International Journal of River Basin Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/trbm20

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Published online: 23 Aug 2010.

To cite this article: A.K. Mishra PhD Scholar & V.R. Desai (2005) Spatial and temporal drought analysis in the Kansabati river basin, India, International Journal of River Basin Management, 3:1, 31-41, DOI: 10.1080/15715124.2005.9635243

To link to this article: http://dx.doi.org/10.1080/15715124.2005.9635243

Intl. J. River Basin Management Vol. 3, No. 1 (2005), pp. 31–41

Spatial and temporal drought analysis in the Kansabati river basin, India

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ABSTRACT
The identification, monitoring and characterization of droughts are of great importance in water resources planning and management. To investigate the spatial and temporal relationships of drought occurrence, the Standardized Precipitation Index (SPI) (calculated from the probability distribution of precipitation using a two-parameter gamma function) was used. The SPIs were applied at the local scale using monthly rainfall data for the period of 1965–2001 from five raingauge stations in the basin. The basin is divided into 25 grid-cells of 13 × 13 km with each grid correspondence to approximately 4% of total area. The inverse distance weighting (IDW) approach is used for the spatial interpolation of rainfall at each grid point. Drought severity is then assessed from the estimated gridded SPI values at multiple time scales. The spatial and temporal characteristics of SPI are used to develop drought severity – area – frequency curves that can assess the severity of the localized drought within the basin. The analysis of SPI suggests that the basin endured severe drought during the 1980's. These frequency curves can be used for planning sustainable water resources projects within the basin.

Keywords: Droughts; Kansabati river basin; SPI; drought severity; drought severity – area – frequency curves.

1 Introduction

Drought is considered by many to be the most complex but least understood of all natural hazards affecting more people than any other hazard. Drought is a normal feature of climate and its recurrence is inevitable. However, there remains much confusion within the scientific and policy making community about its characteristics. Research has shown that the lack of a precise and objective definition in specific situations has been an obstacle to understanding drought which has led to indecision and inaction on the part of managers, policy makers, and others (Wilhite and Glantz, 1985; Wilhite *et al*., 1986). In the quarter of a century since 1967, droughts have affected 50 percent of the 2.8 billion people who suffered from all natural disasters. Because of direct and indirect impacts of droughts, 1.3 million human lives were lost, out of a total number of 3.5 million people killed by disasters (Obasi, 1994). Nearly 50 percent of the world's most populated areas are highly vulnerable to drought and more importantly, almost all of the major agricultural lands are located there (USDA, 1994). Drought produces a complex set of impacts that span many sectors of the economy and reaches well beyond the area experiencing physical drought.

Like many countries drought is common in India also and these drought areas are mainly confined to the Peninsular and Western parts of the country. In addition, there are a few more drought-prone pockets in other parts of India. Out of 3.28 Million km^2 of geographical area in India about 1.07 Million km^2 of land are subjected to different degrees of water stress and drought conditions. Urban areas are growing and so are many rural areas. As a result, demands for municipal and industrial water supplies are growing. There is also a rising awareness of "quality of life" issues and concern for environmental values and related water uses. Periodic occurrence reminds us that water is precious. Incidentally, drought is the most frequent natural disaster affecting more people than any other disaster in India as shown in Table 1.

2 Concept and definition of drought

Precise definition is required for progress in any scientific field of study especially for drought investigation that requires increasing specifications in both concepts and technique. Drought differs from other natural hazards like floods, tropical cyclones, and earth quakes in several ways. First, since the effects of drought often accumulate slowly over a considerable period of time that may linger for years after the termination of the event, the onset and end of drought is difficult to determine. Because of this, drought is often referred to as creeping phenomenon (Tannehill, 1947). Drought means different things to different people – for a meteorologist a deviation from normal precipitation, for a hydrologist a fall in stream flow, lake level or ground water level. For an agricultural scientist lack of soil moisture to sustain crop growth, for an economist a famine condition, for an urbanite shortage of tap water supply (Dracup *et al*., 1980). Linsely *et al*. (1959) have

Received on September 7, 2004. Accepted on March 11, 2005.

Table 1 Top ten natural disasters in India during the 20th century.

Disaster	Year	Casualty population	Disaster	Year	People affected
Epidemic	1920	2,000,000	Drought	1987	300,000,000
Drought	1942	1,500,000	Drought	1979	190,000,000
Epidemic	1907	1,300,000	Flood	1993	128,000,000
Drought	1900	1,250,000	Drought	1982	100,000,000
Drought	1966	500,000	Drought	1983	100,000,000
Drought	1967	500,000	Drought	1972	100,000,000
Epidemic	1920	500,000	Drought	1973	100,000,000
Drought	1965	500,000	Drought	2000	90,000,000
Epidemic	1926	423,000	Drought	1965	50,000,000
Epidemic	1924	300,000	Drought	1966	50,000,000

Source: "EM-DAT: The OFDA/CRED International Disaster Database, Université catholique de Louvain, Brussels, Belgium".

defined drought as 'sustained period of time without significant rainfall'.

Drought has been grouped as follows: meteorological, hydrological, agricultural, socio-economic (Wilhite and Glantz, 1985). Precipitation has been commonly used for meteorological drought analysis (Santos, 1983; Chang, 1991; Eltahir, 1992). Meteorological drought is defined usually on the basis of the degree of dryness (in comparison to some "normal" or average amount) and the duration of the dry period. Stream flow data have been widely applied for hydrologic drought analysis (Dracup *et al*., 1980; Sen, 1980; Zelenhasic and Salvai, 1987; Clausen and Pearson, 1995). Hydrological drought is associated with the effects of periods of precipitation shortfalls on surface or subsurface water supply.

A large number of regional drought analyses may be found in the literature. Karl (1983) showed that droughts have longer persistence in the interior of United States than in the costal regions in the east and west. Clausen and Pearson (1995) presented a method for investigating the spatial and temporal variability of droughts by a regional frequency analysis of annual minimum stream flows. During the recent years various indices have been developed to detect and monitor droughts. There is an extensive literature on the quantification of droughts by using indices, models and water balance simulation (Palmer, 1965; Alley, 1985; Karl *et al*., 1987; Sen, 1998; Lana and Burgueno, 1998; Stahl and Demuth, 1999). Among the indices Palmer Drought Severity Index (PDSI) and Standardized Precipitation Index (SPI) are more commonly used. The regional drought distribution model presented in this paper is based on SPI as drought index. The SPI is used in this study for the following advantages, which are discussed by Hayes *et al*. (1999). The primary reason is that the SPI is based on rainfall alone, so that drought assessment is possible even if other hydro-meteorological measurements are not available. Another advantage of the SPI is its variable timescale, which allows it to describe drought conditions important for a range of meteorological, hydrological and agricultural applications. The third advantages of SPI come from its standardization, which ensures that the frequencies of extreme events at any location and on any time scale are consistent. The SPI can also detect moisture deficit more rapidly than PDSI, which has a response time scale of approximately 8–12 months (Hayes *et al*., 1999). Hughes and Saunders (2002) have demonstrated that SPI-12 (It indicates how the most recent 12 months of precipitation compares to that same 12 month historically) exhibits a close correspondence to the PDSI in studying drought climatology for Europe. Guttman (1998) studied droughts in the USA and Bussay *et al*. (1999) studied drought in Hungary and found the same results. It indicates that much of the variation seen in PDSI results directly from precipitation.

The objective of this paper is to develop quantitative relationships between drought severity, area and frequency using SPI values for different time scales. In this paper historical droughts with in the basin are compared with severity – area – frequency curves and are associated with the return period of regional drought.

3 Drought identification

Yevjevich (1967) proposed the use of 'run theory' to define the hydrologic drought characteristics, as shown in Figure 1. A run is defined as a portion of time series of drought parameter X_t, in which all values are either below or above the selected truncation

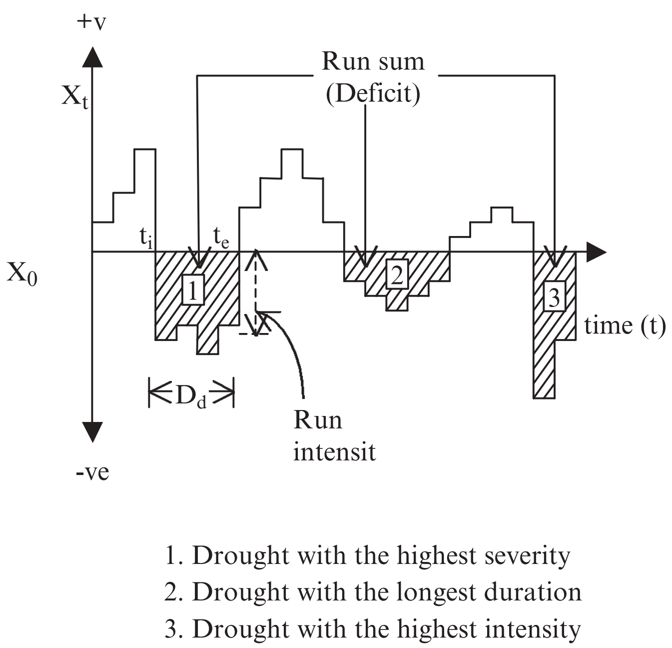

Figure 1 Drought characteristics using run theory for a given critical level, X_o.

level of X_o; accordingly it is called either a negative run or a positive run. The knowledge of the components of a drought event is very important for the mathematical analysis of drought. According to Yevjevich (1967) and Dracup *et al*. (1980), a hydrologic drought event has major components listed below. Likewise, Sirdas and Sen (2003) also used a run analysis method for determining the following drought characteristics using precipitation records in Turkey. Components of the run theory shown are shown in Figure 1.

(a) Drought initiation time (t_i): It is the starting of the water shortage period, which indicates the beginning of the drought event.
(b) Drought termination time (t_e): It is the time when the water shortage became sufficiently small so that drought conditions no longer persist.
(c) Drought duration (D_d): It is expressed in years/months/weeks etc., during which a drought parameter is continuously below the critical level. In other words, it is time period between the initiation and termination of a drought event.
(d) Drought severity (S_d): It indicates a cumulative deficiency of a drought parameter below the critical level.
(e) Drought intensity (I_d): It is the average value of a drought parameter below critical level. It is measured as the drought severity divided by the duration.

4 Standardized precipitation index for drought analysis

A deficit of precipitation impacts soil moisture, stream flow, reservoir storage, and ground water levels, etc., at different time scales. McKee *et al*. (1993) developed the SPI to quantify precipitation deficits on multiple time scales. Shorter or longer time scales may reflect lags in the response of different water resources to precipitation anomalies. McKee *et al*. (1993) defined the criteria for a "drought event" for any time scale as occurring at the time when the value of the SPI is continuously negative and reaches −1.

The event ends when the SPI becomes positive. Table 2 provides a look at drought classification based on SPI.

After the conceptualization of SPI, many researchers in drought studies have used it. Bussay *et al*. (1999) and Szalai and Szinell (2000) assessed the utility of SPI for describing drought in Hungary. They concluded that the SPI was suitable for quantifying most types of drought events. Stream flow was best described by SPIs with a time scale of 2 to 6 months. Strong relationship between the SPI and ground water levels were found at time scales of 5 to 24 months. Agricultural drought (quantified by soil moisture content) was indicated by the SPI on a scale of 2–3 months. Lana *et al*. (2001) recently used the SPI to investigate patterns of rainfall over Catalonia, Spain. Hughes and Saunders (2002) studied drought climatology for Europe based on SPI values at time scales of 3, 6, 9, 12, 18, and 24 months for the period 1901 to 1999.

Table 2 Weather classification based on SPI. (Hayes *et al*., 1999)

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

5 Computation of SPI

The SPI is computed by fitting a probability density function to the frequency distribution of precipitation summed over the time scale of interest. This is performed separately for each month (or any other temporal basis of the raw precipitation time series) and for each location in space. Each probability density function is then transformed into a standardized normal distribution.

The gamma distribution is defined by its probability density function is

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \quad \text{for } x > 0 \tag{1}$$

where $\alpha > 0$ is a shape factor, $\beta > 0$ is a scale factor, and $x > 0$ is the amount of precipitation. $\Gamma(\alpha)$ is the gamma function which is defined as

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

Fitting the distribution to the data requires that α and β be estimated. Edwards and McKee (1997) suggested a method for estimating these parameters using the approximation of Thom (1958) for maximum likelihood as follows:

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

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

where

$$A = \ln(\bar{x}) - \frac{\sum_{i=1}^{n} \ln(x)}{n} \tag{5}$$

for n observations.

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month or any other time scale.

$$G(x) = \int_0^x g(x)\, dx = \frac{1}{\hat{\beta}^{\hat{\alpha}}\Gamma(\hat{\alpha})} \int_0^x x^{\hat{\alpha}-1} e^{-x/\hat{\beta}}\, dx \tag{6}$$

Substituting t for $x/\hat{\beta}$ reduces Eq. (6) to incomplete gamma function:

$$G(x) = \frac{1}{\Gamma(\hat{\alpha})} \int_0^x t^{\hat{\alpha}-1} e^{-1}\, dt \tag{7}$$

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

$$H(x) = q + (1 - q)G(x) \tag{8}$$

where q is the probability of zero precipitation. It is found that there are only very few incidences where the monthly rainfall is zero. For larger time scales (like 3-, 6-, 9-, 12-, 24-month) the probability of monthly null precipitation is zero. So the errors in calculating the parameters α and β due to the monthly null precipitation does not affect the distribution at larger time scales.

The cumulative probability, $H(x)$, is then transformed to the standard normal random variable Z with a mean of zero and a variance of one, which is the value of SPI. Following Edwards and McKee (1997) and Hughes and Saunders (2002), an alternative approximate conversion is used in this paper, as provided by Abramowitz and Stegnum (1965):

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

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

where

$$t = \sqrt{\ln\left[\frac{1}{(H(x))^2}\right]} \quad (10)$$

For $0.5 < H(x) < 1$

$$Z = SPI = \left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad (11)$$

where

$$t = \sqrt{\ln\left[\frac{1}{(1 - H(x))^2}\right]} \quad (12)$$

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

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

The statistical tests (Kolgomorov–Smirnov (K–S) and Chi-Square tests) show that rainfall in the basin follows a gamma a distribution.

6 Study area

The physical area considered in this study is the portion of the Kansabati river basin (Figure 2) upstream from the Kansabati dam, in the extreme western part of West Bengal state in eastern India. The region has an area of 4265 km^2. The elevation ranges from minimum of 110 m to a maximum of 600 m. The average elevation of the region is approximately 200 m. The basin experiences very hot summer and temperature in the region reaches up to 45°C in May and June. Generally the dry periods are accompanied with high temperatures, which lead higher evaporation affecting natural vegetation and the agriculture of the region along with larger water resource sectors. The mean annual precipitation in the basin is about 1268 mm. Mainly three rivers are contributing the flow in Kansabati catchment that is Kansai, Kumari, and Tongo. There is Kansabati dam constructed at the confluence of three rivers in Purulia district. The waters of the primarily used for irrigation. The major crops grown in the catchment are paddy, maize, pulses and vegetables. It is considered a drought prone area with irregular rainfall and the soils are mostly laterite in nature having a low water holding capacity. About 50 to 60% of the study area is upland, which is managed by the poor farmers. Lands are mostly mono-cropped having limited surface irrigation facilities. The water demand due to the extensive cultivation lead to over-exploitation of ground water resources. The overexploitation of ground water, especially in summer has lead to degradation of water resources. Irrigated crops are not wide spread because there is not always enough water the purpose. For this study, five raingauge stations were considered and monthly rainfall data was procured for the period from 1965 to 2001. The statistical properties of rainfall series along with their geographic location is shown in Table 3. The mean annual rainfall varies from 1152.57 mm to 1345.7 mm. The standard deviation for Phulberia station is quite high because of the high fluctuation of annual rainfall from a maximum of 2081 mm to a minimum of 674 mm. The SPI values are calculated

Figure 2 Location of precipitation stations used in the study.

Table 3 Raingauge stations in the Kansabati river basin.

Raingauge stations	Elevation (m) (a.m.s.l)	Geographic coordinates		Statistical properties of annual rainfall series (1965 to 2001)					
		Latitude	Longitude	Mean (mm)	Max (mm)	Min (mm)	Standard deviation	Skewness	Kurtosis
Simulia	220.97	23°10′	86°22′	1300.68	1840	828	260.32	0.174	−0.605
Rangagora	222.92	23°4′	86°24′	1152.57	1729	743	219.1	0.782	0.656
Tusuma	158.6	23°08′	86°43′	1268.3	1683	746	239.31	−0.221	−0.547
Kharidwar	135.96	23°00′	86°38′	1216.97	1814	827	248.2	0.637	−0.306
Phulberia	144.32	22°55′	86°37′	1345.7	2081	674	322.73	0.329	−0.006

based on the monthly precipitation data. These precipitation data were used for the spatial distribution of monthly precipitation over the basin.

7 Spatial interpolation of precipitation data

In Thiessen polygon method the attributes corresponding to rain-gauge stations varies from 14 to 30%, which will lead to crude approximation of the spatial variation of SPI. To overcome the above problem the total area of Kansabati basin is divided into 25 grids with each grid (13 × 13 km) approximately correspondence to 4% of total area. Due to the limitation of precipitation data in the basin, it is necessary to spatial interpolate the data at smaller grid. The Inverse Distance Weighting (IDW) approach is used in the present paper for spatial interpolation of precipitation over the Kansabati basin. This interpolation technique weights the contribution of each input (control) points by a normalized inverse of the distance from the control point to the interpolated point. IDW assumes that each input point has a local influence that diminishes with distance. It weights the points closer to the processing points, greater than those farther away. A specified number of points, or all points within a specified radius is used to determine the output value for each location. The power parameter in the IDW interpolator controls the significance of the surrounding points upon the interpolated value. A higher power results in less influence from distant points.

The general form of IDW approach (Shepard, 1968; Rase, 2001) is given by:

$$zn_i = \frac{\sum_{j=1}^{m} z_j * d_j^{-p}}{\sum_{j=1}^{m} d_j^{-p}} \tag{13}$$

zn_i is the new value for grid i; z_j value of m nearest neighbors; d_j distance to m nearest neighbors; p exponent of distance.

In the present study, the exponent of distance is taken as 2 to spatial interpolate the rainfall in the basin.

8 Temporal variation of drought over Kansabati basin

The SPI was used to provide an indicator of drought severity in this study. The temporal characteristics of droughts in Kansabati basin was analyzed based on the regional SPI value. The regional time series of SPI value is calculated using the mean areal rainfall time series of all grided values over the Kansabati basin shown in Figure 3. Analysis of the computed SPI series shows the basin has experienced droughts in terms of severity and duration in the 1980's. A drought is defined whenever the SPI reaches a value of −1.00 and continues until the SPI becomes positive again. The number of drought incidences along with their duration is shown in Table 4. It is found that the number of drought incidences for SPI-1 is 65 with a maximum duration of 4 month. The number of drought incidences for SPI-3 is 42 with the maximum duration of 8 month. The number of drought incidences for SPI 6 is 27 with a maximum duration of 10 month. The number of drought incidences for SPI 9 is 16 with a maximum duration of

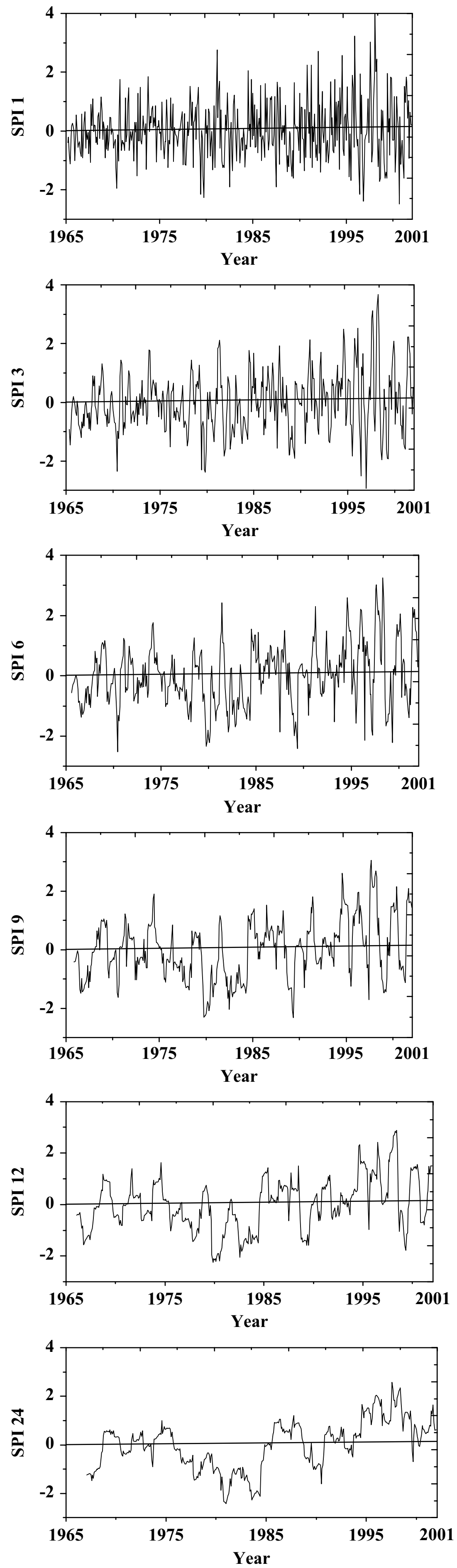

Figure 3 SPI time series in the Kansabati basin.

Table 4 Drought properties of SPI series in the Kansabati basin.

SPI series	Number of drought months (SPI < −1) (1965–2001)	Number of drought incidences	Duration of drought in months		
			Minimum	Maximum	Average
SPI 1	98	65	1	4	1.50
SPI 3	95	42	1	8	2.26
SPI 6	82	27	2	10	3.04
SPI 9	87	16	2	13	5.43
SPI 12	84	8	3	24	10.5
SPI 24	90	4	7	50	22.5

13 month. The number of drought incidences for SPI 12 is 8 with maximum duration of 24 month. The number of drought incidences for SPI 24 is 4 with the maximum duration of 52 month which was occurred in 1980's. Based on the average duration of drought (which is calculated by dividing total number of drought months with the total number of drought incidences for a particular series), the droughts are classified in the present paper. The average duration of drought for SPI 1 and SPI 3 are 1.50 and 2.26 month respectively, which are termed as short-term drought. Similarly the average duration of drought SPI 6 and SPI 9 are 3.04 and 5.43 months respectively, which are termed as medium term drought. When the drought due to SPI 12 and SPI 24 occurs it persist for a longer duration and the average duration are 10.5 and 22.5 month respectively. So SPI 12 and SPI 24 are considered as long tem drought.

9 Development of severity – area – frequency curves for droughts

A regional drought is assumed when a significant fraction of the total area of the region is under drought conditions. In other words, when the sum of the areas affected by local drought reaches a selected areal threshold so that it is very important to assess the drought for the entire region. Frequency of drought occurrence cannot fully cover the study of droughts, unless it is quantitatively related to other aspects such as severity, area and frequency of droughts.

This led to the development of drought severity – area – frequency curves. This can be a very useful method to assess drought in a region. A regional drought may be defined by its duration, cumulated areal deficit, intensity and mean regional coverage.

The following procedure was adopted in this study for deriving the drought severity – area – frequency curves:

- The monthly SPI values for each grid are calculated based on different time scales of 1-, 3-, 6-, 9-, 12-, and 24-months.
- Obtain the annual drought severity (sum of negative SPI values in dry spells) for each station using run theory.
- Calculate the drought severity associated with the different areal extents (in terms of percentage of total area) taking different areal thresholds into account.
- Test drought severity for different areal extents using different probability distributions to find out the best distribution for the frequency analysis.
- Perform the frequency analysis using the selected probability distribution for drought severity of different areal extents to associate drought severity with corresponding return periods.
- Construct the annual drought severity – area – frequency curves for the region for the time scale selected and repeat the analysis for different time scales.

In this study the annual values of drought severity were used for the frequency analysis. To be applied before fitting to an available distribution, the drought magnitude is converted to positive values in order to represent the extreme condition and to analyze the associated risk of droughts using the exceedance probability. These severity values were fitted with Normal, Log-normal, Gamma and Extreme Value Type 1 (EV-1) probability distributions. The K-S test and Chi-Square tests, which are standard tests for probability distributions are used at 1% and 5% significance levels, shown in Table 5 at different grid points for SPI-12. It is observed that the EV-1 and Gamma distribution passed the tests for all grid points. In the present work EV-1 distribution is selected for the frequency analysis as it passed the two tests for all SPI time scale and at all grid values. It is also a two parameter probability distribution and its parameter values may be estimated with less uncertainty, as the small sample size is used here. It is also used for the numerous extreme drought studies (for example, Lana *et al*., 1998; Henriques and Santos, 1999; Dalezious *et al*., 2000; Kim *et al*., 2002).

Chow (1951) has shown that many frequency analyses can be reduced to the form

$$X_T = \bar{x}(1 + C_v K_T) \tag{14}$$

where X_T is the magnitude of event having a return period T and K_T is frequency factor for the EV-1 distribution given by (Chow, 1951).

$$K_T = -\frac{\sqrt{6}}{\pi}\left(\gamma_e + \ln\left\{\ln\left[\frac{T_X(X)}{T_X(X)-1}\right]\right\}\right) \tag{15}$$

where γ_e is the Euler number (0.577216) and $T_X(X)$is the desired return period of the parameter.

Table 5 The results of Goodness fit test for candidate distributions for SPI 12 series at all grids.

Grid No.	K-S test				Chi square test			
	EV-1	Gamma	Log-normal	Normal	EV-1	Gamma	Log-normal	Normal
1	0.1236	0.1556	0.2230	0.2043	4.9159	5.5688	9.6646	7.3337
2	0.1303	0.1609	0.2000	0.2142	4.3891	5.3405	8.5656	7.5081
3	0.1436	0.1726	0.1666	0.2288	2.9241	4.4679	5.737	7.9662
4	0.1330	0.1666	0.1874	0.2283	2.9036	4.4321	5.4528	7.9828
5	0.1293	0.16	0.2243	0.2078	3.5658	4.2511	8.8824	6.2432
6	0.1289	0.1563	0.2203	0.2052	3.8953	4.9347	7.7501	7.0212
7	0.1504	0.1538	0.1713	0.2328	4.1455	5.438	6.7261	8.8921
8	0.1092	0.1448	0.1900	0.2144	3.9406	5.2312	5.0187	9.0960
9	0.1260	0.1599	0.2090	0.1993	4.4229	5.1142	7.7522	7.8092
10	0.1296	0.1394	0.2505	0.1914	4.4142	4.5270	9.7449	6.3664
11	0.1056	0.1437	0.2024	0.2084	3.2742	4.9722	6.6488	5.3737
12	0.1327	0.1466	0.2504	0.1926	2.7835	4.3265	9.1198	5.3704
13	0.1276	0.1792	0.2384	0.2105	2.1222	3.5514	9.7511	6.7177
14	0.1282	0.1300	0.2130	0.1640	4.2455	3.8558	5.437	5.5376
15	0.1021	0.0916	0.2265	0.1632	8.7436	6.8435	13.8515	8.1053
16	0.1149	0.1276	0.2319	0.1771	4.4463	3.4185	11.3446	4.2053
17	0.1421	0.1534	0.2020	0.2119	3.4327	5.0197	6.321	8.4063
18	0.1428	0.1369	0.2097	0.2106	3.1231	4.3713	5.876	7.3996
19	0.0835	0.1048	0.1587	0.1784	2.8361	3.4715	6.1899	6.8488
20	0.1642	0.1510	0.1752	0.2662	9.968	10.024	13.3670	20.076
21	0.0905	0.118	0.1665	0.1688	7.6440	5.1818	18.9504	4.2419
22	0.0951	0.1236	0.1907	0.1813	7.1478	5.1267	18.3297	5.1719
23	0.1264	0.1466	0.1657	0.2334	8.7812	9.879	13.3613	15.545
24	0.0957	0.0891	0.2119	0.1382	2.9329	5.1769	17.3199	4.5850
25	0.1024	0.0934	0.2164	0.1511	5.817	7.0289	8.1463	14.885

Significant level of K-S Test at 1% = 0.27 and 5% = 0.23; Significant level of chi-square test for 5 degrees of freedom at 1% = 15.1 and 5% = 11.1.

9.1 Drought severity – area – frequency (SAF) curves for Kansabati basin

Drought severity – area – frequency curves were constructed for different time scales of SPI values based on the annual drought severity. The procedure for the development of SAF curves have been outlined earlier in the paper. These curves were used to analyze historical drought in the basin. The SPI is suitable for quantifying most types of drought events like short term durations on the order of months (important to agricultural interests) and also while very long term durations spanning years (important to water supply management interests) (Guttman, 1998). Only droughts having return periods of more than 5 years are considered in the present drought analysis. The drought severity – area – frequency curves are plotted in Figure 4, where X axis represents percentage of area affected by drought and Y axis represents annual drought severity (sum of negative SPI values in dry spells) with different return periods. The timescale over which precipitation deficit accumulates becomes extremely important and separates the different types of drought. Based on the average duration of drought for different SPI series shown in Table 4, the droughts are classified for the study area. The SPI-1 and SPI-3 are used for short-term drought analysis. The SPI-6 and SPI-9 are used for medium-term drought analysis while the SPI 12 and SPI 24 are used for long term analysis. Under this analysis, it is observed that the short-term drought oscillation (SPI-1 and SPI-3) affects the basin frequently. Agricultural crops are more prone to this type of oscillations as crop period is generally of the order of 4 months. The drought that occurred in 1979 has an associate return period of 80 to 100 years. Even in more recent times it can observed that 1996, 1998, 1999 and 2000 suffered from drought that had return periods between 5 to 30 years with an increase in spatial extent.

The medium term drought analysis is done through SPI-6 and SPI-9. This indicates that these droughts are less frequent than short-term droughts and occurred in the years 1966, 1967, 1977, 1979, 1980, 1982, 1983, 1988, and 1989. The drought that occurred in 1979 and 1980 has an associate return period between 50 to 100 years. It is observed in the present study that, when the annual rainfall in a year is less than normal annual rainfall medium type of droughts are found to occur. It can be seen that some of the major droughts in India occurred in and around the early 1980's (1979, 1981, 1982) and in 1966, and 1967, which are shown in Table 1. Incidentally the Kansabati basin was also severely affected simultaneously just like many parts of India.

The long term Drought analysis is done through SPI-12 and SPI-24. The analysis of long term drought shows that they occur less frequently than medium-term drought and occurred in the years 1966, 1967, 1977, 1979, 1980, 1981, 1982, 1983 and 1984. The droughts of 1980, 1981 and 1983 have returned period

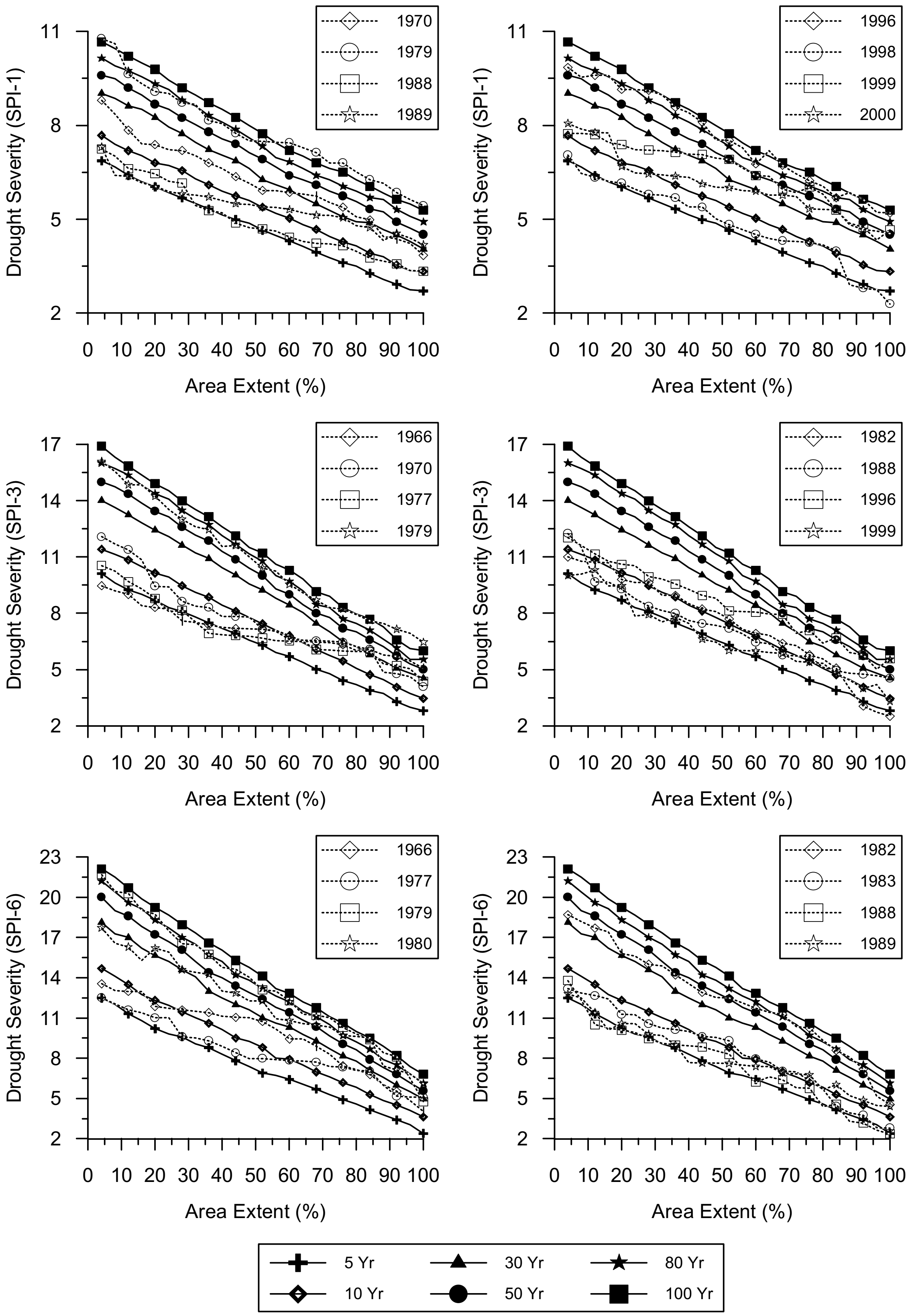

Figure 4 Drought severity – area – frequency curves for the SPI-1, SPI-3 and SPI-6 Kansabati basin compared to historical droughts.

between 50 to 100 years. It is observed that when the annual rainfall is less than normal annual rainfall for two consecutive years, long term droughts are found to occur. For example the long term drought occurrence in 1967 is due to result of less annual rainfall than normal in year 1965, 1966, and 1967 (shown in Figure 5). Similarly, the long-term droughts found in 1980's were due to less than normal rainfall in the years 1975, 1976, 1977, 1979, 1980, 1981, 1982 and 1983 (shown in Figure 5). The drought classification based on their average duration seems to be an attractive approach to classify drought in this basin.

The drought periods are found to be common between the neighboring SPI series (like SPI-4 with SPI-3 and SPI-5), this

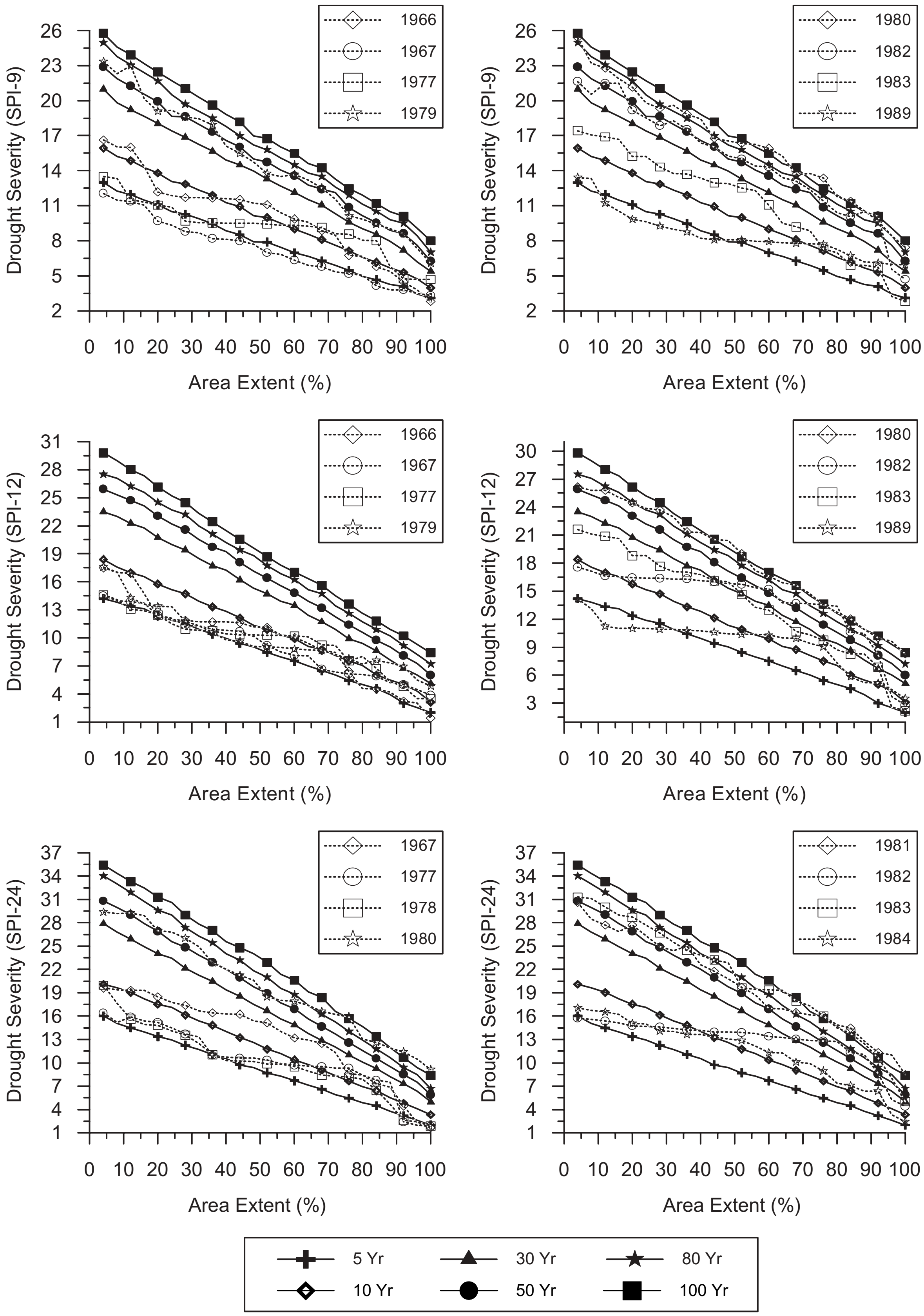

Figure 4 Drought severity – area – frequency curves for the SPI-9, SPI-12 and SPI-24 Kansabati basin compared to historical droughts.

is due to high correlation coefficient between SPI values of neighboring series. The drought periods are found to be highly correlated for drought having return period more than 5 years with larger spatial extent in most of the SPI series.

10 Conclusions

This study was focused on analyzing temporal and spatial extents of droughts in the Kansabati River basin using SPI as an indicator

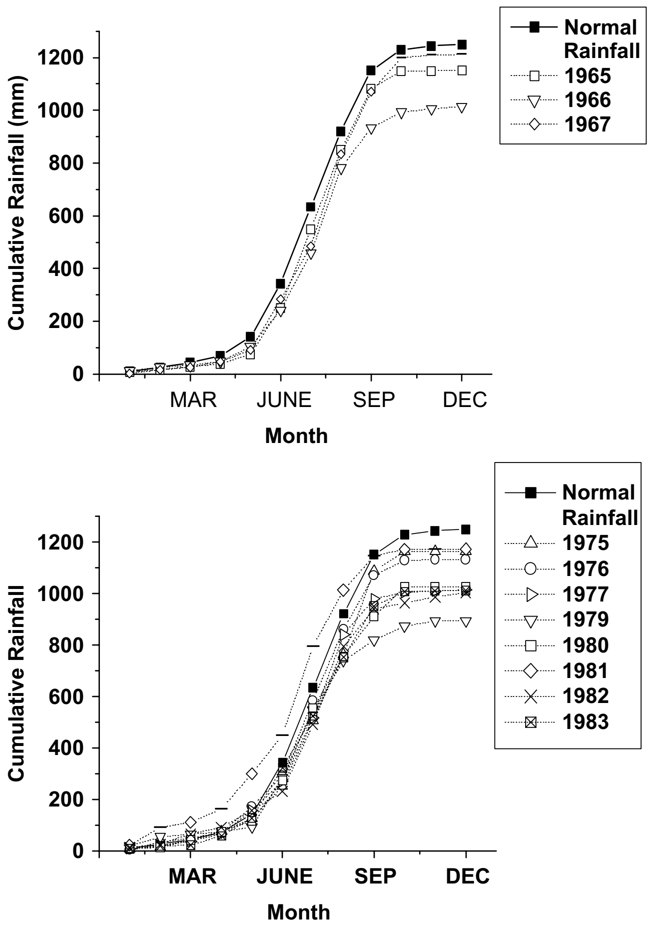

Figure 5 The cumulative precipitation in mid 1960's and mid 70's to early 80's in Kansabati catchment.

of drought severity. The SPI is one of the drought indices that have been more widely used by decision makers for quantifying most types of drought events. In addition it provides spatial and temporal representations of historical droughts. The SPI was computed based on the rainfall grid in the present analysis. This study was carried out to develop drought severity – area – frequency curves and to analyze temporal variation of drought using the SPI for different time scales. The temporal analysis of drought is done with average rainfall over the basin, which indicates long term drought persistence in 1980's. The drought severity – area – frequency curve constructed in this study depicts drought severity and drought area with respect to drought return period so as to describe and characterize the spatial and recurrence patterns of drought. These SAF curves are used to find out the drought affected years in terms of their severity. The drought classification was done for this basin based on average duration of drought for different SPI series. It is observed that the short-term drought oscillations are common in the Kansabati basin. The short-term drought based on SPI-1 and SPI-3 was high in 1979 where the return period is between 80 to 100 years covering whole basin. The medium and long-term drought is found to be frequent in 1980's with return periods between 50 to 100 years covering the whole basin. The high persistence of droughts in the 1980's seriously affected the urban water supply and agricultural irrigation, ground water as well as storage in the reservoir. The Kansabati basin was also simultaneously affected with major drought events like many parts of India. These frequency curves developed in Kansabati basin can be used for the development of a drought preparedness plan in the region so as to ensure sustainable water resource planning within the basin.

Acknowledgements

The authors would like to thank Mark Svoboda and an anonymous reviewer for giving valuable suggestions for improving the quality of the paper. The authors would also like to acknowledge the editor, Paul Bates, for the timely handling the review processes of the paper.

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