Poll Res. 40 (1) : 281-289 (2021)

ISSN 0257–8050

HISTORICAL PRECIPITATION AND VARIABILITY ANALYSIS IN CAUVERY RIVER BASIN

KUMARASWAMY, T.R. AND B.C. NAGARAJA

Department of Environmental Science
Bangalore University, Bangalore 560 0056, Karnataka, India

(Received 4 August, 2020; accepted 8 September, 2020)

ABSTRACT

Information about the spatial trend and variability of mean precipitation is vital for the effective management of water and agriculture. The current study analyses the precipitation data of the Cauvery basin, which plays a significant role in the agrarian economy in the riparian states of Karnataka and Tamil Nadu. The analysis determines the trends, distribution and variability in precipitation over the Cauvery basin during the last four decades 1989–2019. The impact of climate change on the trend and variability of precipitation is evident from this analysis. It is observed that the coefficient of variation shows significant fluctuations during the winter than in other seasons. Future changes in precipitation are determined by a significant decreasing trend within the winter precipitation and increasing trend within the post-monsoon. Significant levels are inferred and supported by the Mann-Kendall rank statistics and linear trend. Overall, an insignificant decrease in annual precipitation over the Cauvery basin is observed during 1989-2019.

KEY WORDS : Precipitation, Variability, Trend, Mann-Kendall, Cauvery basin

INTRODUCTION

Water is crucial component for sustenance of life. It's increasing demand has put tremendous pressure on river basin, thus river basins are critical from hydrological, economic and ecological points of view. They capture the run-off from precipitation, which, when wisely managed, can provide freshwater for drinking water, aid growth of food, hydropower, etc. Impacts of climate change on will be most critical in river basins. Therefore, characterization of the impacts of climate change on the temporal and spatial distribution of available water resources is critical to ensuring sustainable development of water, land and other related natural resources. Researchers agree that the most straightforward approach for conserving the world's freshwater resources is by managing river basins sustainably (Skoulikaris and Zafirakou, 2019). Decisions regarding the utilization, management of freshwater will be critical for sustaining the ecosystem in the near future. Despite this, the inter-linkages between the hydrological, ecological and socio-economic components of river basins have rarely been considered by decision-makers. As a result, most of the river basins around the world are not being managed systematically. In the recent decade, the need to conserve and manage freshwater ecosystems at the basin scale are increasingly being recognized by various countries. The principle of integrated basin management is given importance in many international agreements.

Recent reports on climate change emphasize that understanding the trends and variability of precipitation is crucial for the planning and management of water resources, especially at a basin-level (Mirza, 2011; Meenu *et al*., 2013; Narsimlu *et al*., 2013, Sanchez*et al*., 2019). This information is vital in agricultural planning, flood frequency analysis, flood hazard mapping, hydrological modeling, water resource assessments, climate change impacts and ecosystem services (Kumar *et al*., 2010; Alam *et al*., 2011; Guhathakurta *et al*., 2011). Precipitation is one of the most variable climatic factors, both spatially and through time scales ranging from daily to decadal and longerterm fluctuations (Aravena and Luckman, 2009).

Various studies have analyzed the distribution, variability and trends in precipitation at global, regional and basin levels (Rodhe, 1976; Nicholls., 1997; De Lius *et al.,* 2000; Marengo, 2004; Batisani and Yarnal, 2010). In India, studies have been done Mooley and Parthasarathy (1983) have examined the normal monsoon precipitation and its variability over the region employing the Index of Dryness over India (IDI) and the Index of Wetness over India (IWI). They have concluded that precipitation over the country during 1871–1978 was homogeneous, random, highly variable and positively skewed. Considering India as a whole unit, precipitation data for 306 precipitation stations for the period 1871–1993 were merged and by giving proper area weightages to estimate long-term changes and trends in Indian monsoon (Parthasarathy *et al.,* 1994). Linear trend analysis was done to assess the contribution of monthly monsoon to annual precipitation at the subdivision level from 1901-2003 (Guhathakurta and Rajeevan, 2008). Studies have concluded that in India, monsoon months of June to September accounted for more than 80% of the annual precipitation and no significant trend was detected for annual, seasonal, or monthly precipitation. Annual and monsoon precipitation decreased, while pre-monsoon, post-monsoon and winter precipitation increased at the national scale. Precipitation in June, July and September decreased, whereas in August it increased, at the national scale (Kumar *et al.,* 2010; Jain and Kumar, 2012). At regional level studies indicate a significant decrease of precipitations during the southwest monsoon and an increase during the post-monsoon season during the twentieth century in Kerala, Odissa, Madhya Pradesh, Assam and Karnataka (Krishnakumar *et al.,* 2009; Patra *et al.,* 2012; Goyal, 2014; Kundu *et al.,* 2015; Chandrashekar, 2018).

Likewise, at basin level, a significant negative trend in annual, pre-monsoon and post-monsoon season in Ganga river basin (Bera, 2017). It was also observed that the drought effect increased due to increased precipitation variation, both Ganga and Brahmaputra basin (Asada and Matsumoto, 2009). Tapi basin, there is a decreasing trend in rainy days and an increasing trend in precipitation intensity. The seasonal precipitation has been found to decrease for all the seasons except post-monsoon, which is affecting the rain-fed agriculture in the basin (Sharma *et al.,* 2018). In the Cauvery river basin, Raju and Nandagiri (2017) have analyzed the historical trends in hydrometeorological variables for the upper Cauvery Basin.

Though various methods are present to the study, the trend and variability of precipitation, Modified Mann-Kendall (MMK) and Spearman's rho test are the best methods to study the trend and Sen's slope to study the variability. Precipitation analysis using the above methods have been done at Seonath river sub-basin (Chakraborty *et al.,* 2013), Birupa river basin (Mondal *et al*., 2012) and Narmada river basin (Pandey and Khare, 2018). In this context, the precipitation trends of the Cauvery river basin have not yet been studied; hence in this paper, analyzed monthly, seasonal and annual precipitation trends for the Cauvery River Basin. Statistical features of the temporal precipitation series of each district contained within the Cauvery Basin followed by the study of precipitation distribution, variability and trends of the monthly, seasonal and annual total precipitation for each of the districts were analyzed in the present study

Study Area

The Cauvery Basin lies between 75°272–79°542 East longitudes and 10°92–13°302 North latitudes (Figure 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 the 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 influences and the location of the basin in varying topographic and geographic sprawl, the Cauvery Basin region experiences wet and dry periods, resulting in concurrent regions with a prevalence of heavy precipitation, and some areas receive significantly less precipitation.

METHODOLOGY

The precipitation (mm) data over Cauvery basin for the period from 1985 to 2015 has been obtained from the Indian Meteorological Department (IMD) and India Water Portal. Seasonal, annual and century precipitation data series of Cauvery basin were computed using monthly precipitation data of rain gauge stations located in and around the Cauvery river basin. Computation of mean monthly, seasonal and annual Standard Deviation (SD) and Coefficient of Variation (CV) was done. The coefficient of variation indicates the amount of fluctuation in precipitation recorded over a long period from the mean values. It is an index of climatic risk, indicating a likelihood of fluctuations in reservoir storage or crop yield from year to year. Agriculturally itis, perhaps, a more crucial statistic for marginal areas than arid regions, where farming

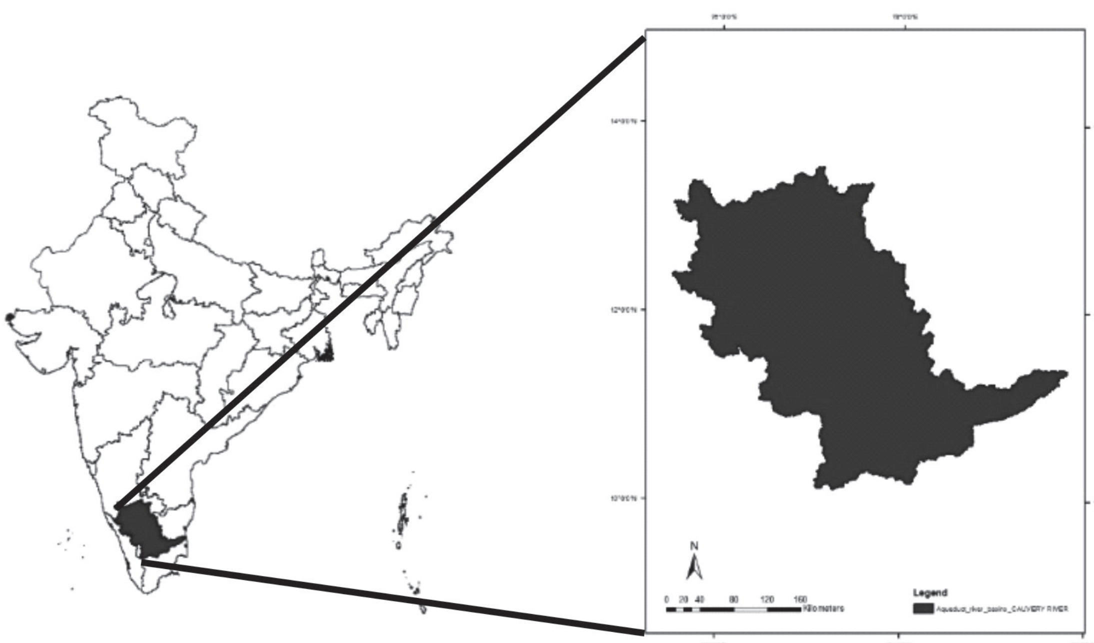

Fig. 1. Cauvery River Basin

Table 1. Three decadal mean monthly, seasonal and annual precipitationin Cauvery basin (1989–2019)

Month	Average	Standard Deviation	Co-Variance	% Contribution
January	5.77	11.69	202.54	0.46%
February	4.61	11.78	255.65	0.37%
March	17.28	29.56	171.07	1.37%
April	54.02	41.66	77.12	4.29%
May	123.30	67.08	54.41	9.78%
June	189.28	221.37	116.96	15.02%
July	204.44	244.39	119.54	16.22%
August	175.47	162.27	92.48	13.92%
September	132.84	71.16	53.57	10.54%
October	205.34	82.37	40.11	16.29%
November	107.53	107.48	99.95	8.53%
December	40.53	55.76	137.59	3.22%
Winter	10.38	17.17	165.37	0.82%
Pre-Monsoon	194.59	83.50	42.91	15.44%
Monsoon	702.03	608.32	86.65	55.70%
Post-Monsoon	353.40	171.86	48.63	28.04%
Annual	1260.40	658.34	52.23	100.00%

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. To find out the long-term variations trend line graphs were constructed with the help of average precipitation. Temporal changes in the monthly, seasonal and annual precipitation were also analyzed by the Mann-Kendall test to confirm the significance of the observed trends. Mann-Kendall test is a statistical test widely used for the analysis of the trend in climatologic and hydrologic time series. 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.

RESULTS AND DISCUSSION

Precipitation Characteristics of the Cauvery Basin

The average annual normal precipitation over the Cauvery Basin from 1989 to 2019 is 1260.40 mm with a standard deviation of 658.34 mm. The coefficient of variation of annual precipitation is 52.23% indicating that it is moderately variable. Precipitation during October is the highest (205.34 mm) and contributes 16.29% to annual precipitation, followed by July (16.22%), June (15.02%) and August (13.94 %). Contribution of the seasonal precipitation to the annual precipitation is highest during the monsoon period (55.70%), followed by post-monsoon period (28.04%), pre-monsoon period (15.44%) and winter period (0.82%) in the decreasing order. Least amounts of precipitation are observed during the month of February (4.61 mm) followed by January (5.77 mm), which contributes only 0.37% and 0.46% to the annual precipitation, respectively. The coefficient of variation is highest in February (255.65%), followed by January (202.54%), December (137.56 %) and March (171.07%) and the least during October (40.11 %) and September (53.57 %). A significant relationship between SD and CV has been observed during September and October, which contributes to 26.84% of the annual precipitation

Monthly Distribution of Rainfall

The monthly precipitation indicate that the major rainfall patterns are generally oriented east northeast to west southwest, with maxima and strong precipitation gradients located along the western and southern parts of the basin. During June–September, the Cauvery basin receives higher precipitation (702.03 mm) as a result of prevalent southwest monsoon wind. Though the northeast monsoon (October–December) provides only half of the total amount of southwest monsoon (353.44 mm), it remains essential since it fulfils the need of agricultural activities, especially in the Cauvery deltaic region. Generally, the highest precipitation (up to 650.81 mm, Kodagu District) pattern is observed in the western region of the basin during May– September. However, in the months of October, November and December, the pattern changes from the west of the boundary to the extreme eastern side (Cauvery Delta). This seasonal shift of precipitation maxima zones could be identified from Figure 2. Overall, the month of January, February, March, April and May experience the lower amount of precipitation, thus known as the dry season.

Seasonal Distribution of Rainfall

Based on the percentage of contribution to the annual precipitation, the basin experiences four distinct periods of precipitation (Fig. 2) namely, the pre-monsoon precipitation season from March to May (Hot summer), the southwest monsoon precipitation 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 precipitation ranges from 102 to 302 mm. Isohyets of low precipitation values (100-150) are located in the eastern and central districts of the basin and are aligned north-south. Contrary to this pattern, isohyets of the higher precipitation values are in the southwest district of the basin. Western and central west districts of the basin experience moderate precipitation. The basin receives copious precipitation (56% of annual precipitation) during the monsoon season. This season has maximum number of rainy days and is called the ‘wet season’. Precipitation during this season is caused by the southwest monsoon winds blowing from the Indian Ocean. Since a part of the basin is shared by the western face of the Western Ghats section, gets higher precipitation throughout the monsoon season, especially the northwest part of the basin.

Precipitation gradually decreases eastwards due to the rain shadow effect. Thus, eastern and south-eastern parts of the basin experience lower precipitation (400 mm) in the southern part (Tamil Nadu) of the basin. The widespread rain in this season in the delta region of the basin is associated with the passage of cyclonic depressions, which originates over the Bay of Bengal. The south-eastern part of the Cauvery basin gets more precipitation during this season than in any other season. The winter season remains dry and contributes very low precipitation (3-31mm) to the annual total. South and southwest part of the basin receives about 15-30 mm and the remaining districts come under dry climate with less than 15 mm precipitation.

Annual Distribution of Rainfall

The spatial distribution of the annual precipitation is shown in Fig. 3. This map clearly depicts the decreasing trend of precipitation from the western to the eastern part of the basin. The margin of the west of the basin receives higher precipitation (>2,000 mm) from June–September due to the 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

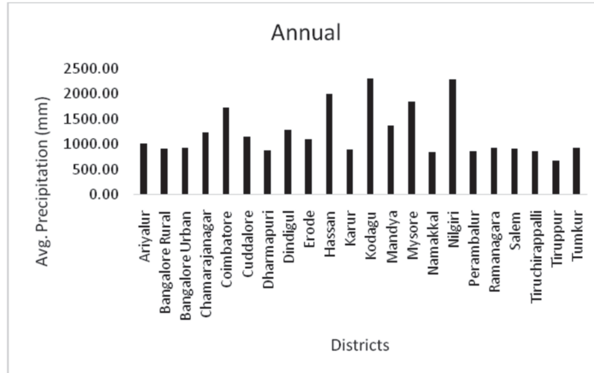

Fig. 3. Spatial distribution of the mean annual precipitation over Cauvery basin (1901–2002).

precipitation from northeast monsoon. Most of the drought phenomena occur in the eastern part of the basin due to the low precipitation.

Coefficient of Variation in Rainfall

In order to understand precisely the spatial variability of rainfall in the Cauvery basin, Coefficient of Variation or C0-Varinace (CV) has been computed using mean seasonal and annual rainfall values as these showed higher variability than on an annual basis. It is observed that the post-monsoonseas on has CV less than 50% which indicates less to moderate variability. Pre-monsoon

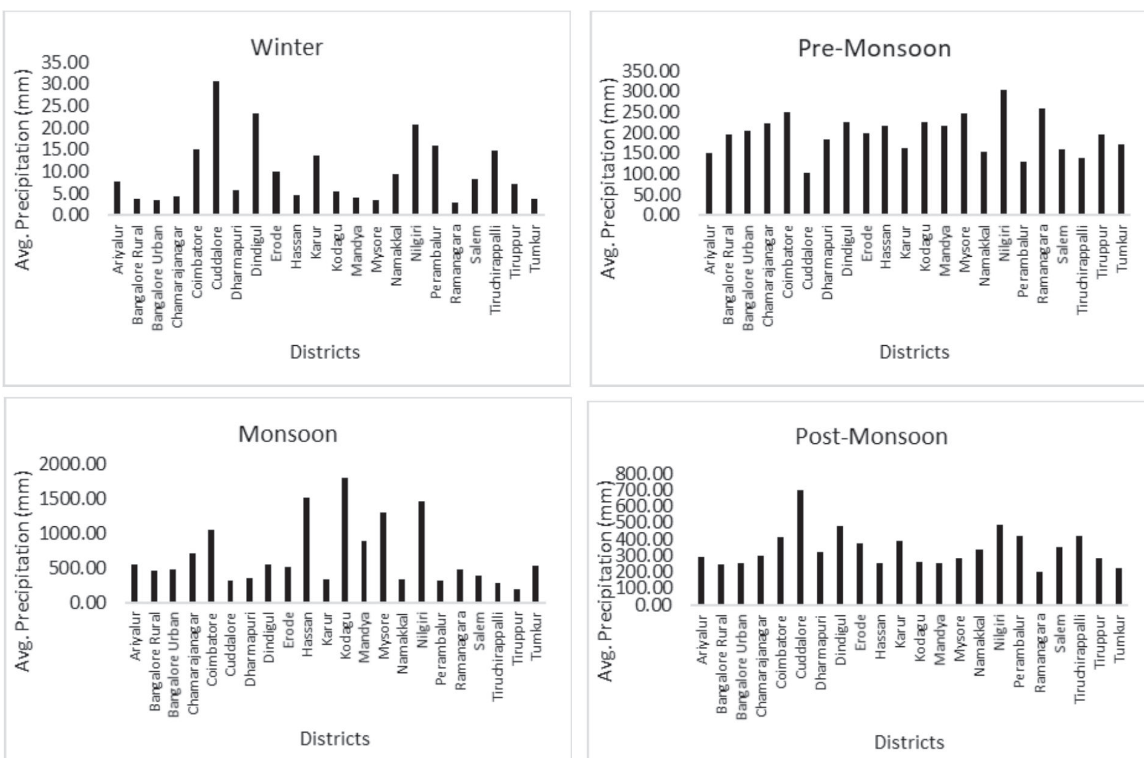

Fig. 2. Spatial distribution of the mean seasonal precipitation over Cauvery basin (1989–2019)

and Monsoon seasons have CV less than 70% which indicates moderate to high variability. On the contrary, the winter season has significant variability (142 %). 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. 4). A rule of thumb established already from various literatures from analysis 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 figure of inter-annual CV is a "best case" scenario of rainfall variation. The CV for annual rainfall ranges between 19 and 51%. Surprisingly, the annual spatial variation in the northwest and southeast parts of the basin are between 20–30% even though both these regions receive comparatively higher annual mean rainfall (Figure 5). This is mainly due to the uncertainty in pre-monsoon rainfall and it is clearly noticed in the figure of CV of the pre-monsoon period (Figure 5). The figure also depicts the occurrence of lower CV.

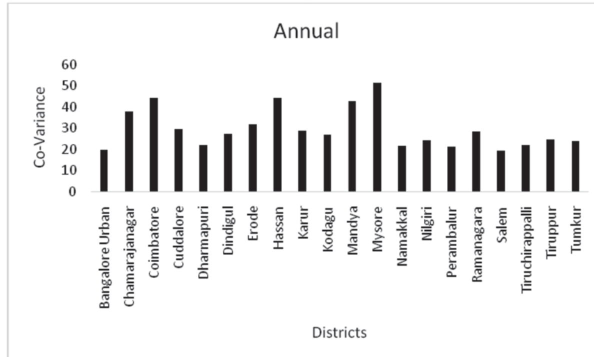

Fig. 5. Coefficient of variation in mean annual precipitation in the Cauvery basin (1989–2019)

Annual Trends in the Rainfall

Annual tends of 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 the Table 2.

With reference to the long-term average (1989–2019), a decrease in the pre-monsoon and monsoon precipitation with negligible fluctuation. Likewise,

Fig. 4. Three decadal coefficient of variation in mean seasonal precipitation in the Cauvery basin (1989–2019)

Table 2. Mann-Kendall trend statistics of seasonal and annual precipitation over the Cauvery Basin

Season	Test Z	Significant level (%)
Winter	“3.453	<90%
Pre-Monsoon	“2.341	<90%
Monsoon	0.042	<90%
Post-Monsoon	0.892	<90%
Annual	“0.356	<90%

and increasing in the winter and post-monsoon precipitation with negligible fluctuation. The mean annual rainfall over the Cauvery Basin shows a long term insignificant declining trend.

CONCLUSION

Analysis of the distribution, variability and trends of rainfall data of three decade 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 south-eastern part of the basin gets more rainfall during the retreating monsoon. The CV ranges between 19 and 51% for the Cauvery Basin as a whole. The CV in the north-western and south-eastern parts of the basin are the lowest (20-30%). Lower CV are observed all over the basin excluding the northwest and southeast regions. The results of

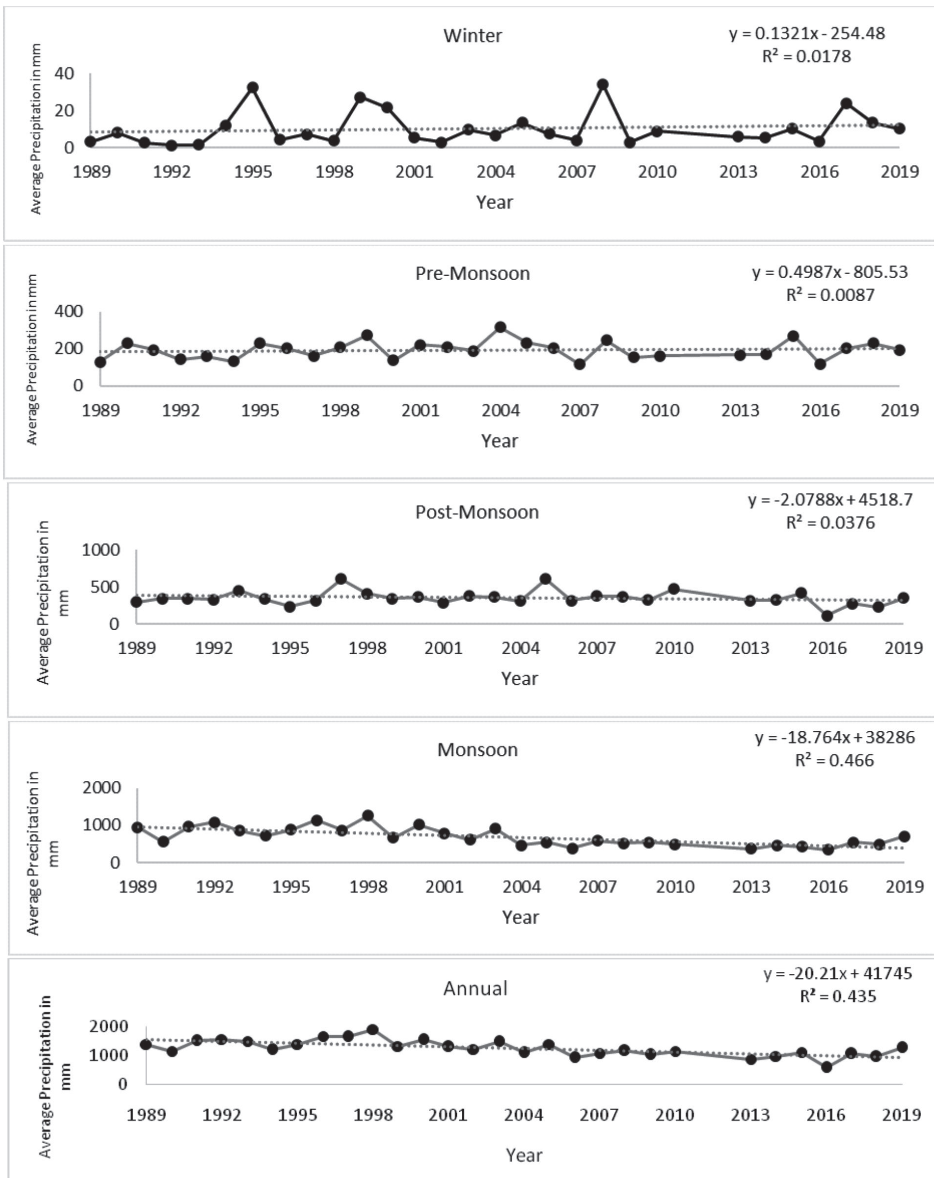

Fig. 6. Time series with trend line of seasonal and annual rainfall over the Cauvery basin

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.

REFERENCES

Alam, M., Toriman, M., Siwar, C. and Talib, B. 2011. Rainfall variation and changing pattern of agricultural cycle. *Alam, MM, Mohd Ekhwan, T., Siwar, C. and Talib, B.* 82-89.

Aravena, J. C. and Luckman, B. H. 2009. Spatiotemporal rainfall patterns in southern South America. *International Journal of Climatology: A Journal of the Royal Meteorological Society*. 29 (14) : 2106-2120.

Asada, H. and Matsumoto, J. 2009. Effects of rainfall variation on rice production in the Ganges-Brahmaputra Basin. *Climate Research*. 38 (3) : 249-260.

Batisani, N. and Yarnal, B. 2010. Rainfall variability and trends in semi-arid Botswana: implications for climate change adaptation policy. *Applied Geography*. 30 (4) : 483-489.

Bera, S. 2017. Trend analysis of rainfall in Ganga Basin, India during 1901-2000. *American Journal of Climate Change*. 6(01) : 116.

Chakraborty, S., Pandey, R. P., Chaube, U. C. and Mishra, S. K. 2013. Trend and variability analysis of rainfall series at Seonath River Basin, Chhattisgarh (India). *International Journal of Applied Science and Engineering Research*. 2 (4) : 425-434.

Chandrashekar, V. D. and Shetty, A. 2018. Trends in extreme rainfall over ecologically sensitive Western Ghats and coastal regions of Karnataka: an observational assessment. *Arabian Journal of Geosciences*. 11 (12) : 327.

De Luis, M., Raventós, J., González Hidalgo, J. C., Sánchez, J. R. and Cortina, J. 2000. Spatial analysis of rainfall trends in the region of Valencia (East Spain). *International Journal of Climatology: A Journal of the Royal Meteorological Society*. 20 (12): 1451-1469.

Goyal, M. K. 2014. Statistical analysis of long term trends of rainfall during 1901-2002 at Assam, India. *Water Resources Management*. 28 (6) : 1501-1515.

Guhathakurta, P. and Rajeevan, M. 2008. Trends in the rainfall pattern over India. *International Journal of Climatology: A Journal of the Royal Meteorological Society*. 28 (11) : 1453-1469.

Guhathakurta, P., Sreejith, O.P. and Menon, P. A. 2011. Impact of climate change on extreme rainfall events and flood risk in India. *Journal of Earth System Science*. 120 (3) : 359.

Jain, S.K. and Kumar, V. 2012. Trend analysis of rainfall and temperature data for India. *Current Science*. 37-49.

Krishnakumar, K.N., Rao, G.P. and Gopakumar, C.S. 2009. Rainfall trends in twentieth century over Kerala, India. *Atmospheric Environment*. 43 (11) : 1940-1944.

Kumar, V., Jain, S. K. and Singh, Y. 2010. Analysis of long-term rainfall trends in India. *Hydrological Sciences Journal-Journal des Sciences Hydrologiques*. 55 (4) : 484-496.

Kundu, S., Khare, D., Mondal, A. and Mishra, P. K. 2015. Analysis of spatial and temporal variation in rainfall trend of Madhya Pradesh, India (1901-2011). *Environmental Earth Sciences*. 73 (12) : 8197-8216.

Marengo, J.A. 2004. Interdecadal variability and trends of rainfall across the Amazon basin. *Theoretical and Applied Climatology*. 78 (1-3) : 79-96.

Meenu, R., Rehana, S. and Mujumdar, P.P. 2013. Assessment of hydrologic impacts of climate change in Tunga-Bhadra river basin, India with HECHMS and SDSM. *Hydrological Processes*. 27 (11) : 1572-1589.

Mirza, M.M.Q. 2011. Climate change, flooding in South Asia and implications. *Regional Environmental Change*. 11 (1) : 95-107.

Mondal, A., Kundu, S. and Mukhopadhyay, A. 2012. Rainfall trend analysis by Mann-Kendall test: A case study of north-eastern part of Cuttack district, Orissa. *International Journal of Geology, Earth and Environmental Sciences*. 2 (1) : 70-78.

Mooley, D. A. and Parthasarathy, B. 1983. Variability of the Indian summer monsoon and tropical circulation features. *Monthly Weather Review*. 111 (5) : 967-978.

Narsimlu, B., Gosain, A. K. and Chahar, B. R. 2013. Assessment of future climate change impacts on water resources of Upper Sind River Basin, India using SWAT model. *Water Eesources Management*. 27 (10) : 3647-3662.

Nicholls, N., Drosdowsky, W. and Lavery, B. 1997. Australian rainfall variability and change. *Weather*. 52 (3) : 66-72.

Pandey, B. K. and Khare, D. 2018. Identification of trend in long term precipitation and reference evapotranspiration over Narmada river basin (India). *Global and Planetary Change*. 161 : 172-182.

Parthasarathy, B., Munot, A. A. and Kothawale, D. R. 1994. All-India monthly and seasonal rainfall series: 1871-1993. *Theoretical and Applied Climatology*. 49 (4) : 217-224.

Patra, J. P., Mishra, A., Singh, R. and Raghuwanshi, N. S. 2012. Detecting rainfall trends in twentieth century (1871-2006) over Orissa State, India. *Climatic Change*. 111 (3-4) : 801-817.

Prabhu, C. N., Reddy, G. S., Keerthi, N. G., Prabha, E., Gavaskar, S. S. M. and Hiremath, P. Variations in Rainfall Trends over Karnataka. *Climate Change: Challenges and Solutions.* 94.

Raju, B. K. and Nandagiri, L. 2017. Analysis of historical trends in hydrometeorological variables in the upper Cauvery Basin, Karnataka, India. *Curr. Sci.* 112 (3): 577-587.

Rodhe, H. and Virji, H. 1976. Trends and periodicities in East African rainfall data. *Monthly Weather Review.* 104 (3) : 307-315.

Sanchez-Plaza, A., Broekman, A. and Paneque, P. 2019. Analytical Framework to Assess the Incorporation of Climate Change Adaptation in Water Management: Application to the Tordera River Basin Adaptation Plan. *Sustainability.* 11 (3) : 762.

Sharma, P. J., Loliyana, V. D., Resmi, S. R., Timbadiya, P. V. and Patel, P. L. 2018. Spatiotemporal trends in extreme rainfall and temperature indices over Upper Tapi Basin, India. *Theoretical and Applied Climatology*. 134 (3-4) : 1329-1354.

Sivapragasam, C., Balamurli, S., Deepak, M., Prakhar, A. and Muttil, N. 2013. Trends in rainfall patterns over the Tamarabarani basin in Tamil Nadu, India. In *20th international congress on modelling and simulation, Adelaide, Australia*.

Skoulikaris, C. and Zafirakou, A. 2019. River Basin Management Plans as a tool for sustainable transboundary river basins' management. *Environmental Science and Pollution Research*. 26 (15) : 14835-14848.