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DEVELOPMENT OF DROUGHT SEVERITY – AREAL EXTENT – FREQUENCY CURVES IN THE PARAMBIKULAM - ALIYAR BASIN, TAMIL NADU, INDIA

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Abstract: Assessment and characterization of regional droughts provide useful information for sustainable water resources planning and management. In the present study, the Standardized Precipitation Index (*SPI*) a most widely used rainfall based drought index was applied to investigate the temporal characteristics, areal extent and frequency of meteorological drought in the Parambikulam-Aliyar basin, Tamil Nadu. For this purpose, the basin was divided into 97 grid-cells of 5 × 5 km with each grid correspondence to approximately 1.03% of total area. Gridded monthly rainfall was developed by spatial interpolation technique with the help of GIS capabilities at each grid point using monthly rainfall data for the period of 40 years (1972-2011) from 28 rain gauge stations. Regional representative of *SPI* values calculated from spatially averaged mean areal rainfall were used to characterize the temporal variation of drought. Drought severity-areal extent-frequency (*SAF*) curves were constructed using gridded *SPI* values to assess the drought severity and areal extent with respect to return period so as to describe and characterize the spatial and recurrence patterns of drought. The analysis of *SPI* suggests that the basin suffered severe droughts in the 1970s, 1980s and 2000s. The *SAF* curves developed in this study can be used for the development of a drought preparedness plan in the region and planning sustainable water resource management within the basin.

Key words*: extreme value type I distribution, GIS, rainfall, SAF curves, SPI, weighted cumulative annual drought severity*

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INTRODUCTION

Drought is a disastrous natural phenomenon that has significant impact on socio-economical, agricultural, and environmental spheres. Drought occurs in virtually all climatic zones, such as high as well as low rainfall areas and is mostly related to the reduction in the amount of rainfall received over an extended period of time, such as a season or a year [1]. In general, drought gives an impression of water scarcity resulted due to insufficient rainfall, high evapo-transpiration, and over-exploitation of water resources or combination of these parameters [2]. Drought impacts both surface and groundwater resources and can lead to reduced water supply, deteriorated water quality, crop failure, reduced range productivity, diminished power generation, disturbed riparian habitats, and suspended recreation activities, as well as affect a host of economic and social activities. Drought differs from other natural hazards in that its onset and end are difficult to determine. It develops slowly, and its impacts may remain for years after termination of the event. Timely determination of the level of drought will assist the decision making process to reduce the impacts of droughts. These types of information may be obtained through drought monitoring.

The definition of drought has been important for drought monitoring and analysis. Drought has been categorized into meteorological (lack of precipitation), hydrological (drying of surface water storage), agricultural (lack of root zone soil moisture), and socio-economic (lack of water supply for socioeconomic purposes) ones. The first three categories are referred as environmental indicators and the last category is considered as a water resources indicator [3]. This study focuses on the meteorological drought which is defined as deficit of rainfall over a region within a certain time interval.

Droughts are usually assessed and monitored by drought indices. A drought index is typically a single value used for indicating the severity of a drought and is far more useful than raw data in understanding the drought conditions over an area. The most commonly used meteorological drought indices are: 1) Rainfall deciles; 2) the Palmer Drought Severity Index (*PDSI*); 3) Percent of Normal; 4) *Z*-index; and 5) the Standardized Precipitation Index (*SPI*). The *SPI* was used in this study because *SPI* quantifies the rainfall deficit for multiple time scales and reflects the impact of drought on the availability of different types of water resources. For example, soil moisture is highly affected by the short term rainfall anomalies, whereas stream-flow, groundwater and reservoir storage slowly respond to longer-term rainfall anomalies.

As droughts are regional in nature and commonly cover large areas and extend for long time periods, it is important to study such events within a regional context. Information on regional drought characteristics provides critical values for different water based activities, and should be included in strategic short and long-term plans for adequate water resource management. The properties of regional droughts can be studied by analyzing the spatial pattern of at-site (point) droughts or one can study regional drought characteristics like the area covered by drought and total rainfall deficit over the drought area. A method to estimate severity-area-frequency curves has been used in this study to estimate the return periods of annual regional droughts [4].

Drought is a frequent phenomenon in India and drought areas are mainly confined to the Peninsular and Western parts of the country and there are only few pockets in the central, eastern, northern and southern parts. Out of 329 Million ha of total geographical area in India about 107 Million ha of lands are subjected to different degrees of water stress and drought conditions [5]. More than 100 districts spread over 13 states of India have been identified as drought prone districts, out of these, about 8 districts occur in the Tamil Nadu [6]. The western regions of Tamil Nadu (Coimbatore and Tiruppur districts) have suffered with severe droughts at many times in the past. Due to the growth of population and expansion of agricultural, energy and industrial sectors, the demand for water has increased manifold and even water scarcity has been occurring almost every year. Other factors, such as climate change and contamination of water supplies, have further contributed to the water scarcity. In recent years, floods and droughts have been experienced with higher peaks and severity levels. Assessment of droughts is of primary importance for water resources planning and management. This requires understanding historical droughts in the region as well as different concepts of droughts that will be helpful to investigate different drought properties. The present study was carried out in the Parambikulam-Aliyar basin spread over drought prone districts of Coimbatore and Tiruppur, Tamil Nadu. The main objective of this study is to analyze the temporal variation of droughts and construct the Drought Severity–Areal Extent – Frequency curves for spatial analyze of regional drought.

MATERIAL AND METHODS

Study area and data used: Parambikulam-Aliyar basin (referred as PAP basin) is located in the south western part of the Peninsular India covering areas in Kerala and Tamil Nadu States (Fig. 1). Parambikulam Aliyar river basin is the only basin in Tamil Nadu having west flowing rivers. Bharathapuzha river or Ponnani river and Chalakudi river are the two important major rivers are originating in Tamil Nadu State at South Western part of Coimbatore district in the Anamalai hill ranges of Western Ghats. Parambikulam – Aliyar basin is drained by west flowing rivers viz. Valayar, Koduvadiaru, Uppar, Aliyar and Palar (tributaries of Bharathapuzha river) and Parambikulam, Solaiyar and Nirar (tributaries of Chalakudi river). They are grouped into 4 sub basins such as Valaiyar sub basin, Aliyar sub basin, Palar sub basin, and Solaiyar sub basin and spread over an area of 2.388,72 km^2. One third of the basin area (822,73 km^2) is covered with hills and dense forest cover. This basin is bounded in north and east by Cauvery basin, south and west by Kerala State. This basin area lies (except the ayacut area) within the coordinates of North latitude between 10° 10’ 00” to 10°57’20” and East longitudes 76°43’00” to 77° 12’30”. Parambikulam-Aliyar river basin has an undulating topography with maximum contour elevation in the plain is 300m and the maximum spot height in the plain is 385m above MSL. The temperature slowly rises to its maximum in summer up to May and afterwards shows a gradual decline. The maximum temperature ranges from 36°C to 41°C and the minimum temperature varies from 14°C to 31°C. The major crops grown in the catchment are Paddy, Coconut, Groundnut, Vegetables, Cotton, Tapioca, Maize and Sugarcane. Northern parts of the basin include Thondamuthur, Madukkarai, Sultanpet and Kinathukadavu block; Central parts include Pollachi North, Pollachi South, Anamalai and Udumalaipet block; Southern parts include Valparai and some parts of Anamalai block.

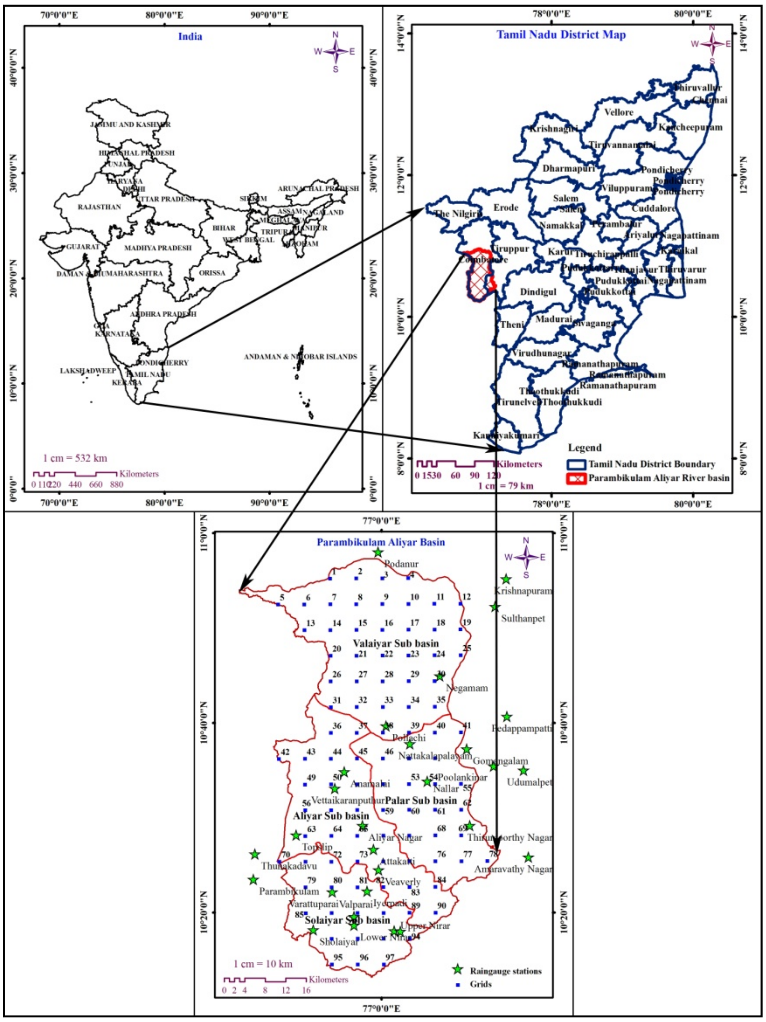


Figure 1. Location of study area and rain gauges in the PAP basin

The investigation used the rainfall as meteorological drought indicator. The monthly rainfall data for the period of 40 years (1972-2011) of 28 rain-gauge stations located in the *PAP* basin was collected from the office of Groundwater division, Public Works Department, Coimbatore. Distribution of these meteorological stations is shown in Fig. 1. The *PAP* basin has a large geographic variation. More rainfall can be observed in the southern parts of the basin. When it comes to the middle and northern parts of the basin, the rainfall decreases. The prolonged and significant decrease on monthly and annual rainfall resulted in irrigation cutbacks, over exploitation of groundwater and significant losses of crop yields. The Parambikulam-Aliyar river basin was considered as a study area because the basin experienced severe, extreme and prolonged droughts during 1970s, 1980s, 1990s and 2000s. During these periods the monthly and annual precipitation and inflows to the reservoir was significantly below normal. Since the basin is affected by short term, medium term and long term drought frequently, it is necessary for the water resources managers to investigate drought in the basin.

The methodology comprised of the generation of gridded rainfall using spatial interpolation technique, development of mean monthly areal rainfall and gridded rainfall at multiple time scale, calculation of *SPI* values using mean areal rainfall for temporal drought analysis, calculation of gridded *SPI* values using gridded rainfall for construction of Drought Severity-Areal Extent-Frequency curves.

Spatial interpolation of rainfall: Spatial interpolation techniques estimate the value of the surface at locations where no observed data exists, based on the known data values (observations). A number of spatial interpolation methods such as inverse distance weighting (*IDW*), Splines and kriging are available for spatial analysis of any variables and some researchers have used these techniques for drought studies [7, 8, 9]. In this study, *IDW* approach which gives better results than Thiessen polygon method [5] was used for spatial interpolation of rainfall and drought characteristics over the PAP basin.

Total area of *PAP* basin was divided into 97 grids with each grid (5 × 5 km) approximately correspondence to 1.03% of total area (2425 km^2) (Fig. 1). The monthly rainfall data for 40 years (1972-2011) was interpolated by ArcGIS 9.3 using *IDW* method and gridded monthly rainfall was created at various time scales (i.e. 3-, 6-, 12-, and 24- month). Mean monthly areal rainfall of PAP basin was estimated by averaging gridded rainfall for the various time scales. The procedure, followed for the calculation of gridded *SPI* values, is referred interpolate-calculate, because first rainfall is spatially interpolated and, then, the SPI time series are calculated [10].

Use of the Standardized Precipitation Index (*SPI*) for Drought Analysis: The Standardized Precipitation Index (*SPI*) as a drought assessment tool was developed at Colorado State University, U.S. to quantify the rainfall deficit, and has been used to monitor drought conditions [11]. A drought event occurs at the time when the value of SPI is continuously negative and the event ends when the *SPI* becomes positive. The *SPI* may be calculated at multiple timescales (3-, 6-, 12-, and 24- months). The use of multiple timescales allows the effects of a rainfall deficit on different water resource components (groundwater, reservoir storage, soil moisture, stream-flow) to be assessed. Tab. 1 provides a drought classification based on *SPI*. Numerous studies have been conducted to analysis the meteorological droughts using *SPI* [8, 9, 12, 13, 14, 15, 16].

Table 1. Drought classification by SPI or SDI value and corresponding probabilities

Sl.No.	Drought Category		SPI	Probability (Per cent)
1	D1	Mild drought	0 to -0.99	34.1
2	D2	Moderate drought	-1.00 to -1.49	9.2
3	D3	Severe drought	-1.50 to -1.99	4.4
4	D4	Extreme drought	≤ -2.00	2.3

Calculation of *SPI*: The *SPI* for any location is calculated, based on the long-term rainfall record for a desired period. This is performed separately for each month and for each grid in space. The long-term record is fitted to a probability distribution, which is then transformed to a normal distribution so that the mean *SPI* for the location is zero and standard deviation of unity [11].

The gamma distribution is defined by its probability density function is:

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

where:

α > 0 [-] - shape factor,
β > 0 [-] - scale factor,
x > 0 [mm] - amount of rainfall.

Γ(α) is the gamma function which is defined as

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

Fitting the distribution to the data requires that α and β be estimated. Edwards and McKee (1997) [17] suggested a method for estimating these parameters using the approximation of Thom (1958) [18] for maximum likelihood as follows:

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

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

Where:

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

for *n* observations.

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

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

Substituting t for $x/\hat{\beta}$ reduces the above equation to incomplete gamma function:

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

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

$$H(x) = q + (1-q)G(x) \quad (8)$$

where q is the probability of zero precipitation. If m is the number of zeros in a rainfall time series, q can be estimated by *m/n*. In this analysis, a small amount of rainfall was substituted for zero rainfall for each grid. This substitution does not affect the distribution of precipitation.

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* [12, 17].

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

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

Where

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

For $0.5<H(x)<1$

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

Where

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

$c_0=2.515517$ $c_1=0.802853$ $c_2=0.010328$
$d_1=1.432788$ $d_2=0.189269$ $d_3=0.001308$

Construction of drought Severity-Areal Extent-Frequency (*SAF*) curves: Regional drought analysis is useful for declaring the drought condition or determining the drought severity during a particular year. A regional drought is assumed when a significant fraction of the total area of the region is under drought conditions or, 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 and areal extent of droughts. This led to the development of drought severity-area-frequency (*SAF*) curves. *SAF* curves are one of the most useful methods to assess drought in a region, which was proposed by Henriques and Santos (1999) [19] and the same procedure was adopted by Kim et al., 2002; Loukas and Vasiliasdes, 2004; Mishra and Desai, 2005; Zhang et al., 2012 [7, 10, 5, 20]. In this study annual *SAF* curves were developed based on weighted cumulative drought severity at multiple time scales.

The weighted annual cumulative *SAF* curves were developed according to the following procedure: (1) The monthly *SPI* values for each grid for every year were calculated at multiple time scales of 3-, 6-, 12-, and 24-months; (2) The annual weighted cumulative drought severity in each grid was estimated by multiplying the annual sum of *SPI* in monthly dry spells (negative *SPI* values) for a particular time scale by the probability of drought occurrence for each year; (3) The probability of annual drought occurrence for each year and in each grid was estimated by dividing the number of months that have a negative *SPI* value for the particular time scale by 12; (4) The drought severity associated with the areal extents (in terms of percentage of total area) taking different areal thresholds into account was obtained; (5) To find out the best distribution for the frequency analysis, drought severity was tested using different probability distributions; (6) Frequency analysis was performed using selected probability distribution for each drought areal extent percentage to associate the drought severity with return periods; (7) Weighted annual cumulative *SAF* curves were developed for the particular time scale and repeated the analysis for different time scale. In this analysis each drought event can be allotted uniformly for a particular year, avoid intermittence, and the duration of dry spells within a particular year is implicitly taken into account.

Analysis of drought frequency: The frequency analysis is commonly used in hydrology and meteorology to assess the return period of particular events. Frequency analysis is performed using the selected probability distribution for annual average drought severity at different return periods. In this study, the annual cumulative drought severity has negative values. To be applied before fitting to an available distribution, the negative values of average annual drought severity were transformed to positive values in order to represent the extreme condition and to analyze the associated risk of droughts using the exceedance probability. Various theoretical probability distributions were statistically tested before fitting the observed drought severity. The commonly used probability distributions viz. Normal, Lognormal, Gamma, and Extreme Value Type I were used to evaluate the best fit probability distribution for *SPI*_12 annual drought severity and tested by non parametric Kolgomorov–Smirnov (*K-S*) test and parametric Chi-Square tests at 5 per cent and 1 per cent significance levels.

The annual cumulative drought severity X_T to be estimated for a given return period (T) may be represented as the mean μ plus the departure ΔX_T of the variate from mean.

$$X_T=\mu+\Delta X_T \tag{13}$$

The departure may be taken as equal to the product of the standard deviation σ and a frequency factor K_T; that is, $\Delta X_T = K_T\sigma$. The departure ΔX_T and the frequency factor K_T are functions of the return period and type of probability distribution to be used in the analysis [21]. The expected annual drought severity at various return periods 5, 10, 25, 50, 75 and 100 years were worked out by the best fit probability distribution.

RESULTS AND DISCUSSION

Analysis of rainfall: Gridded rainfall was developed using spatial interpolation technique in *GIS* environment and mean areal rainfall was calculated from the spatially averaged gridded rainfall. The mean annual areal rainfall over the whole *PAP* basin was about 1410.04 mm and it was distributed unevenly in space and time. The mean annual precipitation varied from about 511 mm at the northern plain areas to more than 4328 mm at the southern mountain areas. The average cumulative areal rainfall was compared with normal cumulative areal rainfall over the study period for identifying the worst rainfall deficit years (Fig. 2). From this analysis, it was found that the *PAP* basin experienced rainfall deficits during the periods of 1970s, 1980s and 2000s. During these three periods the monthly and annual precipitation was considerably below normal. Especially, the year 1982, 1976 and 2002 are the first, second and third driest years, respectively. The prolonged and remarkable decrease of monthly and annual precipitation has a significant impact on water resources of the basin. Severe and extremely dry conditions lead to decrease in supplying the irrigation water, overexploitation of groundwater and dramatic losses of crop yields.

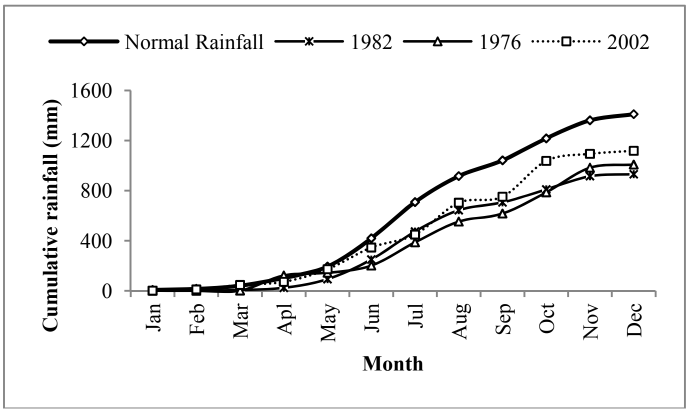


Figure 2. The cumulative areal rainfall for selected rainfall deficit years and periods

Temporal variation of droughts in the PAP basin: The temporal characteristics of droughts in *PAP* basin were analyzed based on the regional representative of SPI value to assess the regional drought. The *SPI* values were computed for each month of the year of study period at 3-, 6-, 12- and 24-month time scales for each grid in the PAP basin. The *SPI* values on shorter time scale describes drought events affecting agricultural practices, while on the longer ones it is more suitable for water resources management purpose. The regional representative of SPI calculated from mean areal rainfall for the *PAP* basin for the time series of 3-, 6-, 12- and 24-month *SPI* (Fig. 3a-d) showed that the region experienced frequent moderate, severe and extreme droughts (i.e. $SPI < -1$) over the period of study. Visual inspection of 3-, 6-, 12- and 24-month *SPI* time series indicated that droughts were quite frequent during the 1970s, 1980s and 2000s. Another notable point observed from the figure that as the time scale increases, drought frequency decreases but its duration increases. At shorter time scales (*SPI*_3 and *SPI*_6), drought becomes more frequent but ends for shorter periods. On longer time scales (*SPI*_12 and *SPI*_24), drought becomes less frequent but lasts longer.

Occurrence of drought categories: Occurrence of drought categories (from mild to extreme drought) in the *PAP* basin was investigated for each time scale based on the percentage occurrence of each event (within each category) with respect to the total number of observations over the basin in the same category and time scale. Tab. 2 presents the percentage of occurrence of drought categories at 3-, 6-, 12- and 24-month in the *PAP* basin. The numbers are obtained by taking the ratio of drought occurrences in each time scale to the total length of data record in the same time scale and drought category across the basin. The results show that for a given time scale mild droughts occur most frequently and extreme droughts occur least frequently. More than 50 per cent of the study period experienced droughts. The percentage occurrence of drought events with drought severity level of mild to extreme drought has nearly comparable values for all time scales.

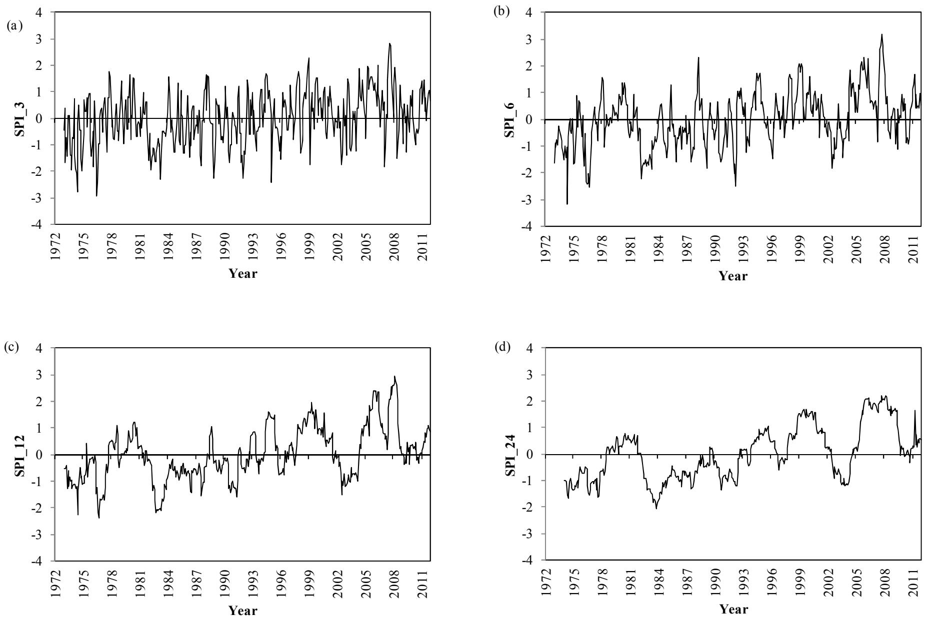


Figure 3. Time series of SPI Values at (a) 3-, (b) 6-, (c) 12- and (d) 24-month, time scales

Table 2. Occurrence of drought categories (percentage) in the PAP basin

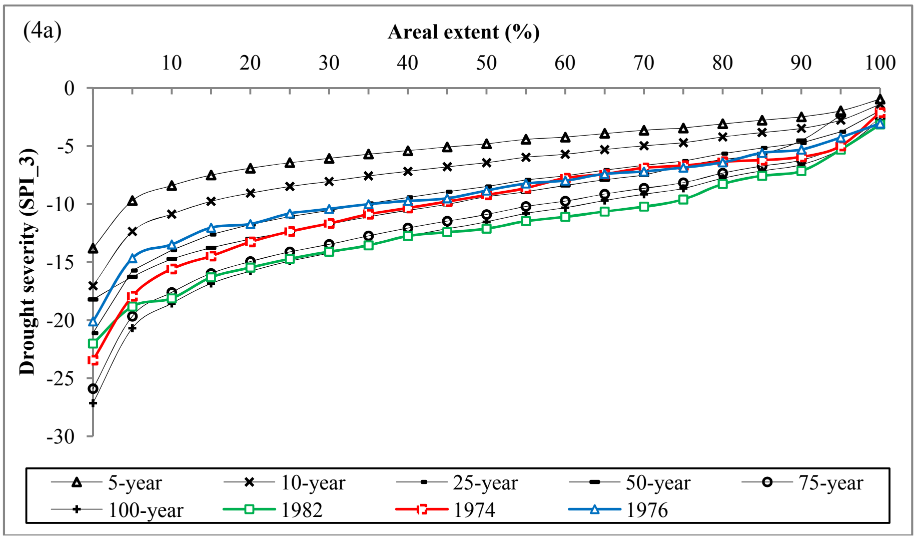
Sl.No	Time scale	D1	D2	D3	D4	Total
1	SPI_3	33.76	9.62	4.27	1.92	49.57
2	SPI_6	35.04	8.33	5.56	1.92	50.85
3	SPI_12	39.53	9.62	2.99	2.35	54.49
4	SPI_24	32.46	14.47	3.29	0.44	50.66

Frequency analysis of weighted annual cumulative drought severity: Frequency analysis was performed using weighted annual cumulative drought severity for searching best fit distribution. In the present work Extreme Value Type I distribution was selected for the frequency analysis as it passed the two tests for *SPI*_12 time scale at all grids. 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 [5, 7, 10, 19, 22, 23]. For the Extreme Value Type I distribution frequency factor can be expressed as:

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + ln\left[ln\left(\frac{T}{T-1}\right)\right]\right\} \tag{14}$$

Frequency factor of Extreme Value Type I distribution was applied in the Equation 13 and calculated annual cumulative drought severity for different return period (*T*).

***SAF* curves of the weighted annual cumulative drought severity:** A method to assess the spatial characteristics and the frequency of drought severity over an area is the Drought Severity-Areal Extent- Frequency (*SAF*) curves. In this study, the *SAF* curves were developed for *PAP* basin using gridded *SPI* values. The calculation procedure outlined in the materials and methods has been followed for construction of *SAF* curves.



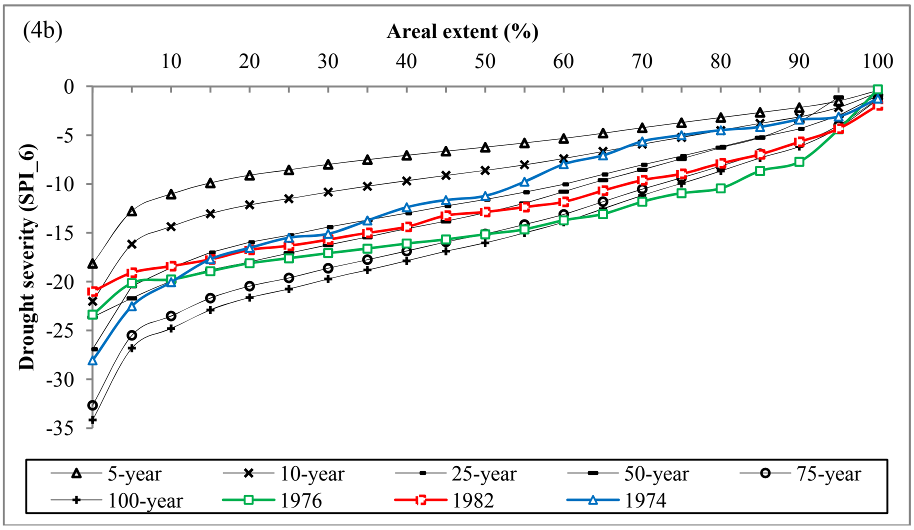
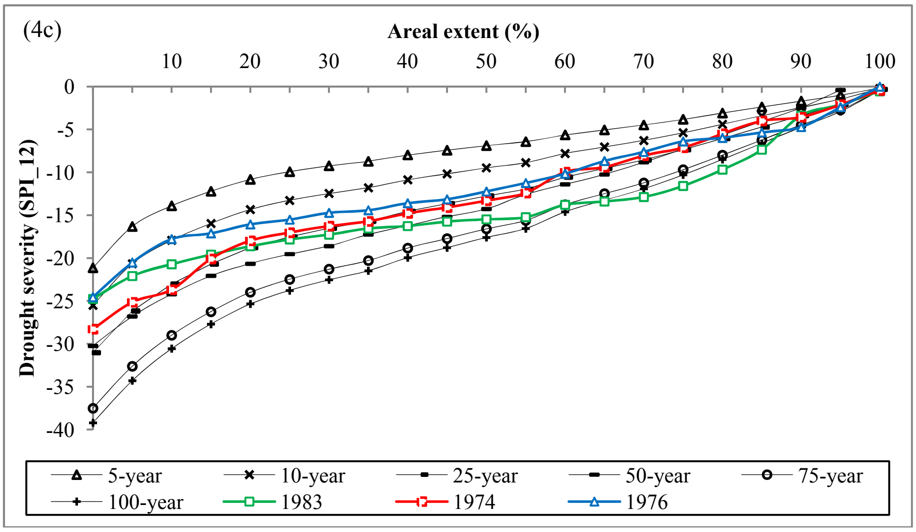


Fig. 4a-d shows the *SAF* curves of weighted annual cumulative drought severity that were developed for 3-, 6-, 12- and 24-month *SPI* values. The *SAF* curves are plotted in Fig. 4a-d, where *X* axis represents percentage of area affected by drought and *Y* axis represents annual drought severity (sum of negative *SPI* values in dry spells) with different return periods. Most severe drought years recorded during the period of analysis was selected based on highest annual drought severity and driest years were drawn in the *SAF* curves to indentify the recurrence pattern and spatial extent of selected droughts.



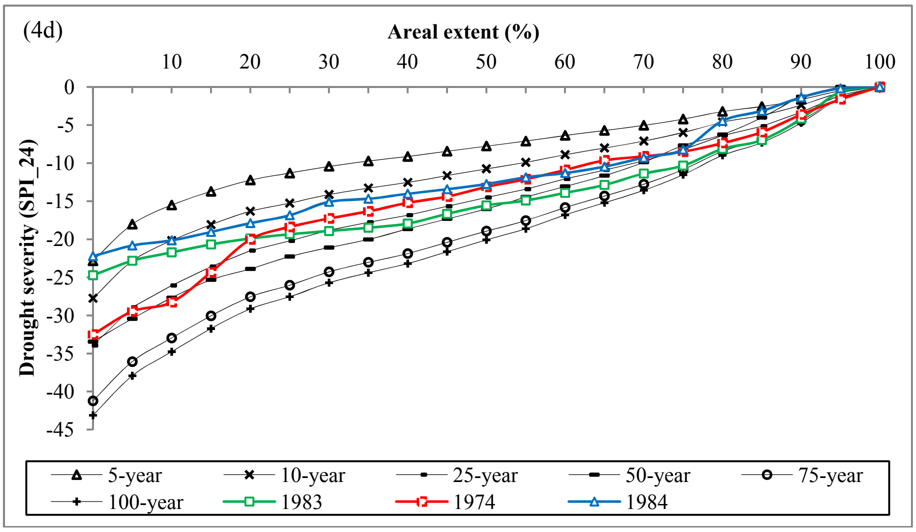


Figure 4. Severity-Areal extent-Frequency curves of the weighted annual cumulative drought severity for (a) 3-, (b) 6-, (c) 12- and (d) 24-month SPI series compared to historical drought

Fig. 4a illustrates the *SAF* curves of SPI_3 for the *PAP* basin and the figure demonstrates that three annual droughts with the highest weighted annual cumulative drought severity in the *PAP* basin occurred during 1982, 1974 and 1976. The drought that occurred in 1982 has an associate return period of above 100 years with more than 50 per cent of the areal extent. The drought event that occurred in 1974 and 1976 has an associate return period between 25 to 50 years. The most three severe drought year for *SPI*_6 based on weighted annual cumulative drought severity was 1976, 1982 and 1974 (Fig. 4b). From the figure, it can be observed that the 1976 drought year has an associate return period of 50 to 100 years. The drought that occurred in 1982 and 1974 has an associate return period between 25 to 50 years.

The droughts of 1983, 1976 and 1974 assessed by *SPI*_12 time series have return period between 10 to 25 years (Fig. 4c) and the curve of drought year 1974 runs between the return periods of 10 to 100 years with an increasing areal extent. The drought that occurred in 1983, 1974 and 1984 for 24- month time series have an associate return period between 10 to 50 years (Fig. 4d). From this analysis the year 1974, 1976, 1982, 1983, and 1985 were the severe drought years have large spatial extent and have return period between 10-50 years. Using these curves one can easily identify the drought severity associated with return period drought for a particular drought event.

CONCLUSIONS

This study was focused on analyzing temporal variation and areal extent and frequency of severe droughts in the *PAP* Basin using the *SPI* as an indicator of drought severity. The *SPI* was computed using gridded rainfall at multiple time scales. The temporal analysis of drought was done with mean areal rainfall and SAF curves were developed with gridded rainfall over the basin. The temporal and spatial drought analyses indicated that *PAP* basin experience quite frequent moderate and severe droughts on monthly basis. The region has experienced prolonged and severe droughts in terms of severity and durations in the 1970s, 1980s and 2000s. In particular, the persistent and prolonged drought of 1974-1976 and 1982-1985 seriously affected urban water supply, agricultural irrigation, ground water as well as reduction of inflows to the reservoir. The drought severity – areal extent - frequency curve constructed in this study contains drought severity and drought area with respect to drought return period so as to describe and characterize the spatial and recurrence patterns of droughts. It is shown that the drought that occurred in the 1970s and 1980s was associated with a return period of 25 to 50 years with a large areal extent. The identification of the temporal characteristics of droughts and construction of *SAF* curves in the *PAP* basin will be useful for the development of a drought preparedness plan in the region and for sustainable water resource planning and management.

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RAZVOJ KRIVIH SUŠE – POLOŽAJA – UČESTALOSTI U PARAMBIKULAM - ALIYAR BASENU, TAMIL NADU, INDIJA

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Sažetak: Procena i karakterizacija regionalnih suša daju korisne informacije za održivo planiranje i upravljanje vodenim resursima. U ovom istraživanju primenjen je Standardizovani indeks padavina (*SPI*), kao najšire primenjeni indeks suše zasnovan na padavinama, za ispitivanje vremenskih karakteristika, prostornog oblika i učestalosti suše u basenu Parambikulam-Aliyar, Tamil Nadu. Za ovu svrhu basen je podeljen na 97 mrežnih ćelija dimenzija 5 × 5 km, tako da svaka ćelija odgovara približno 1.03% ukupne površine. Mesečne padavine u mreži razvijene su tehnikom prostorne interpolacije uz pomoć *GIS*-a u svakoj tački mreže korišćenjem podataka o mesečnim padavinama za period od 40 godina (1972-2011) iz 28 mernih stanica. Regionalne reprezentativne *SPI* vrednosti izračunate iz prostorno prosečnih vrednosti padavina korišćene su za karakterizaciju vremenskih varijacija suše. Krive suše-prostornog položaja-učestalosti (*SAF* krive) su konstruisane korišćenjem mrežnih *SPI* vrednosti za procenu jačine suše i prostornog položaja u odnosu na povratni period, tako da se opišu i karakterišu prostorni i povratni oblici suše. Analiza *SPI* vrednosti pokazuje da su basen pogodile jake suše 1970-tih, 1980-tih i 2000-tih. Razvijene *SAF* krive mogu se koristiti za razradu plana pripravnosti u sušnim periodima u regionu i planiranje održivog upravljanja vodenim resursima u basenu.

Ključne reči: *distribucija ekstremnih vrednosti tipa I, GIS, padavine, SAF krive, SPI, masena kumulativna godišnja suša*

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