areas can be proposed in drought affected areas. Standardized Precipitation Index (SPI) was calculated at different time scales (1, 3, 6, 12, and 24 months). The SPI is a drought index based on the probability of an observed precipitation deficit occurring over a given prior time period. The SPI, calculated for a desired period at any location, are based on the long term precipitation record (30 years or more). The positive SPI values show greater than medium precipitation, while negative SPI values indicate less than medium precipitation. The results shows that the SPI can be used for better assessment of drought as it considers larger range of moving sums of rainfall data. Since SPI uses for the running sum of rainfall values at multi-time scales (1 to 24 months) and more variables depending on the statistical distributions used, it gives better assessment of meteorological drought at multi-time scales. A proper rainwater harvesting and management program is an appropriate option for a severely-dry year, but, on the contrary, a situation of wet years with heavy rainfall during monsoon months followed by severely-dry period calls for the need of rainwater harvesting during monsoon and its proper utilization during subsequent dry periods.

KEYWORDS: Meteorological drought, SPI, probability distribution, Nagina (Bijnor).

INTRODUCTION

Drought is a natural and worldwide phenomenon, usually defined by periods of less than normal water availability, and is one of the major weather related hazards. Droughts have been dramatically increased in number and intensity in many parts of the world. Drought is a decrease of water availability in a particular period and over a particular area. Based on the nature of the water deficit, four types of droughts are defined: a) the meteorological drought which is defined as a lack of precipitation over a region for a period of time, b) the hydrological drought which is related to a period with inadequate surface and sub-surface water resources to satisfy water needs, c) the agricultural drought, which, usually, refers to a period with declining soil moisture and consequent crop failure, d) the socio-economic drought which is associated with the failure of water resource systems to meet the water impacts on the environment and society.

Drought is a temporary reduction in water or moisture availability significantly below the normal or expected amount for a specific period. This condition occurs either due to inadequacy of rainfall, or lack of irrigation facilities, under-exploitation or deficient availability for meeting the normal crop requirements in the context of the agro-climatic conditions prevailing in any particular area. Prolonged, large-area drought events are among India's costliest natural disasters, having major impacts on sectors such as agriculture, forestry, industry, recreation, human health and society, and aquatic ecosystems. The human activities can be directly trigger exacerbating factors such as over farming, excessive irrigation, Deforestation, and erosion adversely impact the ability of the land to capture and hold water. While these tend to be relatively isolated in their scope, activities resulting in global climate change are expected to trigger droughts with a substantial impact on agriculture throughout the world, specially in developing nations. Periods of drought can have significant environmental, agricultural, health, economic and social consequences. The effect varies according to vulnerability. For example, subsistence farmers are more likely to migrate during drought because they do not have alternative food sources. The continuous SPI method can provide better means of quantifying rainfall variability and correlating it changes of shallow watertable levels since it's based on continuous statistical functions comparing rainfall variability over the entire rainfall record. Rainfall is one of the key factors affecting the sustainability of irrigation areas in terms of dictating the need for supplemental irrigation to meet crop water demand and determining drainage requirements to avoid shallow watertable conditions and secondary soil salinisation. The variability of rainfall in the upper catchments of rivers determines the water available in storage reservoirs that can be available for irrigation to meet crop water use requirements. The understanding that a deficit of precipitation has different impacts on groundwater, reservoir storage, soil moisture, snowpack and stream flow, Led McKee, Doesken, and Kleist developed a Standardized Precipitation Index (SPI) (**McKee *et al.* 1993)**. Standardized Precipitation Index is an index based on the probability of precipitation for any time scale and it requires less input data and calculation effort than other methods. Drought scientists from all over the world met during December 8-11, 2009 in Lincoln, Nebraska, USA and reviewed many ways of measuring drought before agreeing that the Standardized Precipitation Index (SPI) should become the global standard. All the 54 scientists from 22 different countries released the Lincoln Declaration on Drought Indices on Dec. 11 at the workshop's conclusion.

SPI values range from more than 2 (extremely wet) to less than -2 (extremely dry), with 0.99 to - 0.99 considered the near-normal range. Maps normally depict SPI values as colors, with reds and yellows meaning dry, and greens and blues meaning wet. The SPI was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short scale. Groundwater, stream flow, and reservoir storage reflect the longer-term precipitation anomalies. For these reasons, McKee et al. (1993) originally calculated the SPI for 3-, 6-, 12-, 24-, and 48-month time scales. A one-month SPI index is very similar to the percent of normal precipitation for a month. It is actually a more accurate representation of monthly precipitation because the distribution has been normalized. Because the 1-month SPI reflects relatively short-term conditions, its application can be related closely with short-term soil moisture. The 1-month SPI may approximate conditions represented by the Crop Moisture Index (CMI). Interpretation of the 1-month SPI may be misleading unless climatology is understood. In regions where rainfall is normally low during a month, large negative or positive SPIs may result even though the departure from the mean is relatively small. Several specific examples demonstrate this limitation. The three-month SPI provides a comparison of the precipitation over a specific 3-month period with the precipitation totals from the same 3-month period for all the years included in the previous records. A 3-month SPI reflects short- and medium-term moisture conditions and provides a seasonal estimation of precipitation. In Indian context a four month SPI was taken because of heavy rainfall in June, July, August and September which is considered as monsoon season and accordingly one can relatively study about the changing behavior of SPI index in pre monsoon, monsoon and post monsoon seasons.

The 6-month SPI compares the precipitation for that period with the same 6-month period over the previous records. But if we compare 6-month SPI index with One year SPI index then the drown graph of both SPI indices show an approximate overlapping situation, so One year SPI index is preferred as it is less sensitive than a 6-month SPI index and gives more accurate scale of drought. The above studies show the possibility of using precipitation indices such as the SPI for seasonal water/irrigation management in several countries around the globe. The knowledge-based for India is rather limited. This study therefore aims to assess the impact of rainfall variability on shallow water tables in selected irrigation areas in India, to provide a management tool to farmers and irrigation companies. Also a model to evaluate SPI forecast on the basis of past values of precipitation has been developed. More specifically, analytical expressions of short-middle term forecasts of the SPI are derived as the expectation of future SPI values conditioned on past monthly precipitation, under the hypothesis of uncorrelated and normally distributed precipitation aggregated at different time scales.

The SPI at one year time scale reflects long-term precipitation patterns. A 12-month SPI is a comparison of the precipitation for 12 consecutive months with the same 12 consecutive months during all the previous years of available data. Due to erratic behavior of monsoon, generally there may be considerable variation of rainfall in the same month from year to year. Thus, it is difficult to develop prediction equation. Under such situations one can predict the occurrence of any event by mainly two methods:

1- Probability analysis: In this method we generally find out the probability of occurrence of all events of previous years individually and based on that we predict the future event.
2- Pattern analysis: Some events may be following a specific pattern and based on that pattern one can find out the next pattern.

Various drought indices were tested and modified in different partsof the world by number of researchers. Some of them are Guttman (1997); Sharma *et al*. (2005) Tiwari *et al.* (2007); Cancelliere *et al*. (2007); Kar *et al.* (2007); Moreira *et al.* (2008); Tabrizi *et al.* (2010); Pandey *et al.* (2010); Angelidis *et al.* (2012); Bonsal *et al.* (2012); Pai *et al.* (2011); Li *et al.* (2012); Zin *et al.* (2012); Roudier and Mahe (2013). They suggested that continuous SPI method could provide better means of quantifying rainfall variability and correlating it with changes of shallow water table levels since it is based on continuous statistical functions comparing rainfall variability over the entire rainfall record.

STUDY AREAS

The data recording site lies in plains, 210 kilometres west of India's capital New Delhi and the district is surrounded by the Plains in the west, The location having an altitude of 115 mt. above mean sea level and is located at 290 2' 290 58' N latitude and 78' 0' to 780 57'E longitude. Nagina (Bijnor) is also located on the northwestern side of the fertile Gangetic plains of India. Nagina (Bijnor) has a sub-tropical climate with cold winters, warm and crisp springs, hot summers and a strong monsoon. The rainy season starts from the 2nd week of June and continues upto September having a maximum rainfall in July. During the summers, the temperature ranges between 39.2 °C and 16.7° C. In winters, the temperature lies in between 27.8 °C and 7.6 °C. The relative humidity ranges from 40% in may to 84% in January. May is the driest and January is the coolest month.

Analyses of Data

The monthly rainfall data of Nagina (Bijnor) for 25 years The rainfall data for 25 years (1990 to 2015) of Nagina (Bijnor) district were taken from the Nagina KVK (Krishi vigyan Kendra) office at (Bijnor). The monthly data were converted into seasonal rainfall of four month period as pre-monsoon (February to May), monsoon (June to September) and post-monsoon (October to January) and multi-temporal rainfall series with running sum for 1-month, 3-month, 6-month, 12-month and 24-month durations for both the locations

Standardized Precipitation Index (SPI)

The standardized precipitation index (SPI) gives better representation of wetness and dryness than other previous methods.SPI is calculated at different time scales which can be 1-, 3-, 6-, 12-, 24-, and 48-months' time scales. The SPI cannot be used for draught prediction, but it can represent the occurrence of wet and dryness. The positive SPI value shows greater than medium precipitation, while negative SPI value indicates less than medium precipitation. It is computed by fitting an appropriate probability density function to the frequency distribution of precipitation summed over the time scale of interest (usually1, 3, 6, 12, 24, and 48 months). This is performed separately for each time scale and for each location in space.

Computation of the SPI involves fitting a gamma probability density function to a given time series of precipitation, whose probability density function is defined as:

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

where,

α is a shape parameter, $\alpha > 0$

β is a scale parameter, $\beta > 0$

x is the precipitation amount in mm, $x > 0$

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

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

Computation of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation totals for a station. The α and β parameters of the gamma probability density function are estimated for each station, for each time scale of interest (3 months, 12 months, 48 months, etc.), and for each month of the year. The maximum likelihood solutions are used to optimally estimate α and β as follows:

$$\hat{\alpha} = \frac{1}{4A}(1 + \sqrt{(1 + \frac{4A}{3}}) \quad ... (3)$$

$\hat{\beta} = \frac{\bar{x}}{\alpha}$ ...(4)

where,

$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n}$ ... (5)

$\bar{x}$ is average rainfall in mm of all previous data of same event,
n is 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. The cumulative probability is given by:

$G(X) = \int_0^x g(X)dx$ ... (6)

$G(X) = \frac{1}{\hat{\beta}^{\hat{\alpha}} * \Gamma(\hat{\alpha})} \int_0^x x^{\hat{\alpha}-1} e^{-x/\hat{\beta}} dx$ ... (7)

Since the gamma function is undefined for *x* = 0 and a precipitation distribution may contain zeros, the cumulative probability become

$H(X) = q + (1-q)G(X)$ ... (8)

where, *q* is the probability of a zero event.

If *m* is the number of zeros in a precipitation time series, *q* can be estimated as *m*/*n*.

The cumulative probability, *H*(*x*), is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI. Panofsky and Brier (1958) stated that this is an equi-probability transformation, which has the essential feature of transforming a variate from one distribution (*ie.* gamma) to a variate with a distribution of prescribed form (*ie.* standard normal) such that the probability of being less than a given value of the variate shall be the same as the probability of being less than the corresponding value of the transformed variate.

The Z or SPI value is more easily obtained computationally using an approximation provided by Abramowitz and Stegun (1965) that converts cumulative probability to the standard normal random variable Z:

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

$Z = SPI = -\left(t - \frac{(Co + C1*t + C2*t^2)}{(1 + d1*t + d2*t^2 + d3*t^3)}\right)$ ... (9)

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

$Z = SPI = +\left(t - \frac{(Co + C1*t + C2*t^2)}{(1 + d1*t + d2*t^2 + d3*t^3)}\right)$ ... (10)

where,

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

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

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

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

and the coefficients are

Co=2.515517	C_1=0.802853
C_2=0.010328	d_1=1.432788
d_2=0.189269	d_3=0.001308

The gamma, normal and log-normal probability distributions were examined to model observed precipitation data and to estimate the changes in the SPI values when computed from these different probability models. In common with the gamma distribution, the log–normal distribution is positively skewed and non-negative. It has the advantage of simplicity since it is just a logarithmic transformation of the data (Wilks, 1995), i.e., Y = ln(x) (for x >0), with the assumption that the resulting transformed data are described by a Gaussian distribution. By fitting the log–normal distribution with the sample mean and variance of the logarithmic transformed data μ_y and σ_y^2, the SPI become.

SPI = Z = $\frac{\{\ln(x) - \mu_y\}}{\sigma_y}$ ... (13)

The central limit theorem suggests that, as one moves to extended time periods in excess of six months, the resultant time averaging will tend to shift the observed probability distributions towards normal. Because the gamma distribution tends towards the normal as the shape parameter α tends to infinity, it is possible to use the normal probability distribution instead of gamma, which is computationally easier to calculate and may be more accurate, because of a better fitting to the data. In this case, the SPI index simply becomes:

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$$SPI = Z = \frac{(x-\mu)}{\sigma} \quad ... (14)$$

where, μ and σ are the sample estimates of the population mean and standard deviation.

On the basis of SPI values the wet and drought conditions, existing at a place can be identified as given in Table 1.

Table 1 Classification of SPI category

SPI value	CATEGORY
SPI ≤+2	Extremely wet
1.50 ≤ SPI ≤1.99	Severely wet
1.00≤ SP I ≤1.49	Moderately wet
0.00≤ SPI ≤0.99	Mildly wet
-0.99 ≤ SP I≤0	Mild drought
-1.49 ≤ SPI ≤-1.00	Moderate drought
-1.99 ≤ SPI ≤-1.50	Severe drought
SPI ≤-2	Extreme drought

A one-month SPI index is very similar to the percent of normal precipitation for a month. The 3-month SPI provides a comparison of the precipitation over a specific 3-month period with the precipitation totals from the same 3-month period for all the years included in previous records. It reflects short and medium-term moisture conditions and provides a seasonal estimation of precipitation. In Indian context, a 4-month SPI was taken because of heavy rainfall during four months of monsoon season (June to September) and accordingly one can study the changing behavior of SPI in pre-monsoon, monsoon and post-monsoon seasons. The 6- month SPI compares the precipitation for that period with the same 6-month period over the previous records. The SPI at one year time scale reflects long-term precipitation patterns. A 12-month SPI is a comparison of the precipitations for 12 consecutive months with the same period during previous years of available data.

RESULTS AND DISCUSSION

This chapter deals with the results of meteorological drought conditions and discussion thereon after the analysis of data using SPI applicable to multi-temporal rainfall data series of Nagina (Bijnor) (1990 - 2015).

SPI-based Drought at Nagina (Bijnor)

The SPI values of running sums for time scales of 1 to 24 months were computed by considering the Gamma, Log-normal and Normal distributions applicable to the rainfall data of **Nagina (Bijnor)**. The variability of SPI with different years for these probability distributions are shown in Figs. (1) to (5) indicating more variability in SPI values for log-normal distribution followed by the normal and gamma distributions. Also, as the duration of running sum increases from1 month to 24 months, the higher SPI values are becoming more distinct.

In order to estimate the SPI for a given rainfall amount corresponding to any time scale, the curve between rainfall amount and its cumulative probability for different distributions can be matched with the curve between the cumulative probability and SPI as shown in Figs. (6) and (7) for 3-month running sum and 12-month running sum as a guide for short term and long term assessment, respectively. On this basis, one can estimate the SPI for a given rainfall amount for running sum for a time scale to assess the condition of wet or drought conditions existing in Nagina (Bijnor) as per Table 1. As shown in Figs. 3 by knowing the rainfall amount for 3 month running sums, the cumulative probability may be read, and again from Fig. 4, the SPI can be read to know the status of drought at Nagina (Bijnor).

Therefore, rainwater harvesting with surplus monsoon rains and occasional winter rains should be encouraged to ensure supplemental irrigation to high value crops, apart from biological measures such as mulching, contour cultivation etc., particularly during pre-and post-monsoon seasons. Also, the surface runoff may be collected and stored at appropriate locations during monsoon season or groundwater recharge to enhance the groundwater potential.

Rainwater management during excess rainfall periods and its multiple uses through farm diversification must be encouraged for increasing crop productivity and sustainability in drought affect areas. A proper rainwater management program would be an appropriate option for a severely dry year. On the contrary, the wet years with heavy rainfall during monsoon months followed by severely dry condition, indicate the need of rainwater harvesting during monsoon season and its utilization during subsequent dry periods. In delayed monsoon conditions, the crop varieties with short duration and/or drought resistance can be promoted in the affected areas.

DROUGHT PLANNING FOR MITIGATION AND WATER MANAGEMENT

Water Management for drought planning focuses on enhancing our abilities to monitor drought, understand drought vulnerabilities, and mitigate drought. By proactively planning for drought, the society will be better prepared to deal with the damaging effects of drought in the most efficient manner. Though the prediction of onset and termination of drought are difficult to determine, one can identify various indicators of drought and by tracking them the crucial means of monitoring drought can be provided. To overcome rainfall deficits and encounter with the droughts in the region, contingent crop planning is needed to ensure stable productivity and appropriate strategies can be adopted to overcome drought problems in the study areas. Therefore, rainwater harvesting with surplus monsoon rains and occasional winter rains should be encouraged to ensure supplemental irrigation to high value crops, apart from biological measures such as mulching, contour cultivation etc., particularly during pre-and post-monsoon seasons. Also, the surface runoff may be collected and stored at appropriate locations during monsoon season for groundwater recharge to enhance the groundwater potential.

Rainwater management during excess rainfall periods and its multiple uses through farm diversification must be encouraged for increasing crop productivity and sustainability in drought affect areas. A proper rainwater management program would be an appropriate option for a severely dry year. On the contrary, the wet years with heavy rainfall during monsoon months followed by severely dry condition, indicate the need of rainwater harvesting during monsoon season and its utilization during subsequent dry periods. In delayed monsoon conditions, the crop varieties with short duration and/or drought resistance can be promoted in the affected areas.

CONCLUSIONS

The rainfall amount and distribution at Nagina (Bijnor) in Uttar Pradesh, being erratic and uneven, are responsible for frequent drought spells throughout the year. Therefore, monitoring of meteorological drought is a must for this region. The standardized precipitation index (SPI) at various time scales can be accepted and practiced for drought monitoring in this region. The SPI is a drought index based on the probability of an observed precipitation deficit occurring over a given prior time period. The assessment periods considered range from 1 to 36 months. The variable time scale allows the SPI to describe drought conditions important for a range of meteorological, agricultural, and hydrological applications. For example, soil moisture conditions respond to precipitation deficits occurring on a relatively short time scale, whereas groundwater, stream flow, and reservoir storage respond to precipitation deficits arising over many months. The monthly data were converted into seasonal rainfall of four month period as pre-monsoon (February to May), monsoon (June to September) and post-monsoon (October to January) and multi-temporal rainfall series with running sum for 1-month,

The following conclusions are drawn from this study:

[1] Since SPI uses for the running sum of rainfall values at multi-time scales (1 to 24 months) and more variables depending on the statistical distributions used, it gives better assessment of meteorological drought at multi-time scales;

[2] The IMD criteria provide the assessment of drought at a larger scale as the limits are substantially large (depending on the mean rainfall value); whereas the SPI can be used for better assessment of drought as it considers larger range of moving sums of rainfall data;

[3] The 3-month SPI can be used for short term drought monitoring and agricultural crop planning and 12-month SPI can be used for long term drought monitoring and water resource planning;

[4] Based on the information for drought analysis using the SPI criteria, appropriate crop planning and design of rainwater harvesting and storage structures in the drought affected areas can be proposed in drought affected areas.

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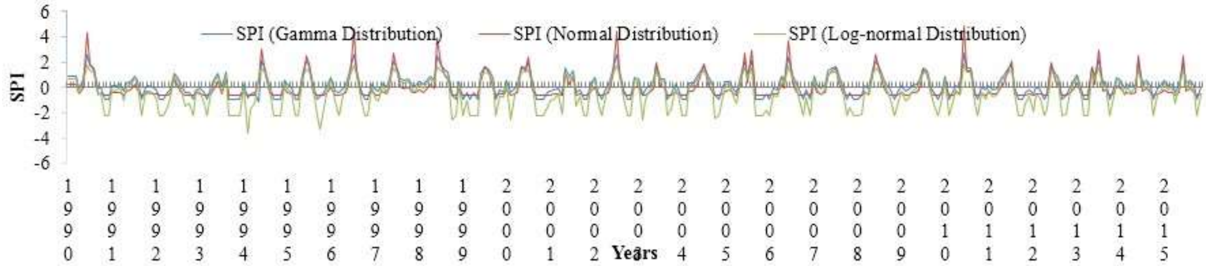

Fig. 1 Drought index SPI for the time series of Nagina (Bijnor) at time scale of 1 month, modelled by gamma, log–normal and normal probability distributions

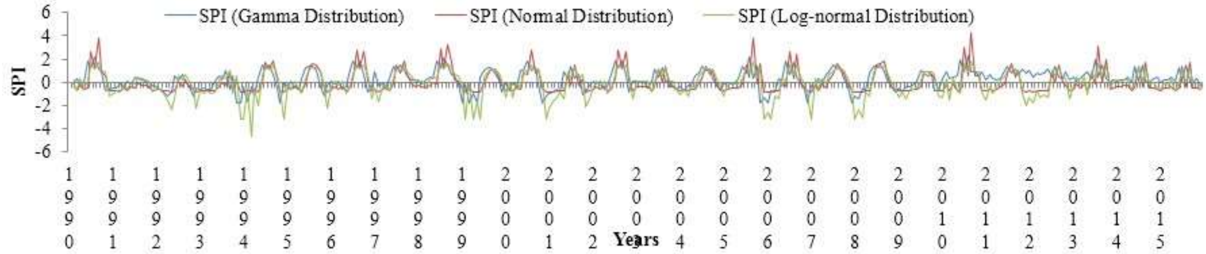

Fig. 2 Drought index SPI for the time series of Nagina (Bijnor) at time scale of 3 months, modelled by gamma, log–normal and normal probability distributions

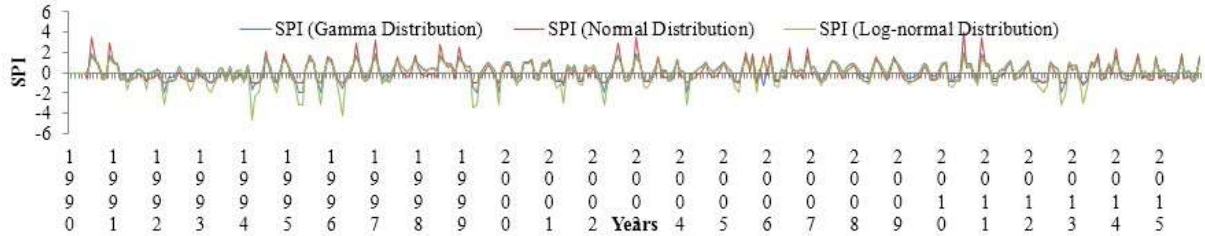

Fig. 3 Drought index SPI for the time series of Nagina (Bijnor) at time scale of 6 months, modelled by gamma, log–normal and normal probability distributions

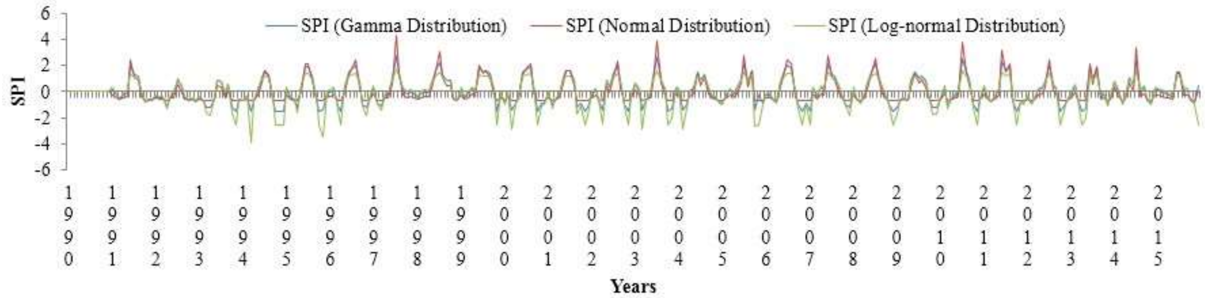

Fig. 4 Drought index SPI for the time series of Nagina (Bijnor) at time scale of 12 months, modelled by gamma, log–normal and normal probability distributions

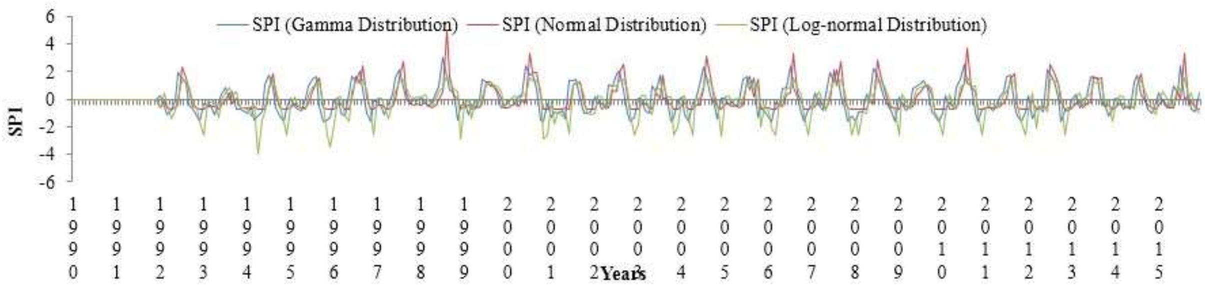

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Fig. 5 Drought index SPI for the time series of Nagina (Bijnor) at time scale of 24 months, modelled by gamma, log–normal and normal probability distributions

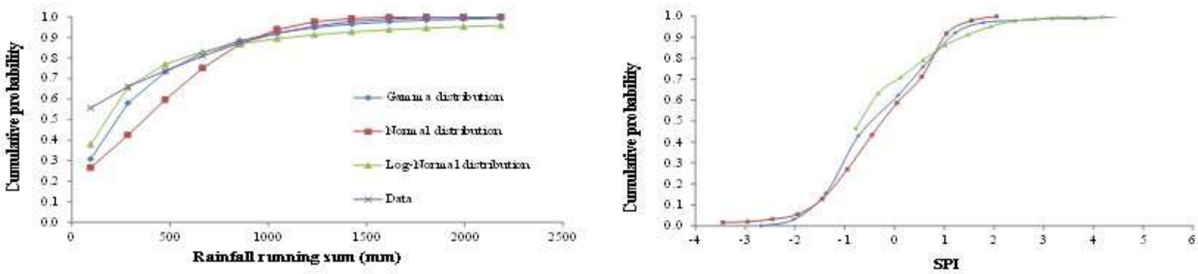

Fig. 6 Empirical and theoretical cumulative probability distributions for the running sum of 3 months precipitation at Nagina (Bijnor)

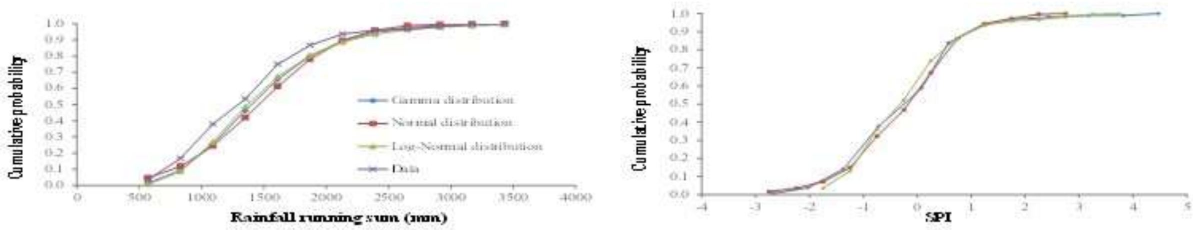

Fig. 7 Empirical and theoretical cumulative probability distributions for the running sum of 12 months precipitation at Nagina (Bijnor)