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Spatial analysis of drought occurrence in the Parambikulam-Aliyar river basin, Tamil Nadu

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ABSTRACT : The identification and characterization of droughts are of great importance in water resources planning and management. In the present study, the standardized precipitation index (SPI) was employed to investigate the spatial characteristics of meteorological drought in the Parambikulam-Aliyar basin, Tamil Nadu. The basin was divided into 97 grid-cells of 5×5 km and monthly rainfall data for the period 1972–2011 from 28 rain gauge stations were used for spatial interpolation of rainfall using the ArcGIS. Occurrence of drought categories and cumulative drought severity were then assessed from the estimated gridded SPI values calculated from gridded rainfall at each grid and maps of spatial variation of drought characteristics were developed. The analysis of the SPI suggests that the basin had suffered severe and extreme drought in the 1970s and 1980s. The spatial extent of drought category showed that moderate and severe drought was more in the central and northern parts of the basin; while extreme drought was high in the southern parts of the basin. Drought severity map at 5 year return period indicated that the annual cumulative drought severity was high in the southern and northern parts of the basin. The results of this study can be used for identifying drought vulnerable areas, developing drought preparedness plan and mitigation strategies within the basin.

KEY WORDS : Drought severity, GIS, Rainfall, Return period, SPI

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Drought is a disastrous natural phenomenon that has significant impact on socio-economical, agricultural, and environmental spheres. Drought is a normal feature of climate, it occur in virtually all climatic zones, such as high as well as low rainfall areas and its occurrence appears inevitable. Drought places huge demands on rural and urban water resources, and enormous burdens on agricultural and energy production. In general, drought is defined as the water scarceness due to insufficient precipitation, high evapotranspiration and over-exploitation of water resources or a combination of these parameters (Bhuiyan, 2004). Timely determination of the level of drought and identifying most vulnerable areas will assist the decision making process to reduce the impacts of droughts. Drought indices have been commonly used to define drought conditions and it is a function of several hydro-meteorological variables. Drought indices provide decision makers with information on drought severity and can be used to trigger drought contingency plans, if they are available.

Drought is a frequent phenomenon in India, affecting some part or the other of the country. 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 (Gupta *et al.*, 2011). The western regions of Tamil Nadu (Coimbatore and Tiruppur districts) have suffered with severe droughts at many times in the past. The present study was carried out in the Parambikulam-Aliyar basin spread over drought prone districts of Coimbatore and Tiruppur, Tamil Nadu. The aim of this study is (i) to investigate the occurrence of drought categories, (ii) to analysis the spatial pattern of drought severity for identifying the drought affected zones within the study area.

METHODOLOGY

Study area and data used :

Parambikulam-Aliyar-Palar 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.A). 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 2388.72 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 monthly rainfall data for the period of 40 years (1972-2011) of 28 rain gauge stations located in the PAP basin (Fig. A.) was collected from the office of Groundwater division, Public Works Department, Coimbatore. The methodology comprised of the generation of gridded rainfall using spatial interpolation technique, development of gridded rainfall at 12-month time scale, calculation of SPI values for each grid, analysis of occurrence drought categories, calculation of cumulative drought severity, frequency analysis of drought severity and spatial extent of drought occurrence to identify the most vulnerable areas.

Gridded rainfall :

Total area of PAP basin was divided into 97 grids with each grid (5 × 5 km) approximately correspondence to 1.03 per cent of total area (2425 km^2) (Fig. A). Monthly rainfall recorded at 28 stations for 40 years (1972-2011) were interpolated by ArcGIS 9.3 using Inverse Distance Weighing (IDW) method and gridded monthly rainfall was created. From gridded monthly rainfall, mean areal rainfall and gridded rainfall at 12-month time scale was calculated.

Use of the standardized precipitation index (SPI) for drought analysis :

The standardised precipitation index (SPI) was developed by McKee *et al.* (1993) for the purpose of defining and monitoring droughts. 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

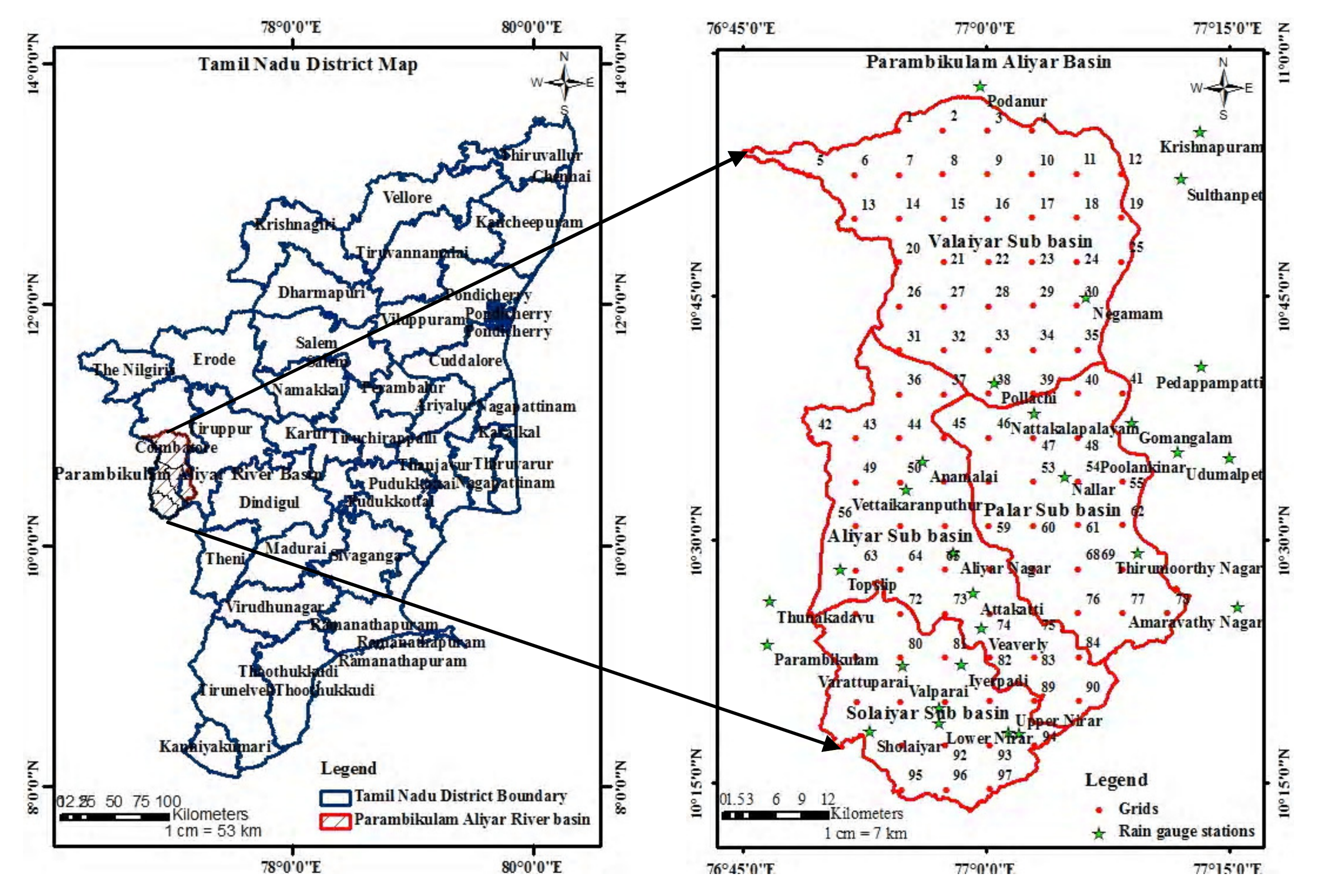

Fig. A: Location of rain gauges in the PAP basin location in space. Each probability density function is then transformed into the standardized normal distribution. A drought event is considered to occur at a time when the value of SPI is continuously negative and end when SPI becomes positive. Table A provides a drought classification based on SPI. The calculation procedure can also be found in McKee *et al.* (1993) and Hughes and Saunders (2002). Numerous studies have been conducted to analysis the meteorological droughts using SPI (Mishra and Desai, 2005; Loukas and Vasiliades, 2004). In this study, gridded monthly rainfall data were used for the estimation of the SPI for 12-month rainfall accumulations for each month of the period of analysis.

Table A : Classification of droughts (McKee *et al.*, 1993)

SPI values	Drought category	
0 to -0.99	D_1	Mild drought
-1.00 to -1.49	D_2	Moderate drought
-1.50 to -1.99	D_3	Severe drought
$\leq$ 2.00	D_4	Extreme drought

Analysis of occurrence of drought categories :

The occurrences in varying drought categories at 12-month time scale were analysed to identify vulnerable areas based on their percentage of drought occurrence frequencies. Percentage of drought occurrence was calculated by taking the ratio of drought occurrences in drought category to the total drought occurrences for each grid and spatial variation of drought categories was developed.

Annual cumulative drought severity :

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. 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 12-month time scale by 12 (Loukas and Vasiliades, 2004).

Frequency analysis was performed using the selected probability distribution for estimating annual drought severity at different return periods. To be applied before fitting to an available distribution, the negative values of cumulative 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. 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 weighted annual cumulative drought severity and tested by Kolgomorov–Smirnov (K-S) test and Chi-Square tests at 5 per cent and 1per 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.

$$X_T = \mu + \Delta X_T \qquad ......(1)$$

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 (Chow, 1951). The expected annual drought severity for each grid at 5-year return periods were worked out by the best fit probability distribution for each grid and spatial extent of drought severity map was prepared.

Spatial extent of droughts :

The regional drought analysis is useful for determining the spatial distribution of drought, and evaluating the most affected areas for a specific drought event. In this study, spatial variation of drought was performed by analysing the occurrence of drought categories and frequency of drought severity using ArcGIS 9.3 with the help of inverse distance weighing approach. Spatial interpolation methods estimate the value of the surface at locations where no observed data exists, based on the known data values (observations). Edossa *et al.* (2010) and Moradi *et al.* (2011) used the interpolation methods for evaluating the spatial pattern of drought characteristics.

■ RESULTS AND DISCUSSION

The results of the present study as well as relevant discussions have been presented under following sub heads:

Historical drought analysis in the PAP basin :

Mean areal rainfall at 12-month time scale was used to calculate 12-month SPI value and presented in Fig. 1. From the figure, it can be observed that the PAP basin experienced severe, extreme and persistent droughts during the periods of 1970s, 1980s and 2000s. The average cumulative areal rainfall during these three periods is compared to normal cumulative areal rainfall in Fig. 2. During these three periods the monthly and annual precipitation was significantly below normal. Especially, the year 1982, 1976 and 2002 were the first, second and third driest years in record, respectively. 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 1410 mm and it is distributed unevenly in space and time. The mean annual precipitation varies from about 511 mm at the northern plain areas to more than 4328 mm at the southern mountain areas (Fig. 3). More than 70 per cent 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). 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 droughts that occurred in the basin are in accordance with the rainfall patterns.

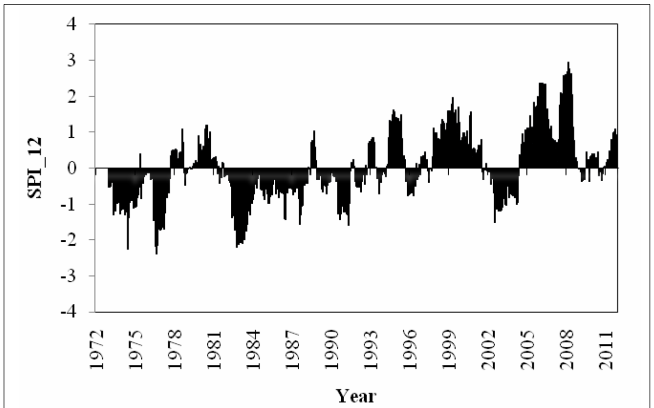

Fig. 1: Temporal variation of SPI values at 12-month time scales in the PAP basin

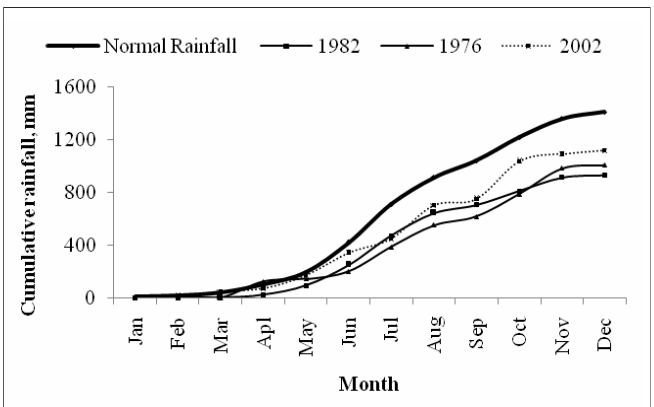

Fig. 2: The cumulative areal rainfall for selected drought years and periods in the PAP basin

Spatial characteristics of droughts in the PAP basin :

Drought occurrences in the PAP basin have been investigated based on relative frequency of the events for each drought category at 12-month time scales. The spatial analysis of moderate drought occurrences indicates that they tend to occur in central and northern parts of basin, while the southern parts are characterized with the lowest frequencies (Fig. 4). In other words, majority of the historical droughts that occurred in the Valaiyar and Palar sub basin were moderate severity. Severe droughts occurred more frequently in the most parts of the basin except southern parts of Solaiyar

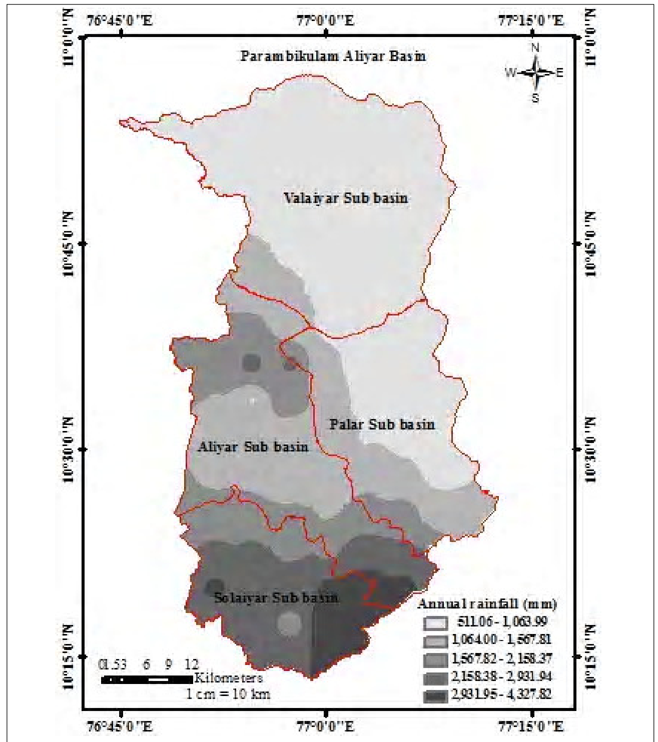

Fig. 3: Spatial variation of annual average rainfall in the PAP basin

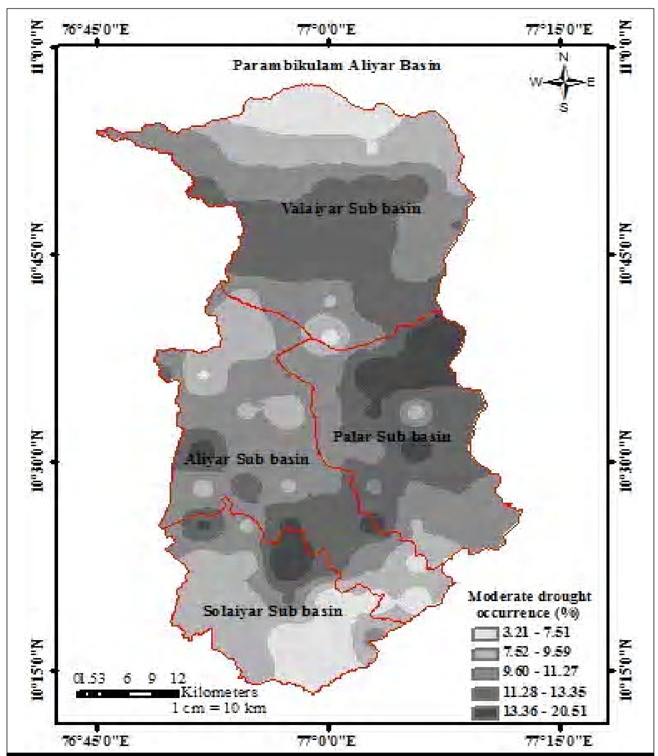

Fig. 4: Spatial variation of occurrence of moderate drought

sub basin (Fig. 5). Northern parts of Valaiyar sub basin and southern parts of Solaiyar sub basin experienced maximum frequencies of extreme drought (Fig. 6).

Extreme Value Type I distribution is selected for the frequency analysis as it passed the two tests for SPI_12 time scale at all grids. For the Extreme Value Type I distribution frequency factor can be expressed as:

$$K_T = -\frac{\sqrt{6}}{\pi}\left\{0.5772 + \mathrm{In}\left[\mathrm{In}\left(\frac{T}{T-1}\right)\right]\right\} \quad ....(2)$$

Frequency factor of Extreme Value Type I distribution was applied in the Equation 1 and calculated annual cumulative drought severity for different return period (T). Spatial variation of annual cumulative drought severity in the recurrence period of 5 years is presented in Fig. 7. As a result, in the recurrence period of 5 years, the droughts will have greater severity in the northern parts of Valaiyar sub basin in comparison to the other parts of the basin.

Conclusion :

Drought is perhaps the most complex natural hazard and has significant impacts on effective water resources management. This study was focused for the analysis of temporal behaviour of drought, spatial occurrence of drought categories and frequency of drought severity in PAP basin,

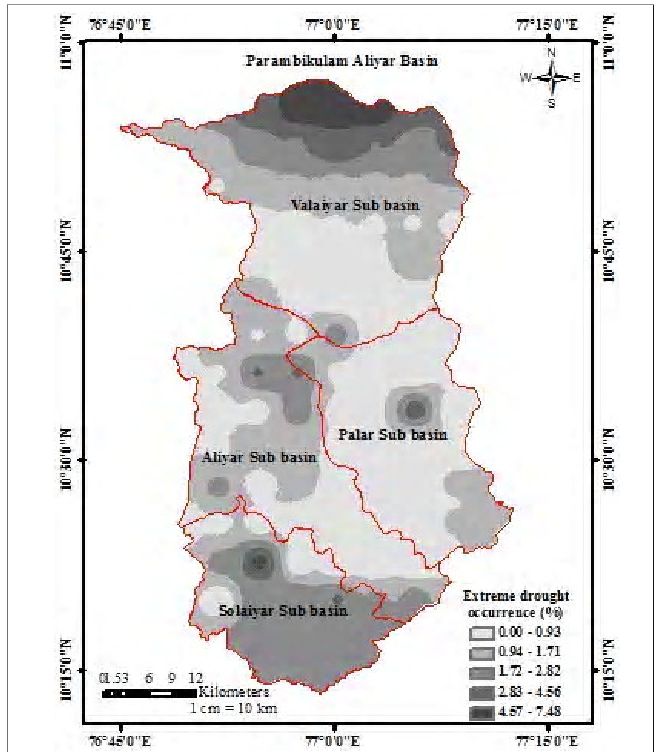

Fig. 6: Spatial variation of occurrence of extreme drought

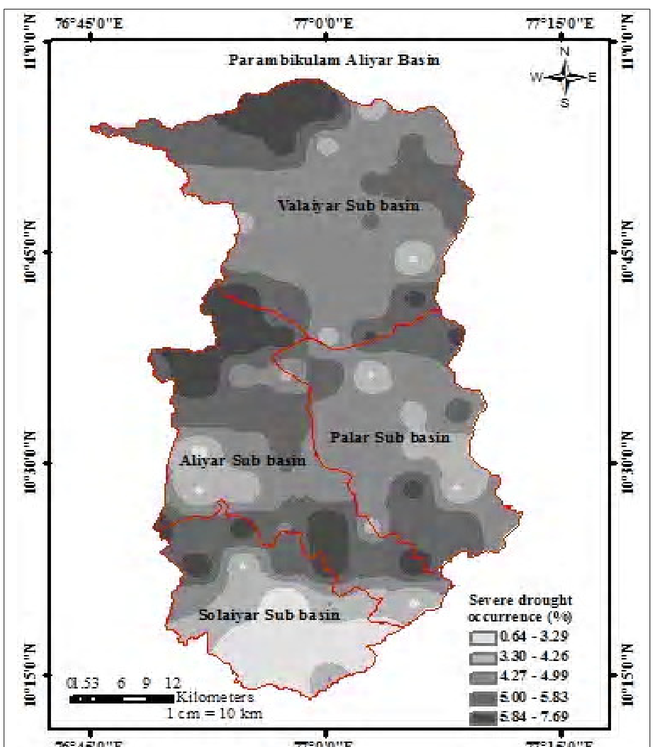

Fig. 5: Spatial variation of occurrence of severe drought

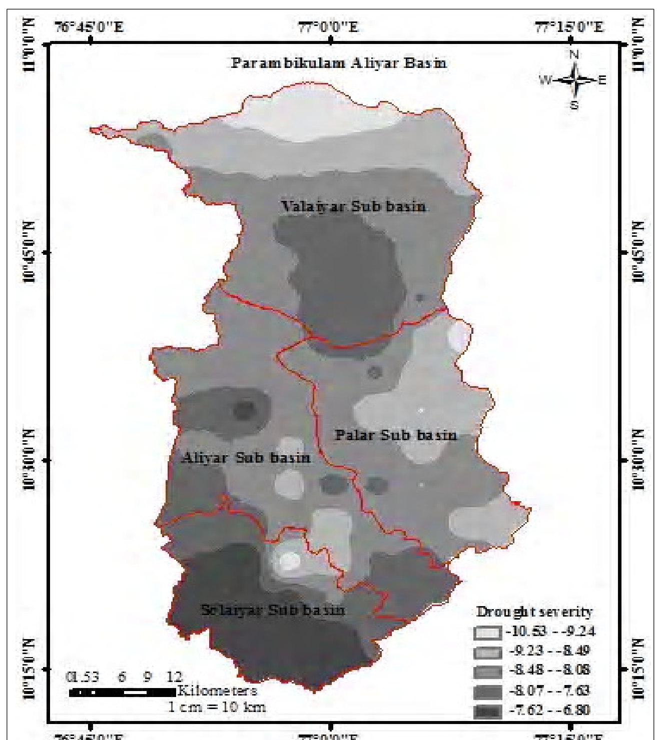

Fig. 7: Spatial variation of cumulative drought severity at 5 years return period

Tamil Nadu. The SPI as an indicator of drought severity was used to assess the drought categories. The results of spatial analysis of drought showed that the central and northern parts of the basin and upper catchment of Solaiyar sub basin have more potential sensitivity to the severe drought. The basin has experienced severe droughts during 1970's, 1980's and 2000's and these prolonged and persistent droughts seriously affected domestic water supply, agricultural irrigation and ground water. As a result, this meteorological drought period was associated with hydrological and water resources drought resulted in significant decrease in the flows of Aliyar and Palar river. The identification and characterization of droughts in the PAP basin will be useful for the development of a drought preparedness plan in the region so as to ensure sustainable water resource planning within the basin.

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