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Precipitation Concentration Index and Rainfall Trend Analysis for South Western Districts of Karnataka, India

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***Abstract*:** A statistical analysis of the annual and seasonal (monsoon) rainfall was carried out for different stations located in south western districts of Karnataka state (adjoining to Western Ghats). The statistical methods such precipitation concentration index analysis (PCI), trend analysis using Sen's slope and Man-Kendall were employed for the observed data between 1960-2018. The findings show that the Spatiotemporal distribution of rainfall in these districts has changed during the later part of the data period, i.e., 1990-2018. There is no discernible upward trend in the region's rainfall. The erratic and increasing pattern of rainfall it these district may lead to the flash floods and at times drought situations. The results may of use to the water resources manager and planner of the region to devise an appropriate contingent plan to minimise the loss and for effective management of water resources.

Keywords: Precipitation concentration index, Mann-Kendell, Dry and wet periods. Soil erosion

In India, the majority of rainfall features are evaluated during the monsoon season, and the climate changes significantly due to unstable monsoon and other meteorological conditions due to variable topography and huge geographic extent in the tropics. During the monsoon months of June to September, around 80% of the yearly rainfall falls (In some localities, spanning mid-May to mid-October). Some areas face catastrophic floods and droughts as a result of the rain's uneven distribution. Therefore, Rainfall intensity and duration are important factors in rainfall variability in the research area. Rainfall levels and seasonal distribution have changed during the last few decades, owing to urbanisation and industrial expansion, both of which have resulted in environmental changes. (Kripalani and Kulkarni2001) There are several studies on evaluation of PCI e.g. Luis et al. (2011) of Spain, Xuemei et al (2011) over Xinjiang, China, Adegun et al (2012), Iskander et al (2014) over Bangladesh, Benhamrouche et al (2015) in Algeria, Milan Gocic et al (2016) of Serbia, Al-Shamarti (2016) of Iraq, Over south-eastern Brazil, Nery et al (2017). In India, however, there are just a few research on PCI, most of which are on a regional size (Patel and Shete 2015).

Precipitation Concentration Index Mann-Kendell test are the major tools which is the indicator of Uniform or Non-Uniform rainfall patterns over the region. Precipitation is one of the most significant components of the hydrological cycle since it assesses dry and wet periods and predicts drought or no drought. Although total precipitation is commonly used as a measure of the amount of water available to ecosystems and water resource schemes, the timing of seasonal precipitation is critical for many environmental processes (Weltzin and McPherson 2000, Pryor and Schoof 2008.) In hydrological processes, the distribution of precipitation throughout the year controls interception, evapotranspiration, infiltration rates, and snow accumulation, and these factors have significant implications for stream discharge and flood forecasting (Beniston 2003, 2006). Changes in the distribution of water inputs may result in a mismatch between water availability and demand when it comes to water resource management. Some poorly impounded systems can be managed in highly regulated basins (Lo'pezMoreno et al 2004). Using a 58-year database of monthly precipitation, the current study looks for monthly, seasonal, and annual distributions, changes, and trends in 10 rain gauge sites in the Mysore and Coorg districts.

MATERIAL AND METHODS

The Mysore district is spatially positioned between the latitudes of 12° 18′ 26″ north and 76° 38′ 59″ east in India's South-Western section of Karnataka state. It is situated at a height of 740 metres (2,427 ft) with Seven Taluk's which borders are shared with Chamarajanagar District, with Annual Average Rainfall of 776.6mm and Coorg District with three Taluk's and it has an area of 4120SqKm (1584 Sq. Mi) and it is located in Eastern slopes of Western Ghat, Karnataka. It is a hilly region with the highest Mean Sea level of 900m (3000Sq.Ft). The Major River of Kodagu is Kaveri. The average Rainfall of Kodagu is 3210mm and the Average

maximum temperature is 25.6^{0}c. A total of 58 Years of Data is used for this study. The data was gathered from the KSNMDC and the Karnataka Department of Economics and Statistics in Bengaluru. For the analysis, three statistical methods were used. Specifically, the Precipitation Concentration Index and the Mann-Kendell test were used to determine Rainfall Trend.

For the period 1960-2018, the average monthly rainfall of 10 Meteorological (Fig. 1) was used to determine the Spatial and Temporal Distribution over the study period using GIS Tool, mean annual rainfall data, annual rainfall, seasonal (monsoon) June-September considered for seasonal, standard deviation (), and coefficient of variation. The rainfall data was subjected to a linear regression test to see if there was any sort of trend or consistency.

Index (PCI): The precipitation concentration index was proposed by Michiels et al (1992), Annually and seasonally. Oliver (1980)

Proposed the precipitation concentration index (PCI), Uniform Precipitation distribution was denoted if the PCI Values are less than or equal to 10 and Moderate Precipitation Distribution is considered as if the values are between 10 to 15, and irregular precipitation distribution is denoted as the PCI Values between 16 to 20 and strong Irregular precipitation distribution considered if the PCI Values are more than 20.Based on the equations of Oliver (1980), the PCI values were estimated on an annual basis using data from ten sites in the research area:

$$PCI_{annual} = \frac{\Sigma_{i=1}^{12} Pi^2}{(\Sigma_{i=1}^{12} Pi)^2} * 100 \ldots..(eq.1)$$

where Pi is the total precipitation in a month I.

$$PCI_{Monsoon} = \frac{\Sigma_{i=1}^{4} Pi^2}{(\Sigma_{i=1}^{4} Pi)^2} * 33.33 \ldots..(eq.2)$$

The monthly rainfall in month I is Pi. The number 100 in the formula for the annual PCI (Equation 1) represents the 12 months of the year, which equals 100%, and the numbers 33 percent in the formula for the seasonal PCI (Equation 2) represent the four monsoon months (June-September) in each season, which equals 33%.

Mann-Kendall Trend Test (MK): The study investigates Rainfall trend changes over the selected area by Mann-Kendall. Mann (1945), Kendall (1975), and Gilbert (1987) for identifying trends in the rainfall precipitation data. The MK test assesses "whether to reject the null hypothesis (H0)" or accept the alternative hypothesis (Ha), where H0 indicates no monotonic trend existed in the investigated time series, and Ha indicates the presence of monotonic trend in the investigated time series (Tatli 2015).

Where, $S = \Sigma_{i=1}^{n-1} \Sigma_{j=i+1}^{n} Sgn(x_j - x_i), \ldots..(eq.3)$

$$Sgn(x_j - x_i) = \begin{cases} +1, & x_j > x_i \\ 0, & x_j = x_i \\ -1, & x_j < x_i \end{cases} \ldots(eq.4)$$

n = sample size; S = large positive value of S exhibits a strongly increasing trend, whereas the large negative value of S exhibits a strong decreasing trend. When the MK test is applied to a time series with many values, the Z test can be used to determine whether a trend is significant or not significant (Ahmad et al 2015).

$$Z = \begin{cases} \dfrac{s-1}{\sqrt{\dfrac{n(n-1)(2n+5) - \Sigma_{j=1}^{q} t_j (t_j - 1)(2t_j + 5)}{18}}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{s-1}{\sqrt{\dfrac{n(n-1)(2n+5) - \Sigma_{j=1}^{q} t_j (t_j - 1)(2t_j + 5)}{18}}} & \text{if } S < 0 \end{cases} \quad \text{(eq..5)}$$

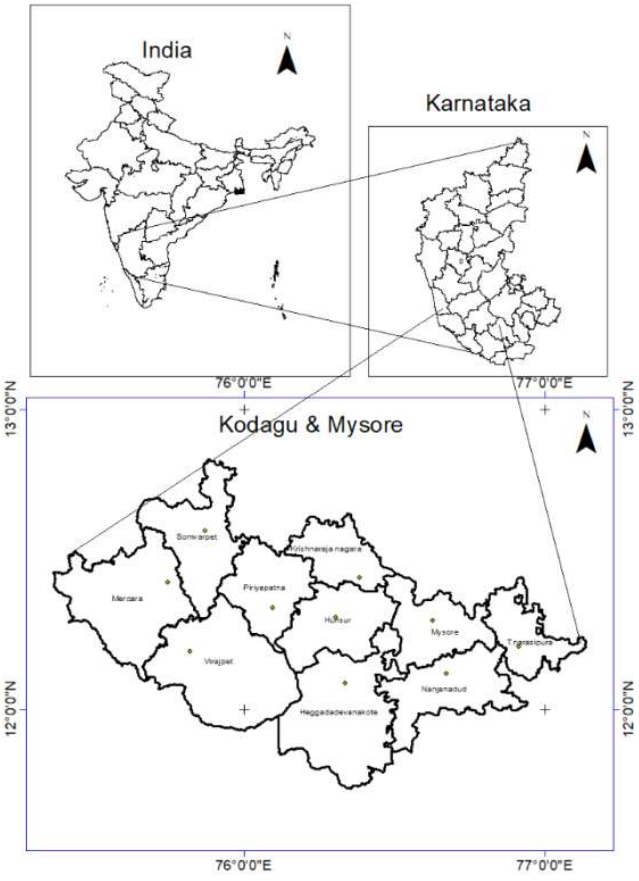


Fig. 1. The study area is depicted on a map

n = sample size, q = number of zero difference groups in the data set, the p-value of 0.05 is used as the significance of a trend. Sen's Slope estimator of rainfall trend is a nonparametric technique applied to evaluate the trends in rainfall data. A positive and negative Sen Slope value indicates increasing and decreasing trends in the time series (Gocic and Trajkovic, 2013).

$$Q_i = \frac{x_j - x_k}{j - k} \; for i = 1,..., N ...(eq.6)$$

The converted yearly Precipitation Departure Z for Each Sub-station is used to calculate the number of wet and dry periods.

$$Z = \frac{X - \mu}{\sigma} .....(eq.7)$$

When x denotes annual precipitation, y denotes annual mean precipitation, and z denotes annual standard deviation. If z 0.5, there was a dry year, and if z 0.5, there was a wet year (Pnevmatikos and Katsoulis 2006).

RESULTS AND DISCUSSION

Descriptive statistics of rainfall data: Madikeri Taluk has the highest average rainfall and Somwarpete has the least in Kodagu District and Heggadadevanakotte recorded the highest T-Narsipura has got the least amount of average rainfall in Mysore District. The Skew values show the rainfall is positively Skewed distribution. The degree of Peakedness (kurtosis) of rainfall distribution indicates a peaked distribution (Nyatuame et al 2014).

Mann Kendall Test (MK): For rainfall series, a positive slope value indicates an upward or increasing trend. The slope with a negative value indicates a downward or decreasing trend in the time series. The positive and negative value implies increasing and declining rainfall trend. Most of the annual precipitation data show the Increasing trend and the Seasonal Precipitation Data also demonstrates an increasing trend. But when it comes to Sen's Slope station Madikeri, Virajapete and Somwarpete of Kodagu district and H.D.Kotte, Hunsur, Mysore Nanjangudu, T-Narsipura Periyapatna Stations of Mysore District exhibits the increasing trend in Sen's Slope for Annual Precipitation Data. The case of seasonal precipitation data which is done for June-Sept month shows the increasing trend for all the taluks, when it comes to Sen's slope Madikeri, Virajapete, Somwarpete of Kodagu, and Krishnarajapuram and Mysore shows the negative trend.

The highest Annual Rainfall was in Madikeri Taluk in the year 1960 and lowest in 2016 and in Somwarpete Taluk highest rainfall was in 2018 and the lowest was in 1987. For the Taluk Virajpete highest rainfall was in the Year 1961 and the lowest was in the year 2016 (Fig. 7).

Annual precipitation concentration index (PCI): Annual precipitation concentration index analysis is performed to calculate the rainfall distribution throughout28-years period for the first half (1961-1989) and the second half of 28 years (1990-2018) values more than 16 in most parts of the Study area especially in the Mysore Region (Nanjangudu, T-Narsipura, Mysore, H.D. Kotte, Hunsur, K.R. Nagara, Periyapatna). This region has got most irregular precipitation concentration and in Kodagu district, almost all the taluks have got strong irregular precipitation (Fig. 3) and for the second half the annual precipitation concentration index spatial patterns differ slightly Heggadadevankotte, Nanjangudu and few Regions of Hunsur got moderate precipitation concentration, whereas, the other than this region has got Irregular and Strong Irregular precipitation Distribution throughout the Study Area. In general, significant changes can be seen in most recent years, the moderate precipitation concentration is detected in the Mysore district and The Kodagu district has had more erratic precipitation distribution.

The seasonal precipitation concentration index: The precipitation concentration index, calculated on a seasonal

Table 2. Statistical tools of rainfall data at the selected stations

Station name	Mean	Std deviation	Skew	Kurtosis	CV
Madikeri	3212.922	707.1795	0.771963	2.045119	0.220105
Virajpete	2446.325	627.1679	1.506094	5.09944	0.256371
Somwarpete	2135.041	533.5571	0.418149	-0.4217	0.249905
H.D. Kotte	837.6356	196.8532	0.08414	-0.85792	0.235011
Hunsur	784.7842	221.6671	0.165828	1.524596	0.282456
Periyapatna	822.4305	203.1267	-0.52754	0.89604	0.246983
Krishnarajanagara	750.2932	240.8797	0.340604	0.530258	0.321047
Mysore	773.3932	220.0671	0.436964	-0.00937	0.284547
Nanjangudu	727.878	201.1097	0.222636	0.04219	0.276296
T-Narsipura	713.8008	187.7974	0.494726	0.358	0.263095

scale (Monsoon Season) from June to September, demonstrates the intricate spatial patterns of precipitation in Karnataka's southern areas. The PCI lower was10.59 and higher 12.28 (1961-1989) and lower value of PCI was10.01 to 11.52 (1990-2018). During the Monsoon (June-September), very few PCI Values is detected for the period (1961-1989) uniform precipitation concentration is detected in Madikeri and some regions of Virajapete (Fig. 3). The precipitation concentration index shows the uniform precipitation distribution and moderate precipitation distribution has been detected in most recent years. In this season the whole study shows only uniform and moderate precipitation distribution. Especially between 1961 and 1989 shows the Uniform precipitation (Low Precipitation) and in the Period 1990-2018, the Precipitation distribution is almost Moderate. Changes in the distribution of Precipitation is analysedas significant (Monsoon Season) and have uniform precipitation distribution over the study area.**T-Test significance:** The T-test has been conducted for the annual and seasonal (June-Sept) to detect the significance level. The T-Test has been carried out for a period total of 57 years. Statistically,a significant difference has been detected for 57 years period. The probability is categorised as follows exceptional likely ($p<0.01$); extremely likely ($p<0.05$); very likely (0.10); very low probability ($p>0.10$) (Fig. 4).**Dry and wet regions:** The dry and wet regions were decided on Z-Values, the total period of 58 years has divided into almost six decade. In the first decade (1960-1970) the very slight negative trend detected with half of the study area was dry

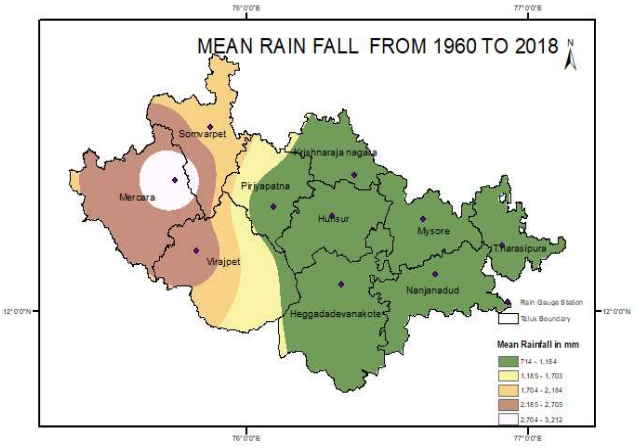


Fig. 2. District having highest average mean and lowest average mean rainfall

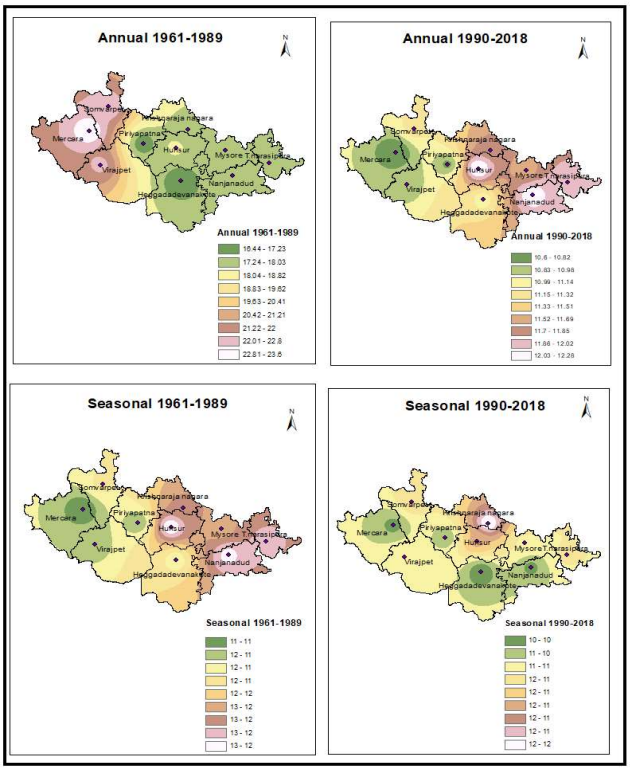


Fig. 3. Precipitation variation of annual 1961-1989 and 1990-2018 and seasonal precipitation variation June-September period (Monsoon month)

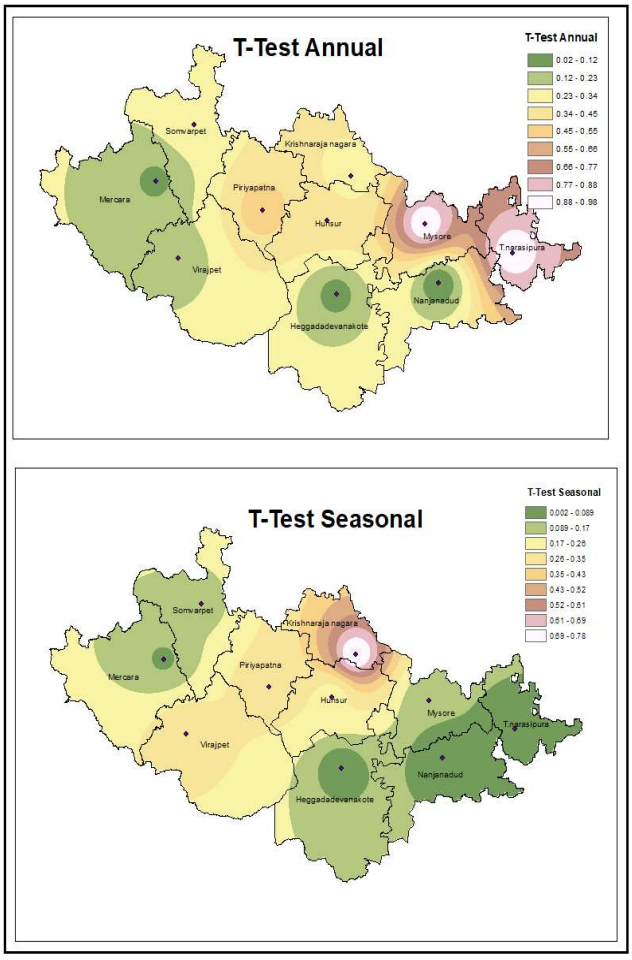


Fig. 4. T-Test significance level for annual and seasonal periods

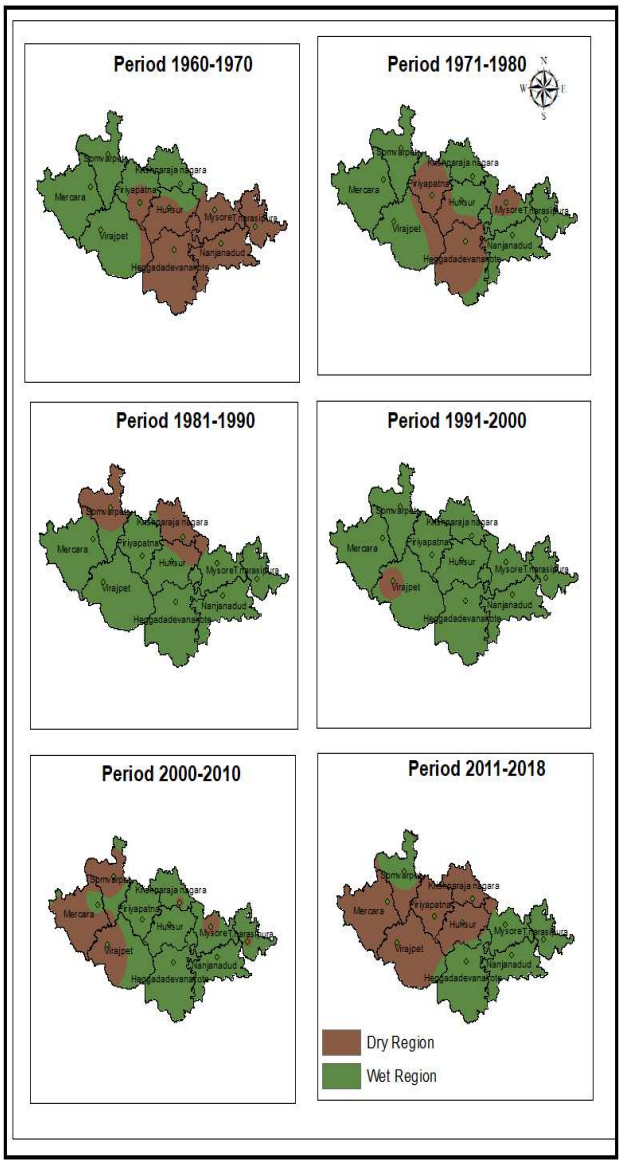
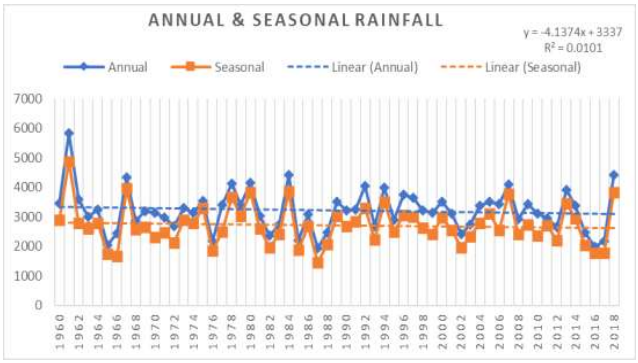
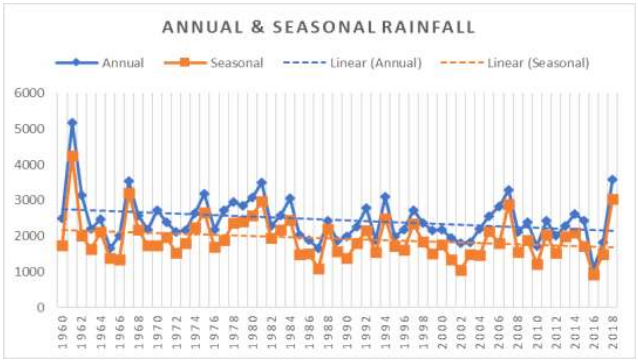


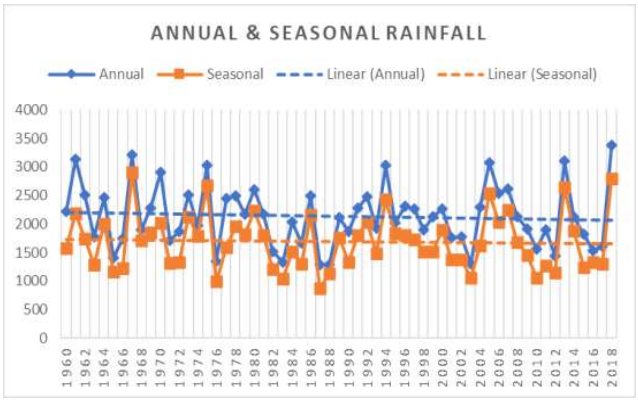
Fig. 5. Variation of rainfall departure (Z-values) dry and wet region over ten years of difference



a. Madikere Taluk



b. Somarwarpete Taluk

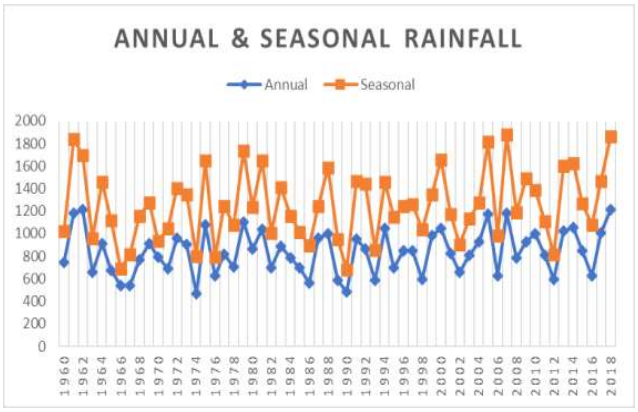


c. Virajapete Taluk

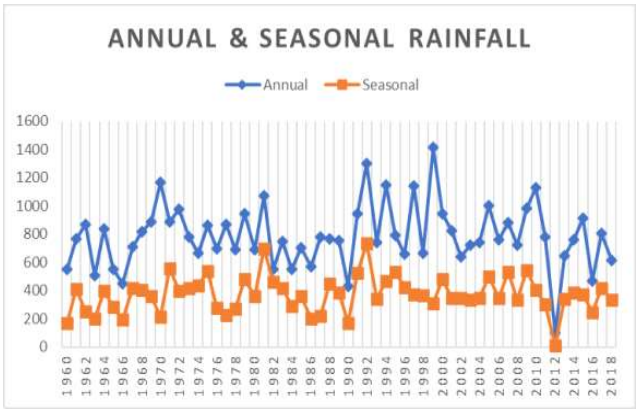
Fig. 6. Annual & seasonal rainfall during 1960-2018

Table 3. Trend analysis of annual and seasonal precipitation

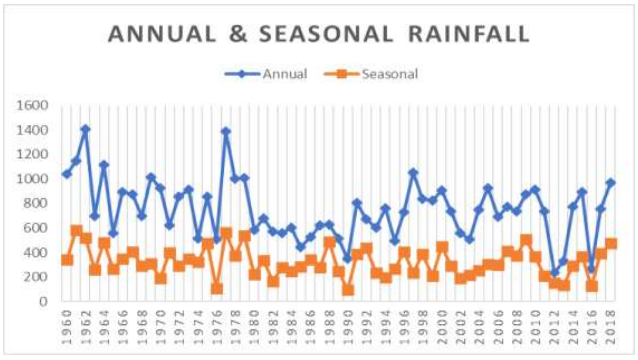
Station	Annual		Seasonal (Monsoon)	
	P value	Sen Slope	P value	Sen Slope
Madikeri	0.676	-1.687	0.008	-0.082
Virajpete	0.069	-7.511	0.132	-28.636
Somwarpete	0.185	-3.852	0.565	-7.433
H.D. Kotte	0.193	2.255	0.338	1.818
Hunsur	0.685	0.646	0.494	3.36
Periyapatna	0.559	0.921	0.460	2.708
Krishnarajanagara	0.089	-3.389	0.059	-5.1
Mysore	0.704	0.606	0.848	-0.504
Nanjangudu	0.031	3.837	0.180	4.715
T-Narsipura	0.468	1.305	0.305	1.153



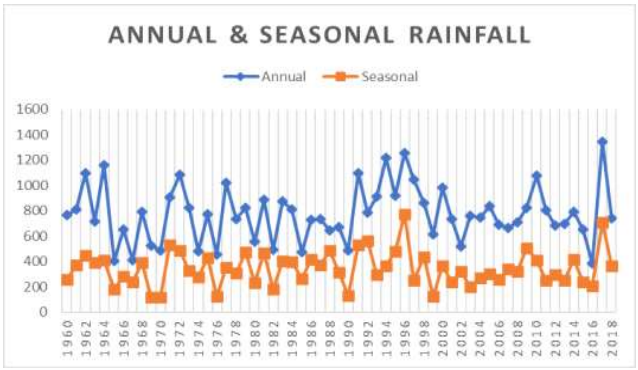
a. Hegaddadevakote



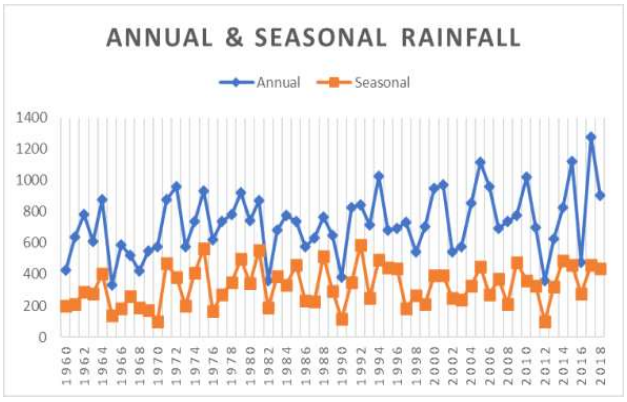
b. Hunsur



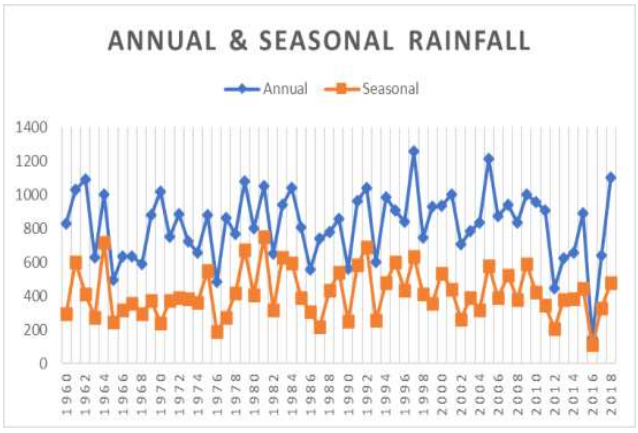
c. Krishnarajanagara



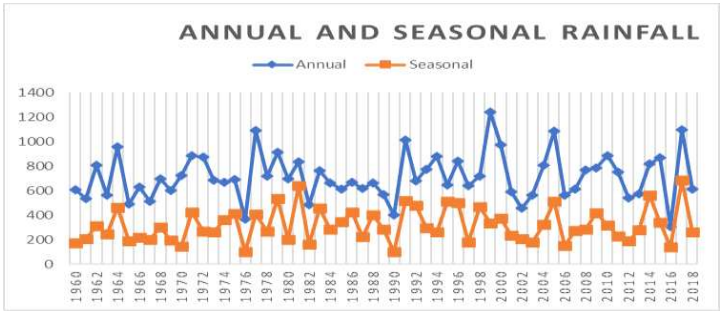
d. Mysore



e. Nanjangudu



f. Periyapatna



g. T-Narsipura.

Fig. 7. Annual & seasonal rainfall throughout 1960-2018

and another was wet. (Fig. 5, 8).The variation of rainfall in the period (1971-1980) was mostly the wet Periods (Fig. 8b). The period (1981-1990) was detected with all the taluk were dry and drought-prone area for this couple of years (Fig. 9) and next decade period of (1991-2000) were detected with full wet regions considering most Wet spell has taken place and the trend was be positive (Fig. 9b). In the period (2001-2010) detected to be almost all wet spell with some regions showed up with dry region also so the trend was decreasing when compared to last decade (Fig. 10a) and Last 8 years spell (2011-2018) were detected with decreasing trend of Rainfall variation (Fig. 10b).

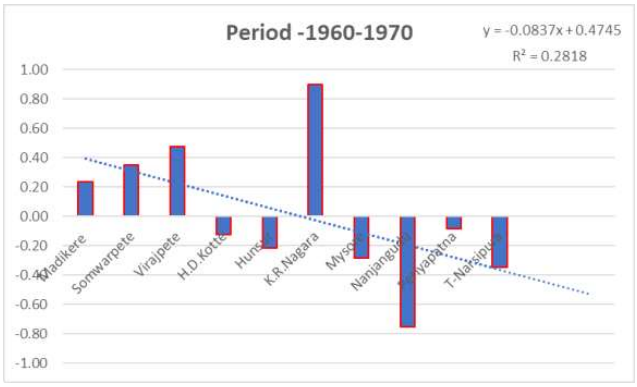


Fig. 8a. Dry and wet regions in period (1960-1970)

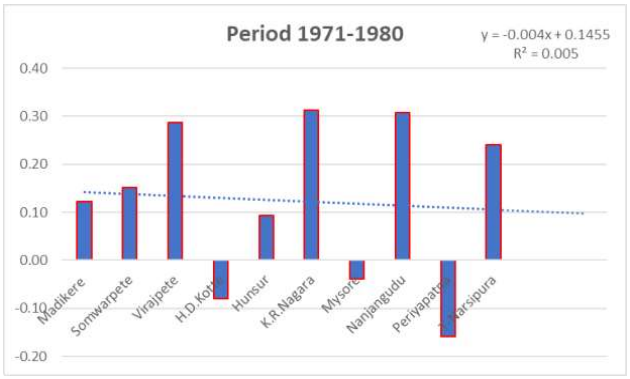


Fig. 8b. Dry and wet regions in period (1971-1980)

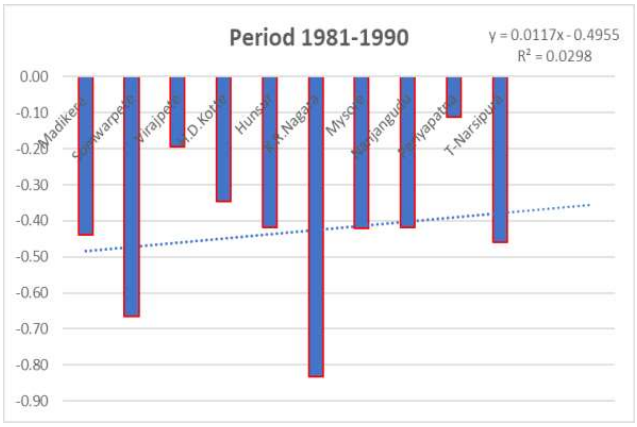


Fig. 9a. Dry and wet regions in period (1981-1990)

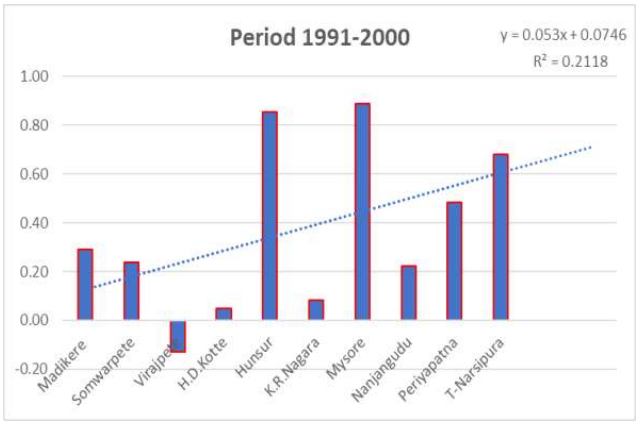


Fig. 9b. Dry and wet regions in period (1991-2000)

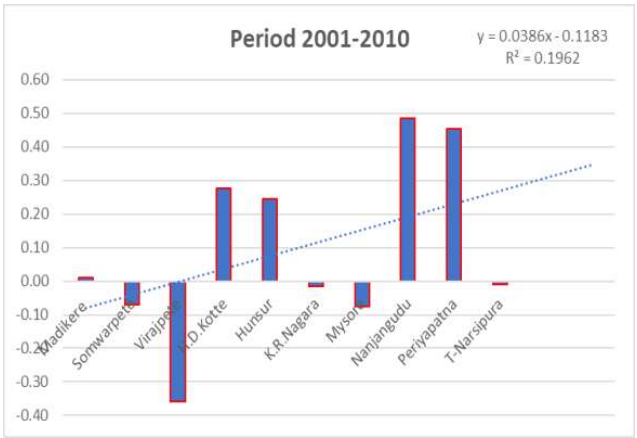


Fig. 10a. Dry and wet regions in period (2001-2010)

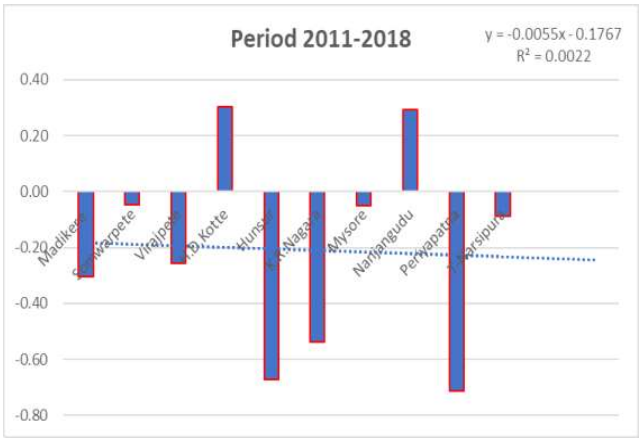


Fig. 10b. Dry and wet regions in period (2011-2018)

CONCLUSION

The study has used Precipitation Concentration Index and Non-Parametric Man-Kendell Trend analysis for Annual and Seasonal Periods of study Area from 1960 through 2018 total of 58 Years. The study was carried out for 10 Taluk's of Kodagu and Mysore District to detect the trends in Annual and Seasonal Precipitation Data.

Based on the discussion above, it may be concluded that

- The annual rainfall values seems to be increasing in part of study area adjoining to the Western Ghats and their magnitude is not significant.
- The seasonal precipitation Concentration Index (PCI) analysis for the period 1990-2018 indicate the rainfall pattern is lineating towards moderate non-uniform distribution.

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