STANDARIZED PRECIPITATION INDEX (SPI)

D.S. Rathore, Scientist E2

National Institute of Hydrology, Roorkee

1.0 INTRODUCTION

The monsoon in the Indian subcontinent occurs due to differential heating of land mass and the Ocean. Rainfall occurs both in the advancing and the retreating phases (latter known as northeast monsoon). Due to complex weather phenomena of global and regional scales, variability occurs in the monsoon system. The excess or deficit in monsoon rainfall is associated to the favorable/ unfavorable conditions of ENSO, EQUINO or both. Due to several reasons, some areas are more affected than other. Studies have been done to identify such areas from time to time at various administrative scales. Nearly 99 districts in 14 states have been identified as drought prone districts. These districts have cultivable area of about 77 M ha which is about 42% of the country's total cultivable area of 184 M ha. Among the States, Gujarat and Rajasthan are the most droughts prone followed by Karnataka and Maharashtra. CWC identified one sixth area of the country as drought prone.

Drought is the dryness due to deficient rainfall or shortage of water for an extended period, season, a year or several years over particular region. Drought may be affecting a region with varied frequency and magnitude. Several criteria are evolved to define an area as drought affected. Criteria adopted in India, rely on rainfall and irrigation information and mainly concern agricultural uses. Irrigation imports water in to an area and thus mitigates short to medium time scale droughts. Thus, areas with large extent of irrigation are not defined as drought prone. As per one criterion, an area is defined as drought affected if the crop damage occurs or land is left fallow due to deficient rainfall in three years or more out of every 10 years. As per Irrigation Commission and Central Water Commission (CWC) an area is defined as drought prone when annual rainfall is less than 75% of the normal in 20% of the years examined and Less than 30% of the cultivated area is irrigated (Anonymous 2011). The Irrigation Commission of 1972 has identified 67 drought prone districts comprising of 326 Talukas located in 8 States having an area of 49.73 M ha. Drought Area Study and Investigation Organisation of Central Water Commission (CWC) studied 99 districts considering the districts identified by the Irrigation Commission and National Commission on Agriculture. Out of 108 M ha area of 99 districts, only 51.12 M ha spread over 74 districts have been identified as drought prone. IMD defines moderately and severely drought affected area as one with rainfall between 26- 50% and less than 50% of the normal rainfall respectively.

1.1 Standardized Precipitation Index (SPI)

SPI was devised by McKee and others (1993). The index is based on a specified non- exceedance probability of rainfall of certain time scale e.g. weekly, monthly, yearly etc. To determine non-exceedance probability of rainfall, empirical or a theoretical probability distribution function is used. Typically, rainfall have negatively skewed distribution i.e. smaller rainfall magnitudes occur with larger frequencies. Thus, instead of common normal pdf, Gamma pdf provides better fit for the data. In a probability distribution, cumulative probability value and a variate (e.g. Z- score) have one- to- one correspondence, cumulative distribution function (cdf) being monotonically increasing function. Thus, a cumulative probability value has one and only one variate value. Thus, for a rainfall value, cumulative probability value is drawn from Gamma cdf. From given cumulative probability, standard normal variate (Z- score) is determined using inverse standard normal cdf. Z- score for precipitation data is termed as SPI. It signifies severity of dryness or wetness. Various drought categories are defined for different threshold values of negative SPI values e.g. -3, -2.5, -2, -1.5, -1, -0.5 and 0 (Table 1.0). Cumulative probability and corresponding SPI values are given in Table 1.1.

Table 1.0 Classifications of SPI

SPI Values	Drought/ Wetness condition
2 and above	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
- 0.99 to 0.99	Near normal
- 1.0 to – 1.49	Moderately dry
- 1.5 to – 1.99	Severely dry
- 2.0 and less	Extremely dry

Table 1.1 Cumulative probability for SPI values

SPI	-3	-2.5	-2	-1.5	-1	-0.5	0
Probability	0.0014	0.0062	0.0228	0.0668	0.1587	0.3085	0.5
SPI	0.5	1	1.5	2	2.5	3	
Probability	0.6915	0.8413	0.9332	0.9772	0.9938	0.9986	

Gamma probability distribution function (Eq. 1) has two parameters, namely α (shape factor) and β (scale factor). The parameters are estimated using maximum likelihood estimator as given by Thom (Eq. 2 to 4). The cumulative probability distribution function is given by Eq. 5.

$$g_x = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \quad (1)$$

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \quad (2)$$

$$\beta = \frac{\bar{x}}{\alpha} \quad (3)$$

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \quad (4)$$

$$G_x = \int_0^x g_x dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} dx \quad (5)$$

Where, α (shape factor) parameter of the gamma probability density function

β (scale factor) parameter of the gamma probability density function

n is number of precipitation observations,

$\bar{x}$ is mean precipitation

The Gamma distribution may be compared with empirical distribution e.g. Weibull plotting position method (Fig. 1.0) using goodness of fit tests e.g. KS test. Table A.0 shows results for KS test for Anantapur monthly rainfall data. The differences in the distributions are not significant at 5% level of significance for the months, except for months of January to March for monthly rainfall. Fig. 1.1 shows plot of monthly rainfall of different SPI values. Fig. 1.2 shows cdf for monthly precipitation for months of June to September. Fig. 1.3 shows plot of SPI verses rainfall for the months of June to September. Curve for August is steep indicating more critical rainfall situation in drought situations compared to other months. The results are based on the monthly precipitation time series for period 1901 to 2002 obtained from India Water Portal. The data is based on Climate Research Unit (CRU) TS2.1 dataset, of the Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia in Norwich, UK with certain processing done by India Water Portal team (http://indiawaterportal.org/node/7160).

1.2 USING SPREADSHEET FOR SPI

Cumulative probability and inverse of the cumulative probability for Gamma, Normal and Standard Normal distributions may be computed in spreadsheet e.g. MS Excel (Table 1.2). Thus, SPI computations may be performed in spreadsheet.

Table 1.2 Statistical formula in MS Excel

Description	Formula
Cumulative probability of gamma distribution	Gammadist(x, α, β, true)
Inverse of cumulative probability for Gamma distribution	Gammainv(p, α, β)
Cumulative probability of Normal distribution	Normdist (x, μ, σ, true)
Inverse of cumulative probability for Normal distribution	Norminv (p, μ, σ)
Cumulative probability of Standard Normal distribution	Normsdist (z)
Inverse of cumulative probability for Standard Normal distribution	Normsinv (p)

Where,

x= variate

α, β= parameters of the Gamma distribution function

μ, σ= mean and standard deviation

p= Cumulative probability

Z= Standard Normal variate

1.3 Computer program for SPI

The computer program to compute SPI may be downloaded from site http://drought.unl.edu/monitor/spi/program/spi_program.htm. The program is already compiled and all libraries are included (it was compiled in C++ for PC) to generate executable file (file with extension exe). At least 30 consecutive years without missing monthly data, and more than 60 years is recommended for the SPI calculation. SPI program for weekly time scale is also available from site http://greenleaf.unl.edu/downloads/.

To execute the program it is run at the DOS prompt. Following input are required for the program:

1. SPI monthly intervals (up to six at one time)
2. Input file name
3. Output file name

1.3.1 File format

Input file (Table 1.3) contains following lines:

1. Single header line
2. Data namely year, month and one hundredth of the monthly Precipitation, in space delimited values

The precipitation values are specified as whole numbers. Convert precipitation values to one hundredths (i.e. multiply precipitation values by 100). Zero precipitation is changed to one- hundredth (smallest denomination). Missing data values are expressed as zero.

Table 1.3 Input data file format for SPI program

Header line
1901 1 673
1901 2 1049
1901 3 2329
1901 4 3556
1901 5 2312
1901 6 11555

Format for output file is also similar (Table 1.4). Output file contains SPI values in the third column onwards.

Table 1.4 Output data format for SPI program

Header line
1901 1 0.47
1901 2 0.96
1901 3 1.24
1901 4 1.25
1901 5 0.49

1.4 Drought duration

A criterion was defined by McKee (1993) to declare meteorological event as drought event based on SPI index. According to this criterion the SPI should be continuously negative and reach -1 or less at least once during the event. Start and end of event are defined based on change in sign of SPI. The event starts when SPI becomes negative and end when it becomes positive. Magnitude is absolute sum of SPI during a drought event. Duration is the time span of the drought event (time between start and end of the drought event). Drought intensity is obtained by dividing the drought magnitude with drought duration. Fig. 1.4 shows probability of occurrence of the drought magnitude for two districts in Andhra Pradesh, namely Anantapur and Kurnool.

1.4.1 Spreadsheet based procedure for drought duration

Months, SPI values, rainfall, median (by repeating median values in each month) column were populated in MS Excel sheet. Rainfall deficit from median was computed. 'AutoFilter' was used to filter the monsoon months for computations. The drought events were identified based on SPI values. The magnitude and duration were entered at end of each drought event. The durations of the drought events were determined by counting drought months. Magnitudes were computed by summing SPI values for the drought durations. The sheet was again filtered for 'non blank' values in drought duration. The values of the sheet were copied to another sheet for further ordering as per magnitude and rainfall deficits. For finding drought probability, only most severe drought event was considered in each year. The Weibull distribution was used for finding the probability of occurrence of a drought event of given magnitude or deficit rainfall.

REFERENCES

1. Gadgil S., P. N. Vinayachandran and P. A. Francis (2003). Droughts of the Indian summer monsoon: Role of clouds over the Indian Ocean. Current Science 85(12): 1713- 1719.
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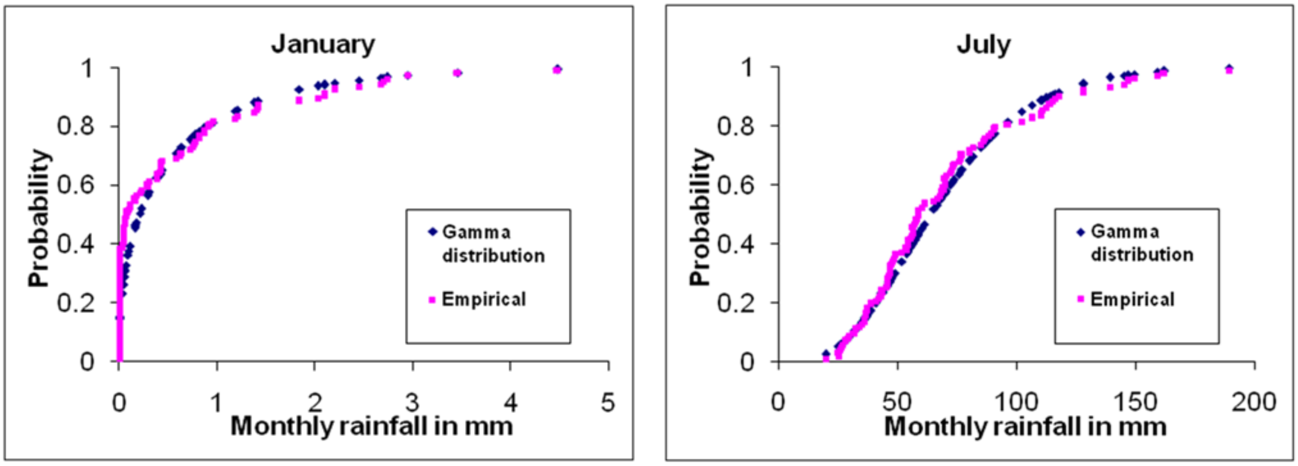

Fig. 1.0 Empirical and theoretical cumulative probability distribution for Anantapur district, Andhra Pradesh

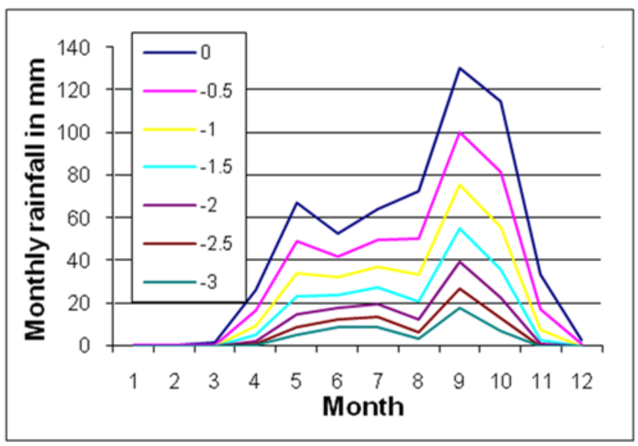

Fig. 1.1 Monthly precipitation for different SPI values for Anantapur district, Andhra Pradesh

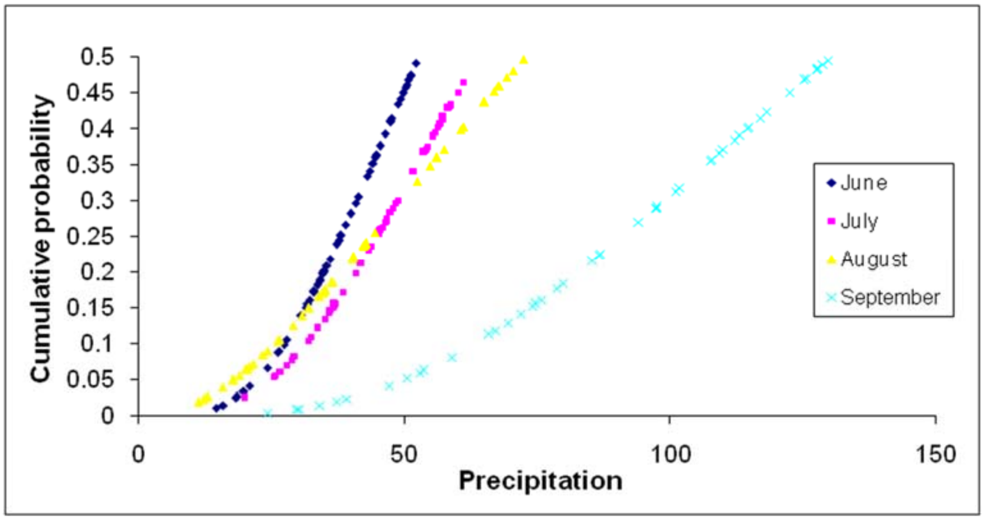

Fig. 1.2 Cumulative probability of monthly precipitation using Gamma cdf for Anantapur district, Andhra Pradesh

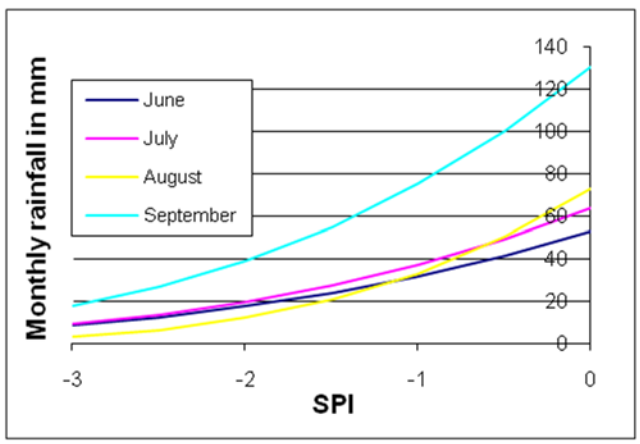

Fig. 1.3 Rainfall for different SPI values for Anantapur district, Andhra Pradesh

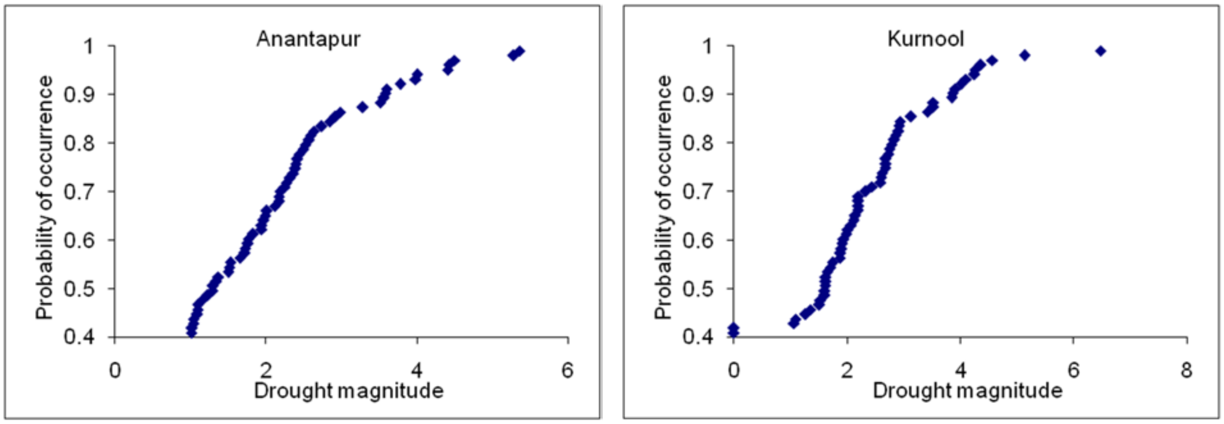

Fig. 1.4 Probability of occurrence of drought magnitudes in Anantapur and Kurnool districts

Table 4 KS statistic between Gamma and empirical distribution for monthly precipitation of Anantapur district, Andhra pradesh

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
D	0.229	0.361	0.174	0.072	0.040	0.036	0.081	0.070	0.069	0.111	0.066	0.097	
KS Statistic													Alpha
	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.106	0.20
	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.10
	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.135	0.05
	0.161	0.161	0.161	0.161	0.161	0.161	0.161	0.161	0.161	0.161	0.161	0.161	0.01