Spatio-temporal Analysis of Rainfall Distribution and Variability in the Twentieth Century, Over the Cauvery Basin, South India

Sawant Sushant, K. Balasubramani and K. Kumaraswamy

Abstract Knowledge on the spatial variability and temporal trends of mean rainfall is essential for efficient management of water resource and agriculture. We have analyzed the rainfall data of the Cauvery river basin, a larger river basin in Southern India which plays a significant role in agricultural development and consequently in the overall growth of Karnataka, Tamil Nadu, Pondicherry and some parts of Kerala. The analysis includes distribution, variability and trends in rainfall over the Cauvery basin during twentieth century (1901–2002). The impact of climate change on temporal and spatial patterns of rainfall over smaller spatial scales is clearly noticed in this analysis. It is also observed that the coefficient of variation shows significant fluctuations during the winter than other seasons. Long term changes in rainfall have been determined by. Significant decreasing trend in the winter rainfall and increasing trend in the post-monsoon season with insignificant levels have been inferred based on the Mann-Kendall rank statistics and linear trend. Overall, insignificant decrease in annual rainfall over the Cauvery river basin has observed during twentieth century.

Keywords Rainfall distribution · Variability · Trend · Mann-Kendall rank statistics · Cauvery basin

1 Introduction

River basins are important from hydrological, economic and ecological points of view. They absorb and channel the run-off from snow-melt and rainfall which, when wisely managed, can provide fresh drinking water as well as access to food, hydropower etc. Experts agree that the best approach to conserving the world's freshwater resources is through managing river basins sustainably. We need to make wise choices about the use of available resources, based on an understanding

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of how to sustain the dynamic, living systems in the long term. Unfortunately, the close inter-linkages between the hydrological, ecological and socio-economic components of river basins have rarely been given adequate consideration by decision-makers such as politicians, land use planners and water engineers. As a result, river basins all over the world are not being managed scientifically. The need to conserve and manage freshwater and its ecosystems at the basin scale is increasingly being recognized by governments and NGOs. The principle of integrated river basin management is included in many international agreements. However, far too little is being done to put words into action.

Given cognizance to the recent reports of climate change and its extreme variability, an understanding of temporal and spatial characteristics of rainfall is crucial to planning and management of water resources especially on a basin-scale. Such information is important in agricultural planning, flood frequency analysis, flood hazard mapping, hydrological modeling, water resource assessments, climate change impacts and other environmental assessments (Michaelides et al. 2009). Precipitation is one of the most variable climatic elements, both spatially and through time scales ranging from daily to decadal and longer-term fluctuations (Juan-Carlos et al. 2009). Several researchers have studied the distribution, variability and trends of rainfall at global, regional and basinal scales (for example, Jagannathan and Parthasarathy 1973; Mooley and Parthasarathy 1983; Thapliyal and Kulshrestha 1991; Parthasarathy et al. 1995; Serrano et al. 1999; Smith 2000; Guhathakurta and Rajeevan 2008; Soltani et al. 2007; Werner 2009; Taschetto and Matthew 2009; Zhang et al. 2009). Krishnakumar et al. (2008) studied temporal (monthly, seasonal and annual) rainfall trends in twentieth century over Kerala, India and reported a significant decrease of rainfalls during the southwest monsoon and an increase during the post-monsoon season. Sivapragasam et al. (2013) studied rainfall trend at basin scale on trends in rainfall patterns over the Tamarabarani basin in Tamil Nadu, India. Anandakumar et al. (2008) studied spatial variation and seasonal behavior of rainfall pattern in lower Bhavani river basin, Tamil Nadu, India and attempt has been made to analyze the occurrence and distribution of rainfall in the basin. Chakraborty et al. (2013) made an attempt to study the spatial and temporal variability of rainfall at Seonath sub basin in the Chhattisgarh State (India) for 49 years (1960–2008). In order to study rainfall characteristics they used different statistic methods. Modified Mann-Kendall (MMK) (non-parametric) and Spearman's rho test (parametric) were applied to detect the trend. Sen's slope was used to detect trend magnitude. The CUSUM and cumulative deviations test were applied to detect change points. The Coefficient of Variation was used for variability analysis. According to both the tests decreasing trend was found in annual and seasonal rainfall series for the whole river basin. Mondal et al. (2002) applied Mann-Kendall test to document the changing trend of rainfall of a river basin of Orissa near the coastal region. Despite providing sustenance to a large geographic area, the rainfall trends of the Cauvery Basin have not yet been studied in the light of changing climatic scenarios and hence in this paper, we have constructed monthly, seasonal and annual rainfall series for the Cauvery River Basin. Statistical features of the temporal rainfall series of each district contained within the Cauvery Basin followed by the study of rainfall distribution, variability and trends of the monthly, seasonal and annual total rainfall for each of the districts.

2 Study Area

The Cauvery Basin lies between 75°27′–79°54′ East longitudes and 10°9′–13°30′ North latitudes (Fig. 1), and extends over the States of Tamil Nadu, Karnataka, Kerala and Union Territory of Pondicherry. It is draining an area of 81,155 km^2 that forms 2.7 % of the total geographical area of the country. It has a maximum length of about 560 km and width of 245 km. It is bounded by the Western Ghats on the west, by the Eastern Ghats/Bay of Bengal on the east and the south and by the ridges separating it from Krishna Basin and Pennar Basin on the north. The major part of basin is covered with agricultural land accounting to 66.21 % of the total area. The Cauvery Basin is heavily dependent on monsoon rains, and thereby is prone to droughts when the monsoons fail. The climate of the basin ranges from dry sub-humid to semi-arid. As per the Indian Metrological Department (IMD) classification, the basin is under the influence of four distinct seasons namely, Winter (January–February), Pre-monsoon with dry season (March–May), South-west monsoon with strong southwest winds (June–September) and Post-monsoon with dominant north-east retreating winds (October–December). Owing to these seasonal

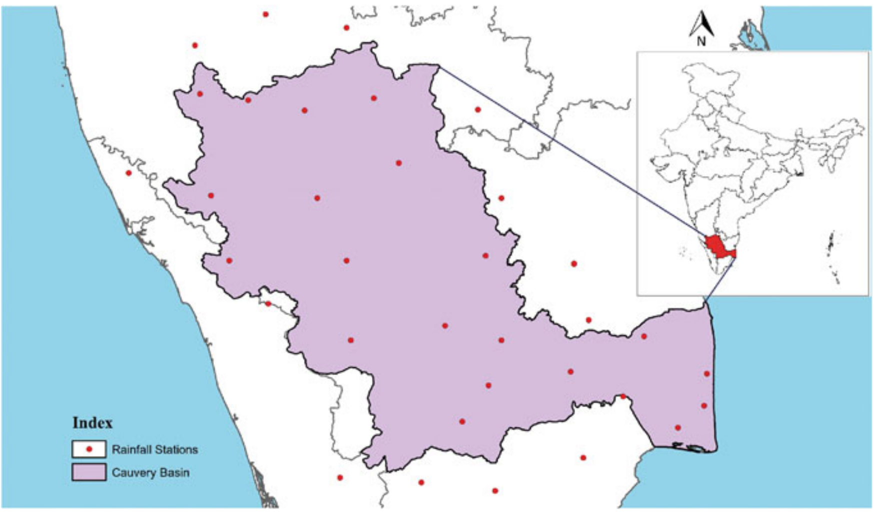

Fig. 1 Location map of the study area and rain gauge stations

influences and the location of the basin in varying topographic and geographic sprawl, the Cauvery Basin region experiences wet and dry periods, resulting in coeval prevalence of heavy rainfall and some areas receive very less rainfall.

3 Materials and Methods

The methodology has been divided into three major parts as (1) data collection and input, (2) data processing function, and (3) presentation of output. The following schematic diagram explains the steps followed in this study (Fig. 2).

The rainfall (mm) data over Cauvery Basin for the period from 1901 to 2002 has been obtained from the Indian Meteorological Department (IMD) and India Water Portal (http://www.indiawaterportal.org/met_data, Accessed date: 30/04/2013). Seasonal, annual and century rainfall data series of Cauvery basin were computed using monthly rainfall data of rain gauge stations located in and around Cauvery river basin area. It was followed by computation of mean monthly, seasonal and annual Standard Deviation (SD) and Coefficient of Variation (CV).

The coefficient of variation indicates the amount of fluctuation in rainfall recorded over a long period of time from the mean values. The coefficient of variation of annual precipitation is an index of climatic risk, indicating a likelihood of fluctuations in reservoir storage or crop yield from year to year. Agriculturally it is, perhaps, a more crucial statistics for marginal areas than in either very dry areas,

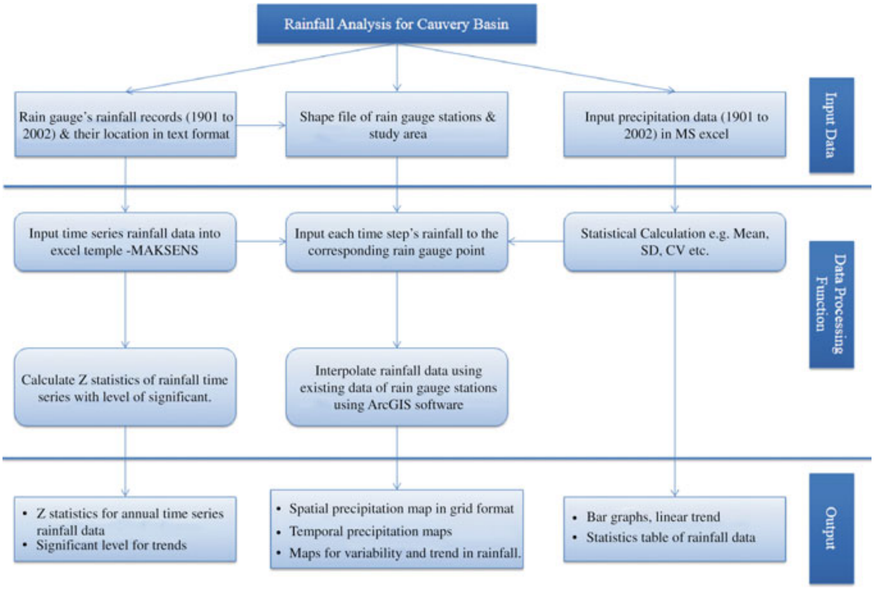

Fig. 2 Schematic diagram representing the methodology of the study

where farming practices have adapted to variability, or in wet areas, where relatively lower inter-annual variability are generally expected. Contrary to these general perceptions, no perceptible spatio-temporal variations were observed, that prompted the authors to find out the long term trends with the help of average rainfall graphs constructed with the trend line. Temporal changes in the monthly, seasonal and annual rainfall were also analyzed by Mann-Kendall test to confirm the significance of the observed trends.

Mann-Kendall test is a statistical test widely used for the analysis of trend in climatologic and hydrologic time series (Milan et al. 2013; Cannarozzo et al. 2006). There are two advantages of using this test. First, it is a non-parametric test and does not require the data to be normally distributed, suiting perfectly for the nature of distribution observed in the Cauvery Basin. Second, the test has low sensitivity to abrupt breaks due to non-homogeneous time series. In this test, the number of annual values in the studied data series is denoted by ‘n’. If ‘n’ is at least 10, the normal approximation test is used. However, if there are several tied values (i.e. equal values) in the time series, it may reduce the validity of the normal approximation when the number of data values is close to 10. First, the variance (S) is computed by the following equation which takes into account that ties may be present.

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} \left(t_p - 1\right)\left(2t_p + 5\right) \right] \tag{1}$$

Here q is the number of tied groups and t_p is the number of data values in the pth group.

The values of S and $VAR(S)$ are used to compute the test statistics Z as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if\ S < 0 \end{cases} \tag{2}$$

Presence of a statistically significant trend is evaluated using the Z value and here the statistics Z has a normal distribution. Significance level α is used for testing either an upward or downward monotone trend (a two-tailed test). If Z appears greater than Zα/2 where α depicts the significance level, then the trend is considered as significant. The value for Zα/2 is obtained from the standard normal cumulative distribution tables for the significance levels (α) 0.001, 0.01, 0.05 and 0.1 (Timo et al. 2002).

4 Rainfall Characteristics of the Cauvery Basin

Rainfall characteristics of the Cauvery basin are presented in the Table 1 and in the Figs. 2, 3, 4 and 5. The observations and inferences from these are discussed herein.

The average annual normal rainfall over the Cauvery Basin from 1901 to 2002 is 1389.20 mm with a standard deviation of 643.4 mm. The coefficient of variation of annual rainfall is 46.3 % indicating that it is moderately variable. Rainfall during July is the highest (250.07 mm) and contributes 18.00 % of annual rainfall (1389.20 mm), followed by June (14.85 %), August (14.10 %) and October (13.94 %). Contribution of the seasonal rainfall to the annual rainfall is highest during the monsoon period (56.81 %), followed by post-monsoon period (27.80 %), pre-monsoon period (13.71 %) and winter period (1.68 %) in the decreasing order. Least amounts of rainfall are observed during the month of February (10.70 mm) followed by January (12.69 mm), which contribute only 0.77 and 0.91 % to the annual rainfall respectively. The coefficient of variation is highest in July (100 %), followed by June (97.96 %), December (97.96 %) and January (78.48 %) and the least during October (15.19 %) and September (23.77 %). Significant relationship between SD and CV has been observed during the months of highest rainfall (July and June).

Table 1 Mean monthly, seasonal and annual rainfall statistics of Cauvery basin (1901–2002)

Month/season	Rainfall (mm)	Standard deviation	Coefficient of variation (%)	% Contribution to annual rainfall
January	12.69	10.0	78.5	0.91
February	10.70	7.0	65.2	0.77
March	15.95	7.0	43.9	1.15
April	60.30	25.4	42.2	4.34
May	114.20	48.1	42.1	8.22
June	206.27	202.1	98.0	14.85
July	250.07	250.2	100.0	18.00
August	195.91	144.9	74.0	14.10
September	136.96	32.6	23.8	9.86
October	193.68	29.4	15.2	13.94
November	133.48	56.1	42.0	9.61
December	58.99	46.3	78.5	4.25
Winter (January–February)	23.39	15.8	67.5	1.68
Pre-Mon (March–May)	190.45	73.4	38.6	13.71
Monsoon (June–September)	789.22	621.4	78.7	56.81
Post-Mon (October–December)	386.14	110.7	28.7	27.80
Annual	1389.20	643.4	46.3	100

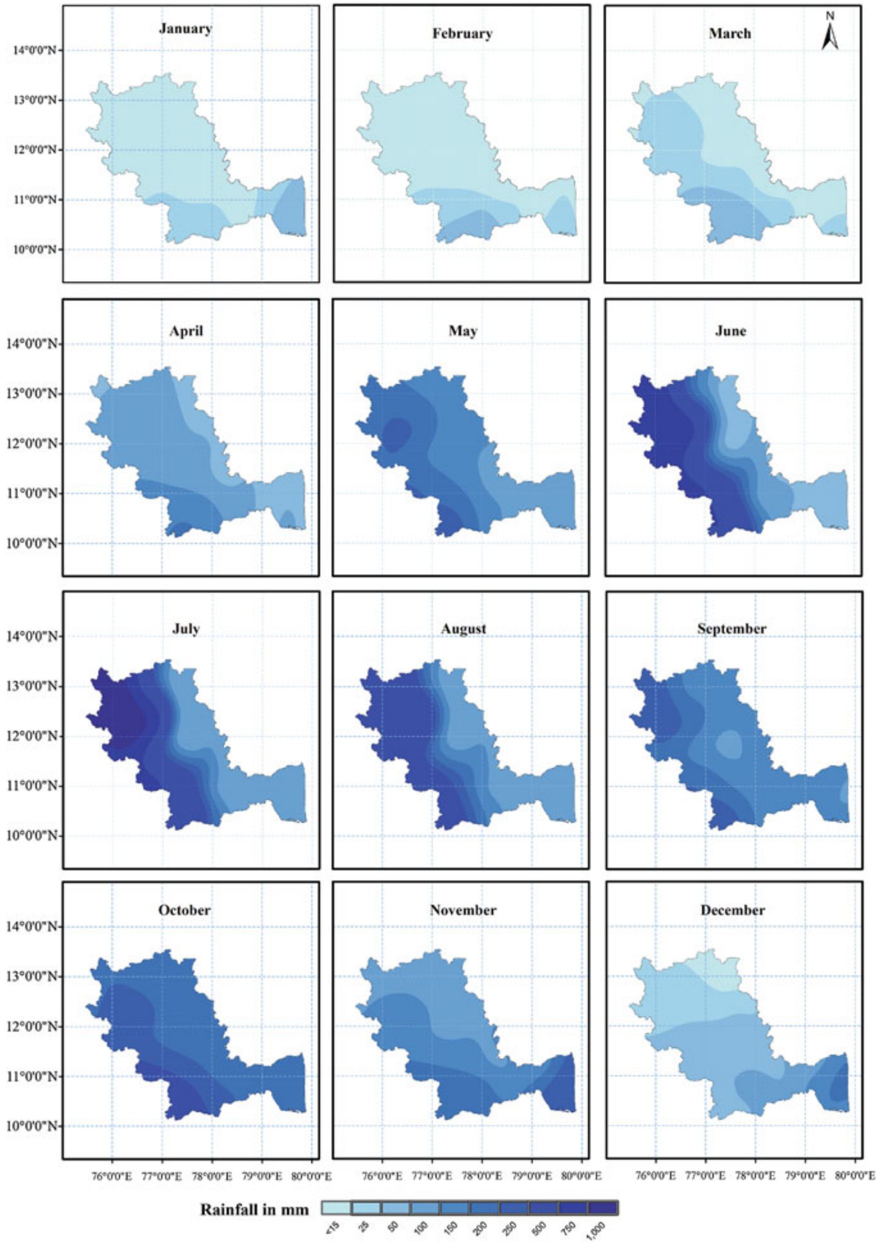

Fig. 3 Spatial distribution of the mean monthly rainfall over Cauvery basin (1901–2002)

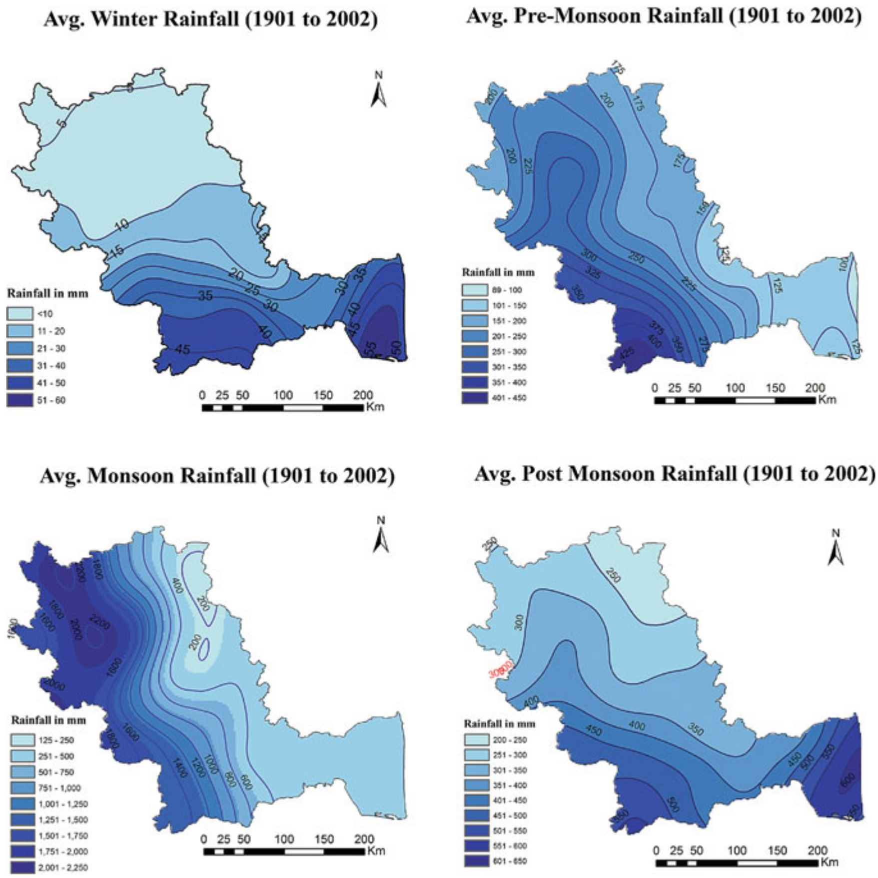

Fig. 4 Spatial distribution of the mean seasonal rainfall over Cauvery basin (1901–2002)

4.1 Spatial Distribution of Rainfall

The monthly rainfall distribution maps show that the major rainfall patterns are generally oriented east northeast to west southwest, with maxima and strong rainfall gradients located along the western and southern parts of the basin (Fig. 3). During the months of June–September, Cauvery basin receives higher rainfall (789.99 mm) as a result of prevalent southwest monsoon wind. Though the northeast monsoon (October–December) provides only the half of the total amount of southwest monsoon (386.14 mm), it remains important since it satisfies the agricultural activities especially in the Cauvery deltaic region. Generally, highest rainfall (up to

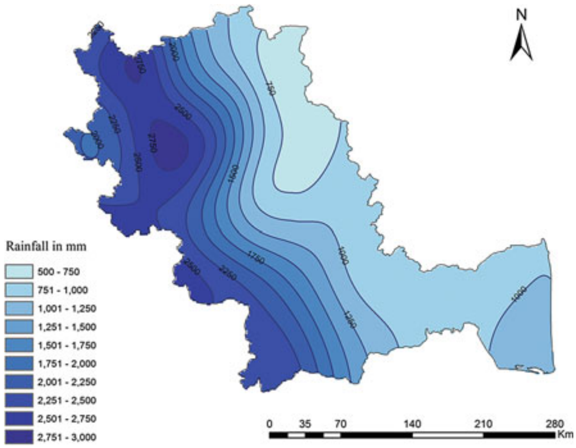

Fig. 5 Spatial distribution of the mean annual rainfall over Cauvery basin (1901–2002)

250 mm) pattern is observed in the western boundary of the study area during May–September. However, in the months of October, November and December, the pattern changes from western boundary to extreme eastern side (Cauvery Delta). This seasonal shift of rainfall maxima zones could be clearly identified from the maps (Fig. 3). Overall, the month of January, February, March, April and May experience lower amount of rainfall thus known as dry season.

4.2 Seasonal Rainfall Distribution

On the basis of the percentage of contribution to the annual rainfall, the basin experiences four distinct periods of rainfall (Fig. 4) namely, the pre-monsoon rainfall season from March to May (Hot summer), the southwest monsoon rainfall season with strong southwest wind (June–September), the post-monsoon with dominant northeast wind during October–December (Northeast monsoon), and the winter season (January–February).

During the pre-monsoon, the rainfall ranges from 90 to 450 mm. Isohyets of low rainfall values (100–200) are located in the eastern and central parts of the basin and are aligned north–south. Contrary to this pattern, isohyets of the higher rainfall values are located in the southwest part of the basin. Western and central west areas of the basin experience moderate rainfall. The basin receives copious rainfall (57 % of annual rain fall) during the monsoon season. This season has maximum number of rainy days and is called the ‘wet season’. Rainfall during this season is caused by the southwest monsoon winds blowing from the Indian Ocean. Since a part of the basin is shared by western face of the Western Ghats section, the western part of the basin gets higher rainfall throughout the monsoon season, especially northwest part of the basin. Rainfall gradually decreases eastwards due to rainshadow effect. Thus eastern and south-eastern parts of the basin experience lower rainfall (<300 mm).

The monsoon withdraws from the peninsula by October and from the extreme southern tip by December. Due to retreat of the monsoon, the rainfall is called retreating monsoon rainfall, also known as the northeast monsoon rainfall. By the end of September, the southwest monsoon becomes weak as the low pressure trough of the Indo-Gangetic plain starts moving southward in response to the apparent southward movement of the Sun. By October, it reaches the Bay of Bengal and moves further southwards as the season advances. The weather in the retreating monsoon is dry in the northern part of the basin (Karnataka) but it is associated with rainfall (>400 mm) in the southern part (Tamil Nadu) of the basin. The widespread rain in this season in the deltatic region of the basin is associated with the passage of cyclonic depressions which originate over Bay of Bengal. Southeastern part of the Cauvery basin gets more rainfall during this season than in any other seasons. The winter season remains dry and contributes very low rainfall (0–60 mm) to the annual total. South and southwest part of the basin receive about 40–60 mm and remaining area comes under dry climate with less than 30 mm rainfall.

4.3 Annual Rainfall

Spatial distribution of the annual rainfall is shown in the Fig. 5. This map clearly depicts the decreasing trend of rainfall from western part to eastern part of the basin. The western margin of the study area receives higher rainfall (>2,000 mm) during June–September due to orographic effect whereas the eastern margin of the basin remains dry due to its location on the leeward side of the Western Ghats. However, the southeast part of the Cauvery basin gets moderate amount of rainfall from northeast monsoon. Most of the drought phenomena occur in the eastern part of the basin due to the low rainfall.

5 Spatial Variability of Rainfall as Deduced from Coefficient of Variation

Thought the distribution characteristics of the raw data show certain patterns, in order to understand precisely the spatial variability of rainfall in the Cauvery basin, Coefficient of Variation (CV) has been computed using mean seasonal and annual rainfall values as these showed higher variability than on an annual basis (Schulze 1983). It is observed that the pre-monsoon, monsoon and post-monsoon seasons

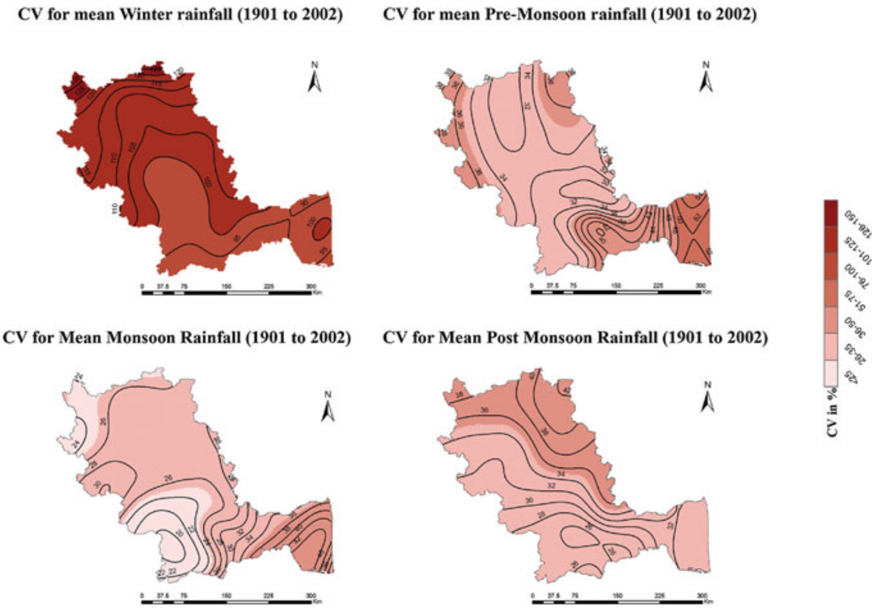

Fig. 6 Coefficient of variation in mean seasonal rainfall in the Cauvery basin (1901–2002)

have CV less than 55 % which indicates less to moderate variability. On the contrary, the winter season has significant variability (139 %). In the winter season, the west, north and eastern part of the Cauvery region has higher rainfall variability and isolines with the value higher than 100 % have been concentrated over this region (Fig. 6). A rule of thumb established already by Conrad (1941), from analyses of precipitation worldwide, is that higher the mean average precipitation the lower its inter-annual variability. In other words, areas with a low annual rainfall are likely to be doubly worse off, because they will additionally suffer from high deviations around their already low average rainfall. In the following Table 2, districts which experience highest and lowest CV in different seasons are listed.

The map of inter-annual CV is a “best case” scenario of rainfall variation. The CV for annual rainfall ranges between 15 and 23 %. Surprisingly, the annual spatial variation in the northwest and southeast parts of the basin is the highest (20–25 %) even though both these regions receive comparatively higher annual mean rainfall (Fig. 7). This is mainly due to the uncertainty in pre-monsoon rainfall and it is clearly noticed in the map of CV of the pre-monsoon period (Fig. 6). The figure also depicts the occurrence of lower CV (<20 %) all over the basin excluding the northwest and southeastern regions.

Table 2 Range of coefficient of variation (in percent) and associated districts

Season	Pre-monsoon		Monsoon		Post-monsoon		Winter		Annual	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
District	Erode	Cuddalore	Kodagu	Pudukkottai	Dindigul	Bangalore (rural)	Idukki	Tumkur	Coimbatore	Karaikal
CV Values	30.80	55.35	21.09	42.61	27.30	40.86	90.42	139.26	15.11	22.69

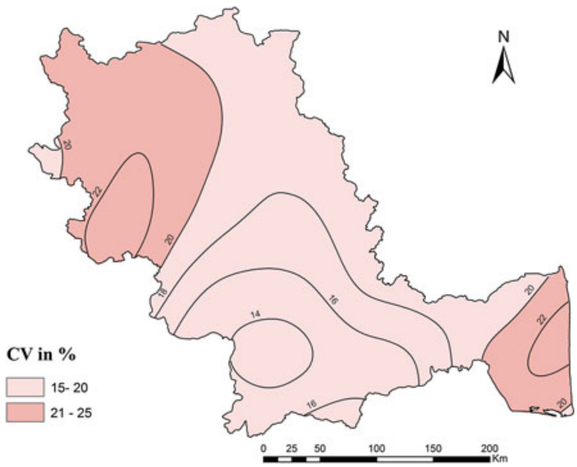

Fig. 7 Coefficient of variation for mean annual rainfall (1901–2002)

6 Deviation in Rainfall from Mean

The deficient or excess rainfall years are defined when rainfall of that year departs from the mean rainfall. In the twentieth century (1901–2002), there were 56 years which recorded annual rainfall below average (Fig. 8). Guhathakurta and Rajeevan (2008) studied the rainfall pattern over India and found 30 years of alternating sequences of dry and wet periods. They delineated the twentieth century into (a) 1901–1930 as dry period (b) 1931–1960 as wet period (c) 1961–1990 as dry period and (d) 1991–2020 as likely wet period. During the multi-decadal dry period 1901–1930 and 1961–1990, there were 12 years (6 years in each spell) of negative deviation of annual rainfall with more than 200 mm over the Cauvery Basin. Similarly, during wet period 1931–1960, there were 6 years of positive deviation of annual rainfall with more than 200 mm.

During the winter season, especially after 1961, more negative deviations of rainfall from the mean have been identified. Winter is the only season in which decreasing trend with significant level has been detected (Fig. 9). This is also validated by the Mann-Kendall trend analysis. For agricultural reason, this declining trend is more important since the agriculturalists grow more crops grow during this season traditionally. Akin to the winter season, rainfall deviation during the pre-monsoon season was higher after 1961 but the number of years was less than the winter season. In contrast, during post-monsoon season the numbers of years with negative (positive) deviation from mean rainfall is higher before (after) 1961. Unlike other seasons, monsoon period had alternate positive and negative deviations from mean rainfall but amount of deviation was higher in positive direction (14 years recorded positive deviation of >200 mm). Notwithstanding, negative deviation years were more (61 years) than the positive deviation years during the monsoon period (Fig. 8).

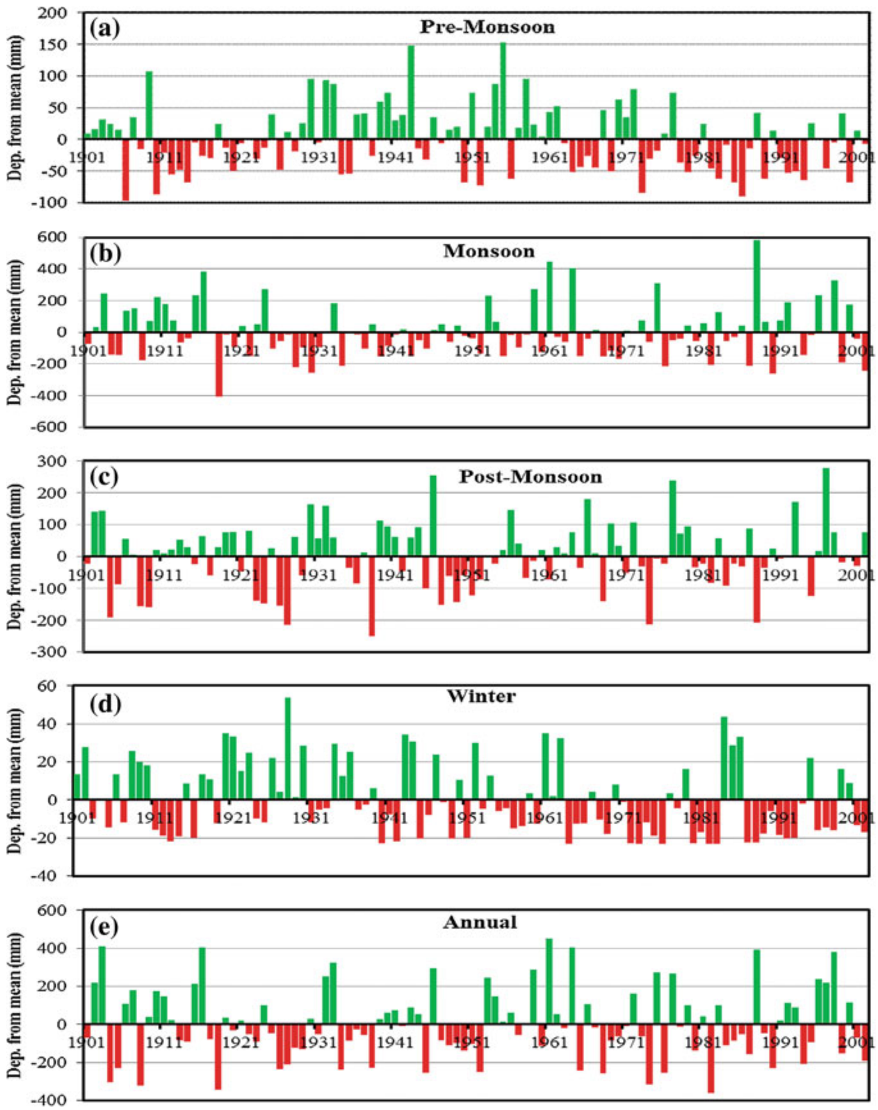

Fig. 8 Rainfall deviation from mean over Cauvery basin (1901–2002)

7 Trends in the Rainfall

Figure 9 shows the 5-year-running mean and trend line drawn based on the linear fit for the seasonal and annual rainfall series of the Cauvery Basin. The results of the Mann-Kendall trend analyses for annual, seasons and all months are summarized in

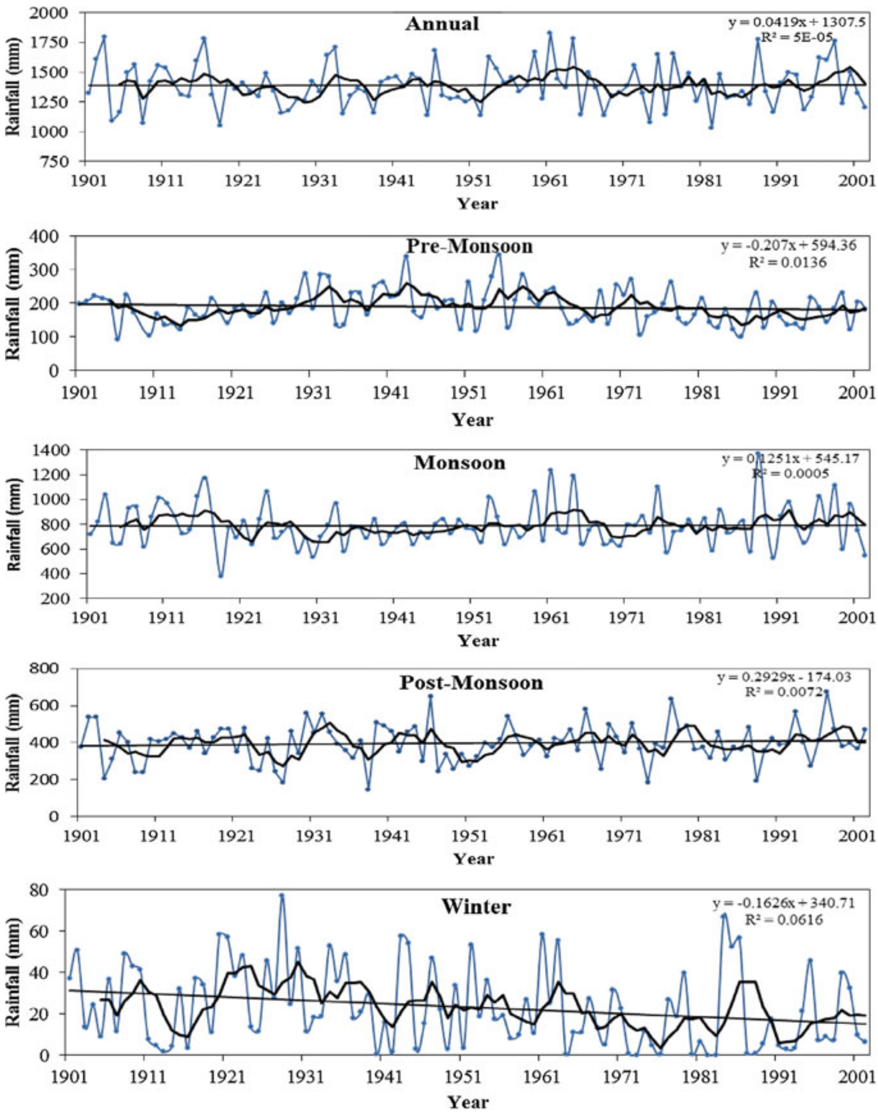

Fig. 9 Time series with 5-year moving mean line and trend line fit of seasonal and annual rainfall over the Cauvery basin (1901–2002)

the Table 3. The results of district-wise Mann-Kendall trend analyses are presented in the Table 4 and the same have been depicted in the Fig. 11. The observations and inferences drawn from these tables and figures are presented herein.

Table 3 Mann-Kendall trend statistics of monthly and seasonal rainfall over the Cauvery Basin

Month/season	Test Z	Significant level (%)
January	−2.32758	95
Febrauary	−1.47188	<90
March	−1.13053	<90
April	−0.27757	<90
May	−0.72284	<90
June	0.38744	<90
July	−0.38166	<90
August	−0.00578	<90
September	0.69393	<90
October	1.68277	90
November	−1.05246	<90
December	0.87319	<90
Winter	−2.76414	99
Pre-monsoon	−1.13341	<90
Monsoon	0.01735	<90
Post-monsoon	0.55514	<90
Annual	−0.1677	<90

First year = 1901; last year = 2002; n = 102

7.1 Monthly Rainfall Trends

The rainfall during January shows negative trend which is significant at 0.05 level. Rainfall in the months of February–May, July, August and November also show negative trends but all are insignificant. Rainfall in October shows positive trend, which is statistically significant at 0.10 level. Rainfall in the month of June, September and December show insignificant positive trends.

7.2 Seasonal Rainfall Trends

With reference to the long-term average (1901–2002), a decrease in the pre-monsoon rainfall from 1910 to 1929 followed by an increase up to 1965 with negligible fluctuation, and a declining trend from 1982 to 1999 are observed. There is an insignificant decrease of 21 mm rainfall over the 102 years period compared to the normal rainfall of 190.45 mm. Decreasing trend with −89 % confidence level has been observed over most parts of the Cauvery Basin (Fig. 10), except the Bangalore Urban, Bangalore Rural and Idukki districts which experienced an increasing trend (89 % level) and Karaikal and Nagapattinam experienced a decreased trend (−90 % level).

Table 4 District-wise mean annual rainfall, CV and Mann-Kendall trend statistics (1901−2002)

District ID	District name	Mean annual rainfall (1901–2002)	Annual CV	Annual Z Stat.	Significant level
1	Ariyalur	876.48	18.78	0.79	<90
2	Bangalore	838.66	18.75	1.14	<90
3	Bangalore rural	834.17	19.25	1.49	<90
4	Chamarajanagar	1532.72	18.87	0.25	<90
5	Chikmagalur	2442.02	22.24	−1.14	<90
6	Coimbatore	2239.09	15.11	−0.02	<90
7	Cuddalore	972.39	19.6	0.67	<90
8	Dharmapuri	815.17	19.6	1.78	90
9	Dindigul	1521.33	15.25	0.56	<90
10	Erode	1306.37	15.56	0.39	<90
11	Hassan	2727.19	20.9	−0.6	<90
12	Idukki	2112.96	15.14	−0.01	<90
13	Karaikal	1020.57	22.69	0.34	<90
14	Karur	1068.17	15.72	0.79	<90
15	Kodagu	1991.91	17.05	−1.64	<90
16	Mandya	1741.63	20.75	0.62	<90
17	Mysore	2586.03	21.15	−0.06	<90
18	Nagapattinam	1000.93	21.4	0.35	<90
19	Namakkal	879.64	17.34	1.54	<90
20	Nilgiris	2583.69	21.81	1.5	<90
21	Perambalur	842.1	19.62	0.52	<90
22	Pudukkottai	862.13	17	1.91	90
23	Salem	822.32	19.23	0.56	<90
24	Thanjavur	913.41	19.93	−0.62	<90
25	Thiruvarur	1073.43	21.74	0.14	<90
26	Tiruchirappalli	886.38	17.19	1.39	<90
27	Tumkur	1017.63	18.2	0.34	<90
28	Wayanad	2514.97	21.63	−3.02	99

Both the Mann-Kendall statistics and trend line manifested an insignificant trend of deviation in the monsoon season from the 5-year moving average value line. These have also shown the cyclic nature of the increases and decreases of the rainfall trend with roughly a period of 15 years. Increase in the rainfall during monsoon period is insignificant (0.017348). Increase in rainfall trend with 90 % significant level has been observed especially in the eastern part of the study area. Besides, the western and south eastern parts show the occurrence of decrease in trend with −89 % significant level (Fig. 10). Interestingly, significant level of −99 % decreasing trend had been observed in Waynad.

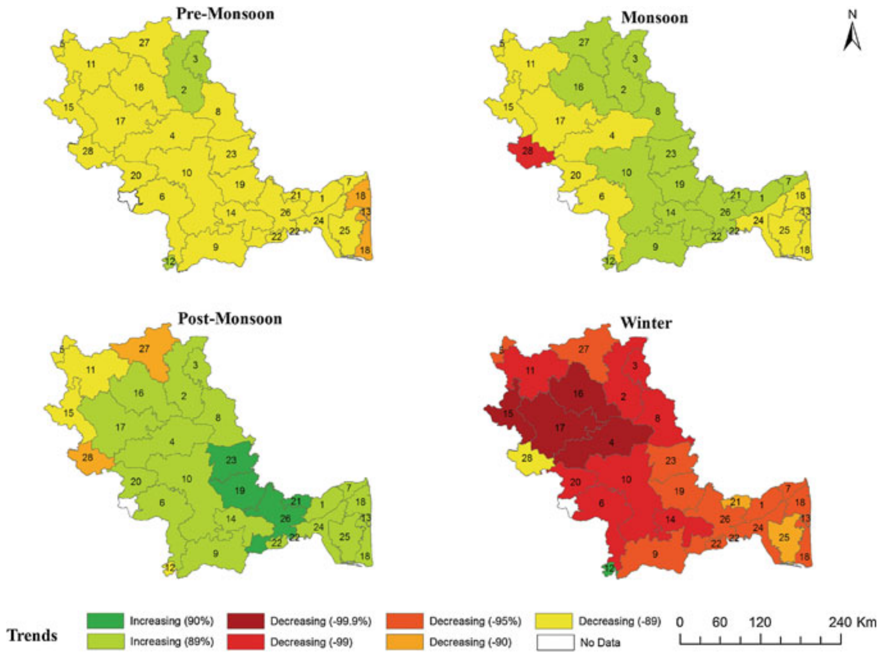

Fig. 10 District-wise trends in the seasonal rainfall over the Cauvery basin (1901–2002)

Rainfall in the post-monsoon season fluctuated moderately from mean. Similar to the monsoon period, post-monsoon is also showing cyclic nature of wet and dry periods as a result of recurrent cyclones over the Bay of Bengal. Overall, during 20th century, the post-monsoon rainfall had increased at insignificant level. This increase was about 0.6 mm/year during the study period (1901–2002). Increasing trend with 89 % significant level is observed in 18 districts and with 90 % significant level is observed in four districts (Fig. 10).

The winter rainfall has decreased significantly from 1901 to 2002. Out of four seasons, only in winter season decreasing trend is with 0.01 significant level is observed. Though, there is a significant level of decrease, the actual rainfall is not significant since the average rainfall in this season is only 23.4 mm. The decrease of 0.16 mm rainfall per year has a negligible contribution in the overall trend. Compared to all other seasons, the winter season manifested significant rainfall trend. Almost all the districts recorded decreasing rainfall trend with different significant levels especially those located in the central, north eastern and western parts of the basin with −99 and −99.99 % significant levels (Fig. 10). There is only one exception of Idukki district which recorded an increase rainfall trend.

7.3 Annual Rainfall Trends

The mean annual rainfall over the Cauvery Basin shows a long term insignificant declining trend. However, the declining trend (−1.02051) in annual rainfall was significant if the annual rainfall is considered from 1901 to 1950. The annual rainfall after 1950 has declined with insignificant level (−0.48136). The 5-year moving average shows the cyclic nature of the wet and dry periods (Fig. 9). During the period of 50 years from 1901 to 1950, a decrease of 150 mm was noticed which is highly appreciable quantity. During 1951–2002, a negligible decline of 33.75 mm rainfall has been recorded. As most parts of the basin in the Tamil Nadu side receive rainfall not only from monsoon season (56.81 %) but also from the post-monsoon season (27.80 %), such a trend is exhibited. Out of 28 districts in the study area, 20 have recorded positive rainfall trend and 8 have negative trend.

8 Conclusions

Analysis of the distribution, variability and trends of rainfall data of more than 100 years over the Cauvery Basin revealed the following.

Over the western part of the basin the amount of rainfall is high since this part experiences southwest monsoon rainfall. The coastal southeastern part of the basin gets more rainfall during the retreating monsoon. The CV ranges between 15 and 23 % for the Cauvery Basin as a whole. The CV in the northwestern and southeastern parts of the basin are the highest (20–25 %). Lower CV are observed all over the basin excluding the northwest and southeast regions. The results of the Mann-Kendall trend analyses show a significant decreasing trend in the winter rainfall over the Cauvery Basin. On the other hand, increasing trend in the post-monsoon season with insignificant level has been observed. The Dharmapuri and Pudukottai have highest positive Z values i.e. increasing trend of rainfall while Wayanad has negative Z values i.e. decreasing trend of rainfall. The maps (Figs. 10 and 11) showing

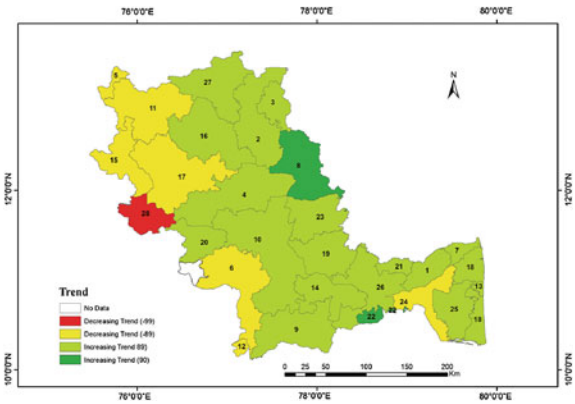

Fig. 11 District-wise trends in the annual rainfall over the Cauvery basin (1901–2002)

district-wise Z values for seasonal and annual rainfall clearly exhibit the trends in spatial dimension over the basin. These results can help the planners, administrators and the stake-holders (principally the agriculturalists) to strategize the development, management and utilization activities.

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