



Spatial and Temporal Variation of Meteorological Drought in the Parambikulam-Aliyar Basin, Tamil Nadu

M. Manikandan¹ · D. Tamilmani²

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Abstract The present study aims to investigate the spatial and temporal variation of meteorological drought in the Parambikulam-Aliyar basin, Tamil Nadu using the Standardized Precipitation Index (SPI) as an indicator of drought severity. The basin was divided into 97 grid-cells of 5×5 km with each grid correspondence to approximately 1.03 % of total area. Monthly rainfall data for the period of 40 years (1972–2011) from 28 rain gauge stations in the basin was spatially interpolated and gridded monthly rainfall was created. Regional representative of SPI values calculated from mean areal rainfall were used to analyse the temporal variation of drought at multiple time scales. Spatial variation of drought was analysed based on highest drought severity derived from the monthly gridded SPI values. Frequency analyse was applied to assess the recurrence pattern of drought severity. The temporal analysis of SPI indicated that moderate, severe and extreme droughts are common in the basin and spatial analysis of drought severity identified the areas most frequently affected by drought. The results of this study can be used for developing drought preparedness plan and formulating mitigation strategies for sustainable water resource management within the basin.

Keywords Drought severity · Rainfall · SPI · Spatial interpolation · Inverse distance weighting · Extreme value type I

Introduction

Drought is a disastrous natural phenomenon that has significant impact on socio-economical, agricultural and environmental aspects. Drought 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]. Drought occurs high as well as low rainfall areas. In general, drought gives an impression of water scarcity resulted due to insufficient rainfall, high evapotranspiration 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, crop failure, reduced range productivity and diminished power generation, as well as affect economic and social activities. Drought develops slowly, its onset and end are difficult to determine 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. 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 [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

✉ M. Manikandan
muthiahmanikandan29@gmail.com

¹ Agricultural Research Station, Tamil Nadu Agricultural University, Bhavanisagar, Tamil Nadu 638451, India

² Department of Soil & Water Conservation Engineering, Agricultural Engineering College & Research Institute, Tamil Nadu Agricultural University, Kumulur, Tamil Nadu 621712, India

than raw data in understanding the drought conditions over an area. Numerous specialized indices have been proposed, some of them are region specific [4]. The most commonly used SPI was applied 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 streamflow and reservoir storage slowly respond to longer term rainfall anomalies.

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 eight districts falls in the Tamil Nadu [6]. The Western regions of Tamil Nadu have suffered with severe droughts at many times in the past. Early detection of droughts helps in implementing drought mitigation strategies and measures, before they occur. This requires understanding historical droughts in the region. The objective of this study is to analyze the temporal and spatial variation of drought in the Parambikulam-Aliyar basin (referred as PAP basin) spread over drought prone districts of Coimbatore and Tiruppur, Tamil Nadu.

Materials and Methods

Study Area and Data Used

PAP basin is located in the South Western part of the Peninsular India covering areas in Kerala and Tamil Nadu States. Parambikulam Aliyar river basin is the only basin in Tamil Nadu having west flowing rivers. Bharathappuzha river or Ponnani river and Chalakudy 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. PAP basin is drained by West flowing rivers viz. walar, Koduvayur, Uppar, Aliyar and Palar (tributaries of Bharathapuzha river) and Parambikulam, Sholayar and Nirar (tributaries of Chalakudy river). They are grouped into four sub basins such as Valaiyar sub basin, Aliyar sub basin, Palar sub basin and Solaiyar sub basin and spread over an area of 2388.72 km². One third of the basin area 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 300 m and the maximum spot height in the plain is 385 m above MSL. The major crops grown in the basin 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.

The monthly rainfall data for the period of 40 years (1972–2011) of 28 rain gauge stations located in the PAP basin (Fig. 1) was collected from the office of groundwater division, Public Works Department, Coimbatore. The methodology used in this study consisted 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, assessment of frequency of severe drought, calculation of annual weighted cumulative severity from gridded SPI values for spatial analysis.

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 [7–9]. 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 (Fig. 1). The monthly rainfall data of 28 rain gauge stations located in the PAP basin (Fig. 1) 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. 1-, 3-, 6-, 9-, 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].

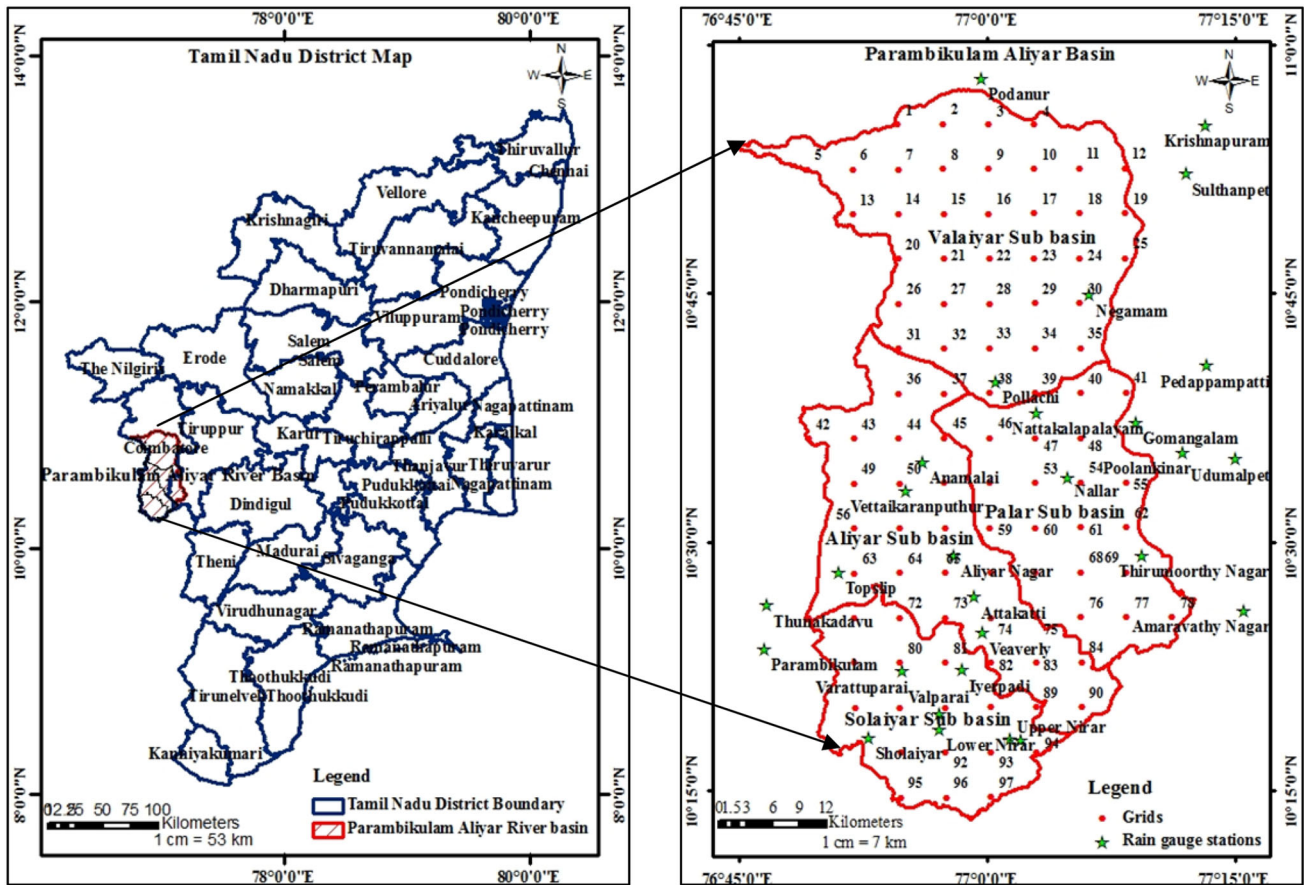


Fig. 1 Location of rain gauges in the PAP basin

Table 1 Classification of drought categories

SPI values	Drought category	
0 to -0.99	D1	Mild drought
-1.00 to -1.49	D2	Moderate drought
-1.50 to -1.99	D3	Severe drought
≤2.00	D4	Extreme drought

Use of the SPI for Drought Analysis

Standardized precipitation index as a drought monitoring tool was designed at Colorado State University, US to quantify the rainfall deficit on multiple time scales [11]. 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 whatever the temporal basis is of the raw precipitation time series) and for each location in space. Each probability density function is then transformed into the standardized normal distribution. A drought event occurs at the time when the value of SPI is continuously negative and the event ends when the SPI becomes positive. Table 1 provides a drought classification

based on SPI. Numerous studies have been conducted to analyze the meteorological droughts using SPI [9, 12]. Detail of the SPI algorithm can be found in [5, 11, 13]. In this study drought was analyzed for determining the temporal variation and spatial distribution of SPI values. The temporal variation of SPI was assessed using the regional representative of SPI values, calculated from mean monthly areal rainfall of the PAP basin at 1-, 3-, 6-, 9-, 12- and 24-month time scales. It is denoted as SPI_1, SPI_3, SPI_6, SPI_9, SPI_12 and SPI_24. Spatial analysis of drought was performed using the gridded SPI values for evaluating the most affected areas.

Frequency Analysis of Drought Severity

The frequency analysis is the traditional and practical method used in hydrology and meteorology to assess the return period of extreme events. Frequency analysis is performed using the selected probability distribution for drought severity at different return periods. The procedure employed in this study for deriving frequency of drought severity is:

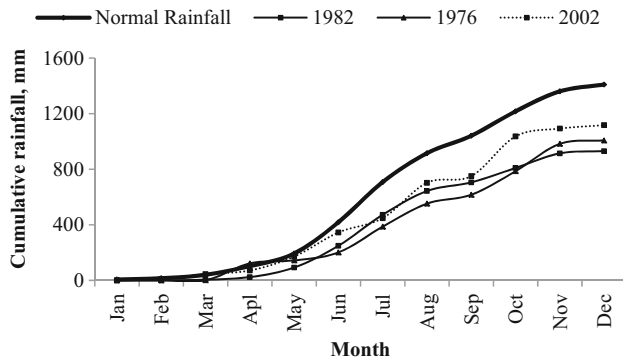


Fig. 2 The cumulative areal rainfall for selected years and periods in the PAP basin

- (1) The annual weighted cumulative drought severity in each grid was estimated by multiplying the annual sum of negative SPI values in monthly dry spells by the probability of drought occurrence for each year;
- (2) The probability of annual drought occurrence for each year was estimated by dividing the number of months that have a negative SPI value by 12;
- (3) To find out the best distribution for the frequency analysis, drought severity was tested using different probability distributions;
- (4) Drought severity was estimated at different return periods using selected probability distribution and repeated the analysis for other time series.

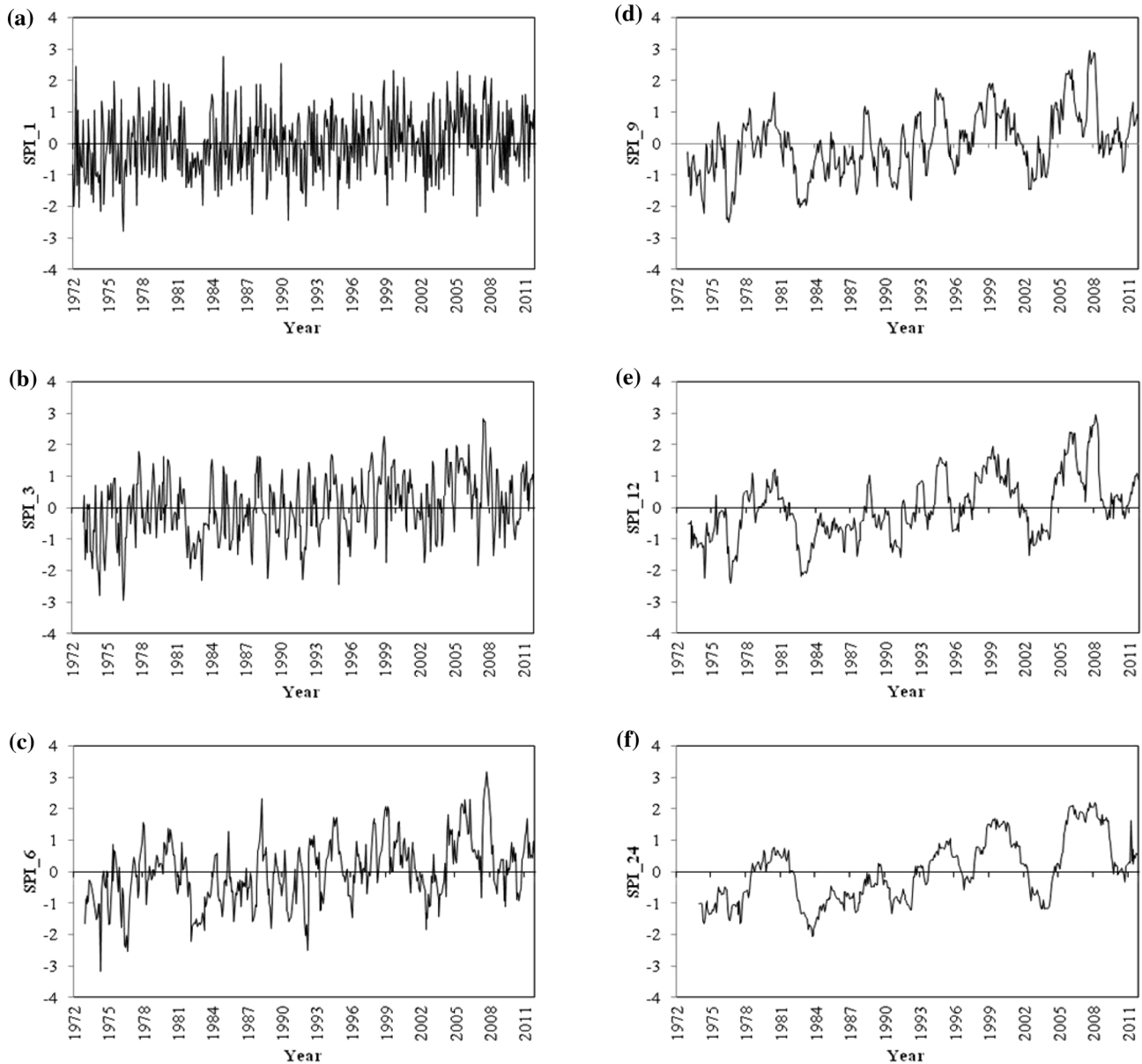


Fig. 3 Time series of SPI Values for PAP basin **a** 1-month, **b** 3-month, **c** 6-month, **d** 9-month, **e** 12-month, and **f** 24-month time scales

Table 2 Occurrence of drought categories in the PAP basin, %

Sl.no	Time scale	Mild drought	Moderate drought	Severe drought	Extreme drought	Total
1	SPI_1	34.19	12.39	3.21	2.35	50.83
2	SPI_3	33.76	9.62	4.27	1.92	49.57
3	SPI_6	35.04	8.33	5.56	1.92	50.85
4	SPI_9	35.26	9.83	4.49	1.50	51.07
5	SPI_12	39.53	9.62	2.99	2.35	54.49
6	SPI_24	32.46	14.47	3.29	0.44	50.66

Table 3 Monthly distribution of occurrence of drought in the PAP basin, %

Month	SPI_1	SPI_3	SPI_6	SPI_9	SPI_12	SPI_24
January	4.79	4.27	4.06	4.70	4.70	3.95
February	4.79	4.49	4.70	4.70	4.70	3.95
March	3.75	3.42	3.42	4.27	4.70	4.39
April	4.38	3.63	4.27	4.06	4.27	4.39
May	4.38	4.06	4.70	4.06	4.91	4.17
June	4.17	4.06	4.70	4.06	4.27	4.61
July	3.96	4.49	4.06	3.85	4.49	4.17
August	4.38	3.85	4.06	3.85	4.70	4.39
September	3.96	4.70	3.63	4.27	4.27	4.17
October	3.75	4.70	4.27	3.85	4.49	4.61
November	4.17	4.49	4.91	4.70	4.27	4.17
December	4.38	3.42	4.06	4.70	4.70	3.73
Total	50.83	49.57	50.85	51.07	54.49	50.66

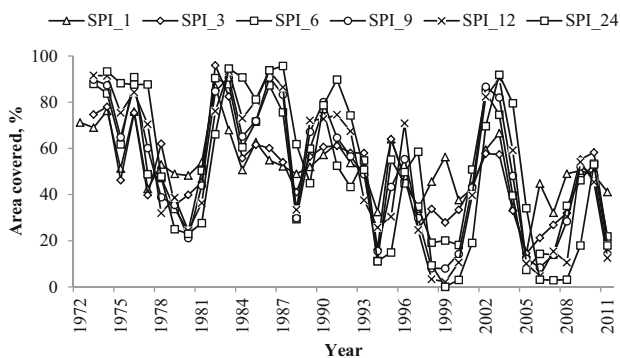


Fig. 4 Areal coverage of drought categories at multiple time scales

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.

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. The commonly used probability distributions viz. Normal, Lognormal, Gamma and Extreme Value Type I were used to evaluate the best fit

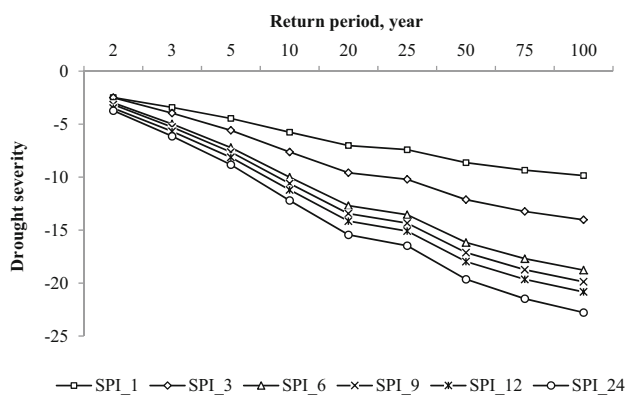
Table 4 The most intense of drought in the PAP basin

Sl.no	Time scale	Year	Month	SPI value
1	SPI_1	1976	June	-2.81
2	SPI_3	1976	July	-2.96
3	SPI_6	1974	June	-3.16
4	SPI_9	1976	August	-2.50
5	SPI_12	1976	September	-2.40
6	SPI_24	1983	October	-2.07

probability distribution for annual severity and tested by non parametric Kolmogorov–Smirnov (K–S) test and parametric Chi Square tests at 5 and 1 % significance levels. The drought severity to be estimated for a given return period may be represented as the mean plus the departure of the variate from mean. The departure may be taken as equal to the product of the standard deviation and frequency factor. The departure and the frequency factor are functions of the return period and type of probability distribution to be used in the analysis [14]. The expected drought severity at various return periods of 2, 3, 5, 10, 20, 25, 50, 75 and 100 years were worked out by the best fit probability distribution.

Table 5 Drought properties of SPI series in the PAP basin

Sl.no.	Time scale	No of drought months	No of drought incidence	Average duration in month	Severe drought			
					Longest duration in month	Period of longest drought duration	Drought severity	Drought intensity
1	SPI_1	244	112	2.18	18	1981/11–1983/04	−14.99	−0.83
2	SPI_3	232	65	3.57	26	1981/11–1983/12	−27.11	−1.04
3	SPI_6	238	40	5.95	28	1981/11–1984/02	−32.48	−1.16
4	SPI_9	239	33	7.24	31	1981/11–1984/05	−34.43	−1.11
5	SPI_12	255	22	11.59	77	1981/11–1988/03	−69.06	−0.90
6	SPI_24	231	13	17.77	88	1982/03–1989/06	−82.58	−0.94

**Fig. 5** Frequency curve of annual weighted cumulative drought severity at various time scales

Results and Discussion

Analysis of Gridded Rainfall

Monthly rainfall from 28 rain gauge stations was spatially interpolated using IDW method to develop monthly gridded rainfall. Mean monthly areal rainfall was calculated by spatially averaged monthly gridded rainfall. The average cumulative areal rainfall was compared to normal cumulative areal rainfall to identify the deficient rainfall years (Fig. 2). During the periods of 1970s and 1980s the monthly and annual precipitation was significantly below normal. Especially, the year 1982 and 1976 are the first and second deficient years, respectively. The average annual rainfall in 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. Mean annual rainfall over the whole PAP basin is about 1,410 mm and it is distributed unevenly in space and time. The mean annual precipitation varies from about 500 mm at the central and northern plain area to more than 4,320 mm at the southern mountain areas. More than 70 % of the PAP basin except

the mountain areas received less than the normal rainfall. Generally, rainfall is rare from January to May (winter and summer season).

Temporal Variation of Droughts

The time series of regional representative of SPI values showed that the basin experienced frequent moderate, severe and extreme droughts over the period of study (Fig. 3). The figures indicate that drought occurrence changes as the time scale changes. At the shorter time scale (SPI_1 and SPI_3), occurrence of drought increases but its duration decreases and ends for shorter periods. On longer time scales (SPI_12 and SPI_24) occurrence of drought becomes less frequent but lasts longer. Occurrence of drought categories was investigated by taking the ratio of drought occurrences in each time scale to the total length of data record and drought category across the basin (Table 2). The results show that mild droughts occur most frequently and extreme droughts occur least frequently. Occurrence of drought categories from mild drought to extreme drought has nearly comparable values for all time scales.

Occurrence of drought for a particular month was calculated and the results showed that the basin experienced frequent droughts for all months of the year for all time scales (Table 3). January, February and March are the months during which the 1-, 3- and 6-month SPI most frequently takes the negative SPI values. Frequent negative SPI values for SPI_9, SPI_12 and SPI_24 series for the period of analysis were mainly observed in January, May and October.

Area covered (as percent of the total basin area) by drought for the study period was computed by counting the number of grids which expressed mild, moderate, severe and extreme drought for each year at multiple time scales (Fig. 4). The analysis of areal coverage of drought categories revealed that the 1976, 1982, 1983, 1986, 1987 and 2003 are the worst years experienced during the period of

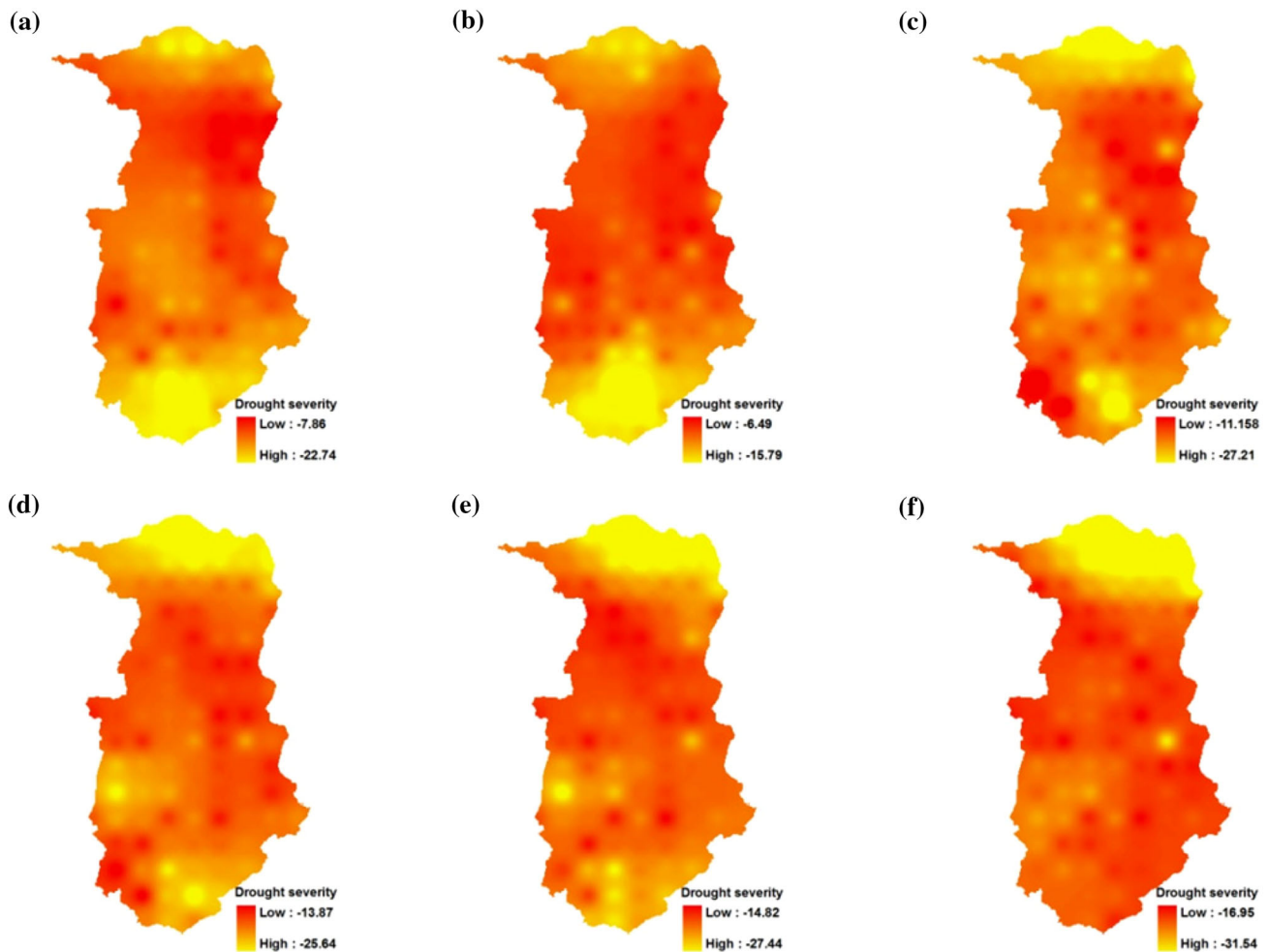


Fig. 6 Spatial variation of annual drought severity for **a** 1-month, **b** 3-month, **c** 6-month, **d** 9-month, **e** 12-month, and **f** 24-month time scales

study with more than 90 % of the total areas of the basin affected by drought for various time scales.

Analysis of Drought Properties

The most intense quantity i.e. minimum negative of SPI values derived from the regional representative SPI values over the study period was presented in Table 4. The number of drought incidences along with their duration and period of occurrence is shown in Table 5. Average duration of drought was calculated by dividing the total number of drought months with the total number of drought. Droughts are classified for the study area based on the average duration of drought for different SPI series. The average duration of 2.18 and 3.57 months for SPI₁ and SPI₃ are classified as short term drought. The average duration of 5.95 and 7.24 months for SPI₆ and SPI₉ are referred as medium term drought. The average duration of drought for SPI₁₂ and SPI₂₄ are 11.59 and

17.77 months respectively, which are termed as long term drought. Study of short term duration of drought is important for agricultural interests whereas medium and long term duration of drought is important for water supply management interests [5, 13]. The period of longest duration of drought and its severity and intensity (ratio of severity and duration) was presented in Table 5. Severity of drought is calculated as the cumulative sum of consecutive negative SPI values and the duration of drought is defined as the corresponding number of consecutive months with continuous negative values. From the analysis, it is noted that the basin has experienced severe drought during 1970s and 1980s in terms of drought severity and duration for all time scales. Based on highest annual weighted cumulative drought severity, the worst year was identified for various time scales. The results revealed that 1982 was the first driest year for 1, 3 and 6-month time scale and 1983 was the second driest year for 9, 12 and 24 month time scales.

Analysis of Drought Frequency

In the present work Extreme Value Type I (EVI) distribution was selected for the frequency analysis as it passed the two tests for SPI₁₂ time scale at all grids. It is also used for the numerous extreme drought studies [5, 7, 10]. Frequency factor of EVI distribution was used for calculating drought severity for different return period. Frequency of annual weighted cumulative drought severity was estimated for various time scales of SPI values (Fig. 5). The results shows that correspond to increasing return periods and time scales increasing severities. It means that greater severities occur in higher return periods and time scales. Frequency analysis of the minimum monthly SPI was assessed using the EVI probability distribution. The results showed that the most extreme 1 and 3 month SPI occurred in June 1976 and July 1976 had a return period of 37 and 39 years, respectively. The analysis of the 6 and 9 month SPI series indicated that the most negative SPI observed in June 1974 and August 1976 had return periods of 46 and 24 years, respectively. The worst drought of 12 and 24 month SPI occurred in September 1976 and October 1983 had an estimated return period of 23 and 16 years, respectively.

Spatial Variation of Droughts

Although the estimation of drought severity as regional representative gives useful information for water management, it is important to assess the drought severity over a basin. The regional drought analysis is useful for determining the spatial variation of drought and evaluating the most affected areas. Highest annual weighted cumulative drought severity observed over the study period for each grid was used for developing spatial variation of drought. Spatial variation of drought severity was high in the southern parts of the basin at the shorter time scales (Fig. 6). As time scale increases drought severity increases towards northern direction. Higher drought severity experienced at the upper catchment areas of basin will affect the central and lower parts of the basin which will reflect the crop production.

Conclusion

This study was focused on analyzing temporal and spatial variation of droughts in the PAP basin by employing the SPI as most widely used drought assessment tool for quantifying most types of drought events. The temporal

drought analyses indicated that PAP basin experience quite frequent moderate and severe droughts on monthly basis. The basin 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, 1982–1985 and 2002–2004 seriously affected urban water supply, agricultural irrigation, ground water as well as reduction of inflows to the reservoir. The results of spatial variation of drought severity showed that the central and northern parts of the basin have more potential sensitivity to the droughts. Assessment and characterization of droughts in the basin at multiples time scales will be useful for developing short term strategy to moderate current drought impact and medium and long term strategy needed to negate such calamities in future. The different short term (rescheduling of the irrigation and appropriate contingency plans, selection of crops, cropping sequences and agronomic practices) and medium and long term measures (conserving and securing quality water and cropping and farming systems) for management of drought may be adopted in the basin to minimise the impacts of drought thereby reduce the degree of risk to human life and environment.

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