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Trend Analysis of Rainfall for the Chaliyar Basin, South India

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Abstract Climate change is recognized to be one of the most serious challenges facing mankind today. Main parameters that are closely related to the climate change are temperature, precipitation and runoff. Knowledge on the spatial variability and temporal trends of mean rainfall is essential for efficient management of water resource and agriculture. Therefore, there is a growing need for an integrated analysis that can quantify the study of climate variability & its arising consequences on water resources. We have analyzed the rainfall data of the Chaliyar river basin, a larger river basin in Southern India which plays a significant role in agricultural development and consequently in the overall growth of Kerala.

In the present study, to analyze the trends of the rainfall series of each individual station, the popular statistical methods; simple regression method (parametric), Mann-Kendall test and Sen's estimator of slope method (non-parametric) have been applied, among which Mann Kendall test has been used to detect significance of the trends in the time series of the precipitation & Sen's slope estimator has been used to find out the magnitude of the detected trend. Monthly precipitation records of four rain gauge stations (Ambalavayal, Kalladi, Manjeri, Nilambur) of Chaliyar river basin, kerala collected for the period 1993 to 2012 have been used for analysis of rainfall trend on seasonal and annual scale. These trend analysis results are very important for effective water resources Planning and management.

Keywords: Climate change, Precipitation, Chaliyar river basin, Mann-Kendall Test, Sen's Estimator of slope method, Regression method, Trend analysis

I. INTRODUCTION

Climate is a measure of the average pattern of variation of meteorological parameters (precipitation, humidity, temperature and others) in a given region over long period of time. Rising amount of greenhouse gases in the atmosphere can cause drastic changes in climate.

Climate change may be described as a change in the climate which can be recognized by changes in the statistical distribution of weather variables for a longer duration of time. Climate change is expected to have an impact on hydrological systems because of changes in precipitation, temperature and evapotranspiration, which are the primary input variables for the terrestrial part of the hydrological cycle. The fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC) says that the annual average river runoff and water availability are projected to increase by 10-40% at high latitudes and in some wet tropical areas and decrease by 10-30% over some dry regions at mid-latitudes and in the dry tropics, some of which are presently water-stressed areas. Climate variability and change are expected to alter regional hydrological conditions & hydrological cycle and result in a variety of impacts on water resource systems throughout the world.

Quantitative estimation of the hydrological effects of climate change will be helpful in understanding potential water resource problems and making better planning decisions. With economic development and increase in population, the conflict between water use and water supply will become increasingly grave in the future. Understanding the possible impacts of climate change on water resources is of utmost importance for ensuring their appropriate management and utilization.

Temperature and precipitation are the key parameters of climate and variations in the pattern of these variables can affect human health, economic growth and development. An increase or decrease in precipitation pattern can result in the increase in the frequency of floods, instances of droughts and impact on water quality. Increase in Earth's temperature results in an increase in evaporation and cloud formation to occur, which increases precipitation, indicating that temperature and precipitation are interconnected. Therefore, it is necessary to carry out statistical analysis to find the trend for the most important important climatic parameters i.e. precipitation. The statistical analyses used in the present study are the Mann Kendall Test (Mann 1945, Kendall

1975) and Sen's Slope estimator (Sen, 1968). The Mann Kendall test has been used to detect trends in the time series of the precipitation and temperature. Sen's slope estimator has been used to find out the magnitude of the detected trend.

Possible climate change, in the sense of variations in temperature and, above all, in the quantity and intensity of precipitation (Eckhardt and Ulbrich 2003), may have a marked influence on the volume of water that comprises aquifer recharge (Scibek and Allen 2006), either increasing or decreasing it. Determining just how these variations affect natural water recharge to aquifers is thus a question of crucial importance, as water recharge constitutes a basic element in the water balance, and knowledge and evaluation of this parameter is absolutely essential to the efficient management of water resources (Sophocleous 1991 in Marechal et al. 2006).

Statistic and probability plays an important role in scientific and engineering community (Ayyub and McCuen, 2011) because statistical tools help to detect spatial and temporal trends for hydrological and environmental studies. Major schemes or projects are formulated based on the historical behaviour of environment under uncertain climatic conditions. Therefore, a study of trend assists to investigate the overall pattern of change over time in hydro-meteorological variables especially for water resources project on temporal and spatial scales.

Rainfall has been widely considered as one of the starting point towards the apprehension of climate change courses. Various studies have indicated due to climate change, rainfall pattern is most likely to change which would have adverse impacts on lives and livelihoods of millions of people. Analysis of the general rainfall trend is vital in understanding the underlying features, for the purpose of forecasting and in identifying the changes and impacts that are very crucial for an agro-based economy like the one of India.

Trends in data can be identified by using either parametric or non-parametric methods, and both the methods are extensively used. Testing the significance of observed trends in hydro-meteorological time series has received a great attention recently, especially in connection with climate change. The changing pattern of rainfall deserves urgent and systematic attention for planning, development, utilisation and management of water resources.

Several researchers have studied the Precipitation trend analysis (for example, P. P. N. Raj & P. A. Azeez 2010; Arun Rana et al. 2011; Telemu Kassile 2013; Sanda Rajitha & A.C. Narayana 2014; Zaheed Hasan et al. 2014; S. Adarsh and M. Janga Reddy 2014; Chithra N R & Santosh G Thampi 2015). Sanda Rajitha & A.C. Narayana (2014) provides an assessment of climate change variability based on analysis of historical data of rainfall and temperatures at Warangal district, Andhra Pradesh for the period of 1960-2012 & determined long term changes in rainfall by Man-Kendall, Sen's slope and regression analysis. Zaheed Hasan et al. (2014) examines temporal variability of precipitation for the region of south-east coast of Bangladesh over the period of 1949-2011 & used Mann-Kendall test and the Sen's slope estimators to detect rainfall trends and to understand magnitude of changes. P. P. N. Raj & P. A. Azeez (2010) examines the general trend of rainfall in the Palakkad plains (South India) using monthly rainfall data collected from four rain gauge stations available in the area & reported that as the years proceed, the annual rainfall pattern of all the stations showed a trend of significant decline. Chithra N R & Santosh G Thampi (2015) worked to statistically detect climatic change signals in the monthly precipitation data of the Chaliyar river basin, Kerala, India & evaluates the f actors contributing to it.

II. STUDY AREA

The study area is the Chaliyar river basin in Kerala, India, situated between 11^0 30'N and 11^0 10'N latitudes and 75^0 50'E and 76^0 30'E longitudes falling in Survey of India (SOI) degree sheets 58A and 49M. Chaliyar River forms the third largest river in Kerala, originates from the Elambalari hills, Nilgiri District of Tamil Nadu, at an elevation of about 2066m above mean sea level (MSL). Chaliyar is a perennial river & flows along the northern boundary of Malappuram district through Nilambur, Mambad, Edavanna, Areakode and Feroke & the river joins the Lakshadweep Sea south of Kozhikode near Beypore after flowing over a distance of about 169 kms in the name "Beypore" River. This river has a total drainage area of 2918km^2 out of which 2530km^2 lies in Kerala State and the remaining area falls in Tamil Nadu. The watershed is predominantly agricultural lands (74.26 %) and forests (14.21 %). The remaining area comprises urban areas, rocky areas and water bodies.

The basin enjoys a tropical humid climate with sweltering summer and high monsoon rainfall, on an average about 3000 mm of rainfall occurs annually in the basin. The principal rainy seasons are the southwest (June-September) and northeast (October-November) monsoons in India. The pre-monsoon months (March-May) are characterized by major thunderstorm activity and the winter months (December-February) by minimal cloudiness and rainfall (Ananthakrishnan et al. 1979). Summer (southwest) monsoon (June-September) accounts for a major part of the average annual rainfall (> 300 cm), whereas the winter monsoon (October-January) accounts for about 50-60 cm rainfall. Temperature in the region ranges between 23° and 37°C.

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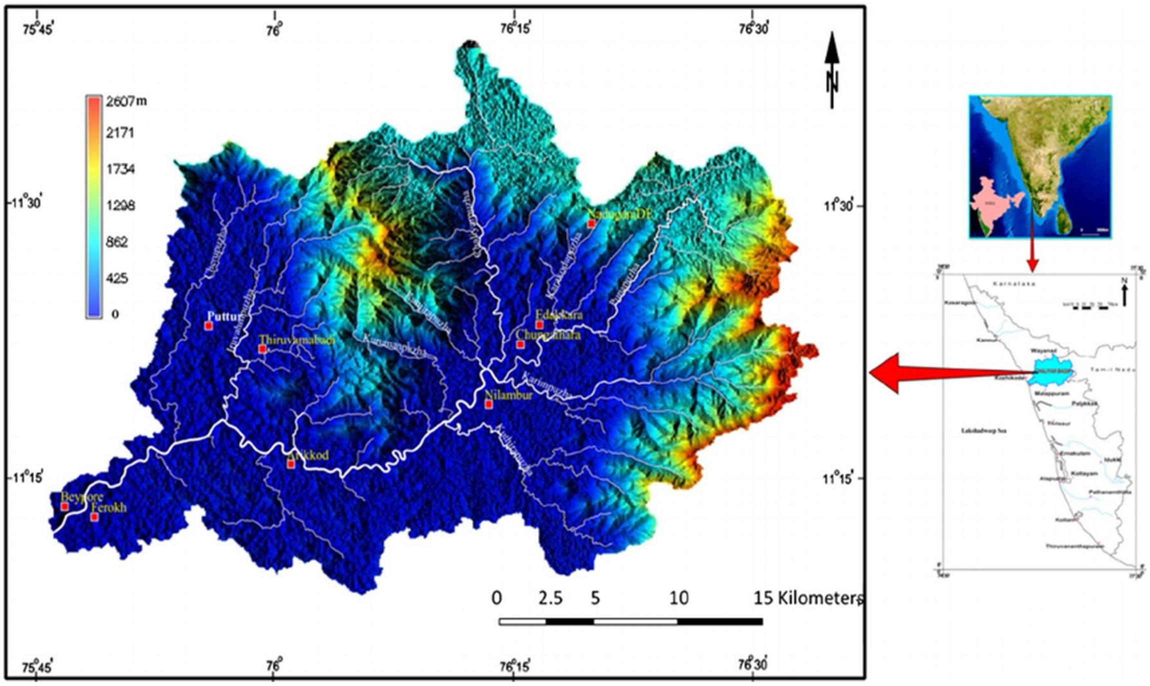


Figure 1: Digital elevation model (DEM) aspect map of the Chaliyar River drainage basin. Source: Google Earth.

III. MATERIALS AND METHODS

The Rainfall data has been collected from CWRDM Kerala. It was collected for 10 different stations for different durations such as 1901 to 2012 & 1993 to 2011 etc, but to maintain continuity & consistency in the data, only the monthly rainfall data of the four stations namely Ambalavayal, Kalladi, Manjeri & Nilambur for the period 1993 to 2012 have been used for analysis of rainfall trend on seasonal and annual scale. In our study, both trend analysis methods were used i.e. Parametric (Regression analysis) and non-parametric (Mann-kendall & sen slope) were used.

A. Trend

The term trend refers to "general tendency or inclination". In a time series of any variable, trend depicts the long smooth movement lasting over the span of observations, ignoring the short term fluctuations. It helps to determine whether the values of a series increase or decrease over the time. In statistics, trend analysis referred as an important tool and technique for extracting an underlying pattern of behaviour or trend in a time series which would otherwise be partly or nearly completely hidden by noise.

Statistic and probability plays an important role in scientific and engineering community (Ayyub and McCuen, 2011) because statistical tools help to detect spatial and temporal trends for hydrological and environmental studies. Major schemes or projects are formulated based on the historical behaviour of environment under uncertain climatic conditions. Therefore, a study of trend assists to investigate the overall pattern of change over time in hydro-meteorological variables especially for water resources project on temporal and spatial scales. Trends in data can be identified by using either parametric or non-parametric methods, and both the methods are extensively used. The parametric methods are considered to be more powerful than the non-parametric methods only when the data series is normally distributed, independent and homogeneous variance (Hamed and Rao, 1998). Conversely, non-parametric methods are more advantageous as they only require the data to be independent and are also less sensitive to outliers and missing values.

Trend analysis of time series consists of magnitude of trend and its statistical significance. In general, the magnitude of a trend in a time series is determined either using regression analysis (parametric test) or using sen's estimator method (non-parametric method) & significance is determined by Mann-Kendall test (non-parametric method).

In the present study, to analyze the trends of the rainfall series of each individual station, the popular statistical methods; simple regression method (parametric), Mann-Kendall test and Sen's estimator of slope method (non-parametric) have been applied. The systematic approach has been adopted to determine the trend in three phases. Firstly, a simple linear regression method to test the long term linear trend, secondly, non-parametric Mann-Kendall test for the presence of a monotonic increasing or decreasing trend in the time series and Thirdly, the non-parametric Sen's estimator of slope test to determine the magnitude of the trend in the time series of meteorological parameter i.e. rainfall at the basin scale. These are described in the following sections.

B. Regression model (Parametric Test)

One of the most useful parametric models to detect the trend is the "Simple Linear Regression" model. The correct application of this method requires the variables to be normally distributed and temporally and spatially independent. The method of linear regression requires the assumptions of normality of residuals, constant variance, and true linearity of relationship (Helsel and Hirsch, 1992).The model for Y (e.g. precipitation) can be described by an equation of the form:

$$y = m x + c \qquad \text{………(1)}$$

Where, x = time (year), m = slope coefficient and c = least-squares estimate of the intercept

The slope coefficient indicates the annual average rate of change in the hydrologic characteristic. If the slope is significantly different from zero statistically, it is entirely reasonable to interpret that there is a real change occurring over time. The sign of slope defines the direction of the trend of the variable: positive sign indicates a rising trend while negative sign indicates a falling trend.

C. Sen's Estimator of Slope (Non-Parametric method)

The magnitude of trend in a time series was determined using a non-parametric method known as Sen's estimator (Sen 1968). This method assumes a linear trend in the time series and has been widely used for determining the magnitude of trend in hydro-meteorological time series (Lettenmaier et al., 1994, Yue and Hashino, 2003, Partal and Kahya, 2006). In this method, the slopes (T_i) of all data pairs are first calculated by

$$T_i = \frac{x_j - x_k}{j - k} \quad \text{for } i = 1,2,\ldots,N \qquad \text{……..............(2)}$$

where x_j and x_k are data values at time *j* and *k* (*j* >*k*) respectively. The median of these N values of T_i is Sen's estimator of slope which is calculated as

$$\beta = \begin{cases} T_{\frac{N+1}{2}} & \text{if } N \text{ is odd,} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right) & \text{if } N \text{ is even.} \end{cases} \qquad \text{.......(3)}$$

A positive value of β indicates an upwards (increasing) trend and a negative value indicates a downwards (decreasing) trend in the time series.

D. Mann–Kendall test (Non-parametric test)

Non-parametric trend technique can be adopted in case with the required data to be normally distributed and containing outlier in the data (Helsel and Hirsch 1992; Birsan et al. 2005). The Mann-Kendall test is a non-parametric rank based test for identifying trend in time series data. To ascertain the presence of a statistically significant trend in hydrologic climatic variables such as temperature, relative humidity, precipitation and stream flow with reference to climate change, the non-parametric Mann–Kendall (MK) test has been employed by a number of researchers (Yu et al. 1993; Douglas et al. 2000; Burn et al. 2004). The MK method searches for a trend in a time series without specifying whether the trend is linear or non-linear. The MK test was also applied in the present study. The MK test checks the null hypothesis Ho of no trend versus the alternative hypothesis H1 of the existence of an increasing or decreasing trend. The statistic *S* is defined as (Salas 1993):

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \text{sgn}(x_j - x_i) \qquad (4)$$

Where *N* is the number of data points. Assuming $(x_j - x_i) = \theta$, the value of sgn(θ) is computed as follows

$$\operatorname{sgn}(\theta)=\begin{cases}1 & if \quad \theta>0,\\ 0 & if \quad \theta=0,\\ -1 & if \quad \theta<0.\end{cases} \qquad (5)$$

This statistic represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples (*N*> 10), the test is conducted using a normal distribution (Helsel and Hirsch, 1992) with the mean and the variance as follows:

E[S] = 0 (6)

$$Var(S)=\frac{N(N-1)(2N+5)-\sum_{k=1}^{n}t_k(t_k-1)(2t_k+5)}{18} \qquad (7)$$

Where, *n* is the number of tied (zero difference between compared values) groups and t_k is the number of data points in the *k*th tied group. The standard normal deviate (Z-statistics) is then computed as (Hirsch *et al*. 1993):

$$Z=\begin{cases}\dfrac{S-1}{\sqrt{Var(S)}} & if \quad S>0\\ 0 & if \quad S=0\\ \dfrac{S+1}{\sqrt{Var(S)}} & if \quad S<0.\end{cases} \qquad (8)$$

If the computed value of $|Z| > z_{\alpha/2}$, the null hypothesis H_0 is rejected at the α level of significance in a two-sided test. In this analysis, the null hypothesis was tested at 95% confidence level.

IV. RESULTS & DISCUSSION

The anomalies of rainfall and their trends were determined for all the stations considered in the study. The rainfall anomalies (deviation from mean) were then plotted against the time (in Year) and the linear trends observed in these have been represented graphically. Anomalies in seasonal and annual rainfall and their trends for the stations within the study area are shown graphically in Fig. 2 to 5. The magnitude of the seasonal and annual trend in the time series as determined using the Sen's estimator is given in Table.2

A. Annual Trend

From figure 2 to 5, it is indicated that, if we talk about results obtained from the parametric approach, the annual rainfall indicates rising trend in Ambalavayal and Kalladi station increasing at the rate of 18.72 mm/year & 57.18 mm/year respectively, while Manjeri & Nilambur indicates falling trend decreasing at the rate of 30.2 mm/year & 5.76 mm/year respectively.

And if we talk about the result obtained from non parametric approach, no significant trend is observed in any of the station (as per Z statistic of Mann Kendall), but still precipitation increases at the rate of 19.5 mm/year & 54.33 mm/year in Ambalavayal & kalladi stations & decreases at the rate of 17.38 mm/year & 0.335 mm/year (as per sen's estimator).

B. Seasonal Trend

From table 1, Seasonal trend for all the four stations by parametric method (linear regression) is described by the following table in which the magnitude of regression slope or 'm' denotes the rate of increase or decrease of seasonal precipitation in mm/year while the sign of 'm' denotes the nature of trend i.e. falling or rising.

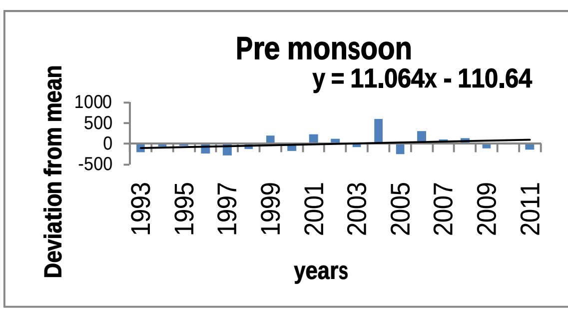
Whereas the seasonal trend for all the four stations by non parametric method (Mann Kendall & Sen's estimator) is described by the table 2 in which the value of Z statistic denotes the significance of trend i.e., whether the trend is significant or not. If the value of z does not lie within the range 1.96<z<1.96 at 95% significance, then the trend is significant, else the trend is not significant & the magitude of Sen slope denote the rate of increase or decrease in seasonal or annual precipitation in the units of mm/year while the sign of sen slope denotes the nature of trend i.e. falling or rising.

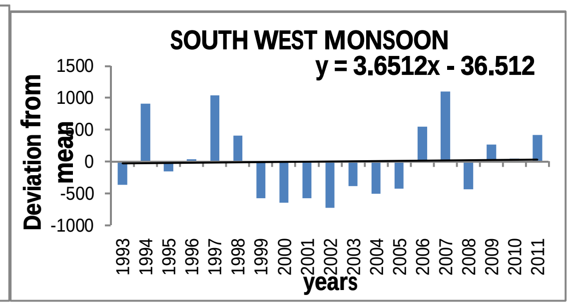
Table 1: Seasonal trends in rainfall of different stations in Chaliyar basin

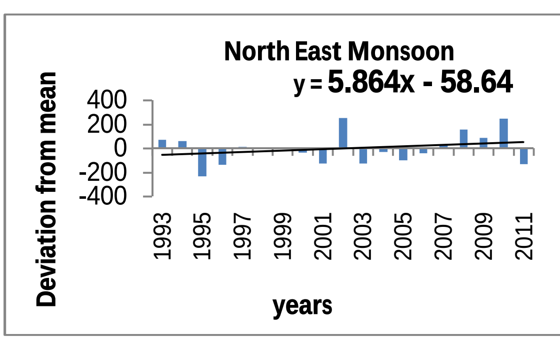
Season	Station	Trend	Magnitude
Premonsoon (Mar - May)	Ambalavayal	Rising	11.06
	Kalladi	Rising	5.785
	Manjeri	Falling	-5.422
	Nilambur	Rising	0.607
South west Monsoon (Jun - Sept)	Ambalavayal	Rising	3.651
	Kalladi	Rising	55.94
	Manjeri	Rising	16.59
	Nilambur	Rising	1.909
North east Monsoon (Oct - Nov)	Ambalavayal	Rising	5.864
	Kalladi	Falling	-2.529
	Manjeri	Rising	6.638
	Nilambur	Falling	5.739
Winter (Dec - Feb)	Ambalavayal	Falling	-2.091
	Kalladi	Falling	-1.962
	Manjeri	Rising	1.572
	Nilambur	Falling	-2.631

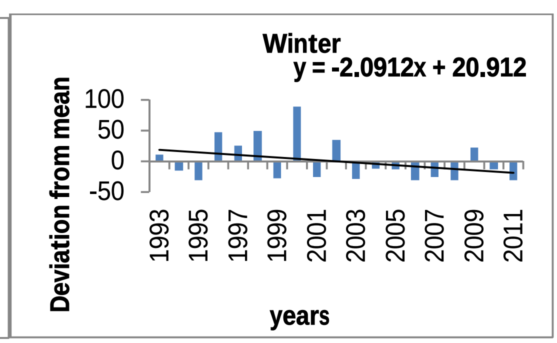
Table 2: SEN estimator of slope (mm/year) & Mann Kendall Z statistics for significance of trend

Station	Premonsoon		South west Monsoon		North east Monsoon		Winter		Annual	
	Z statistic	Sen slope	Z statistic	Sen slope	Z statistic	Sen slope	Z statistic	Sen slope	Z statistic	Sen slope
Ambalavayal	1.36	13.892	0.08	1.25	1.14	7.9	-0.87	-1	0.76	19.5
Kalladi	0.38	3.05	0.76	45.244	0.53	5.888	-0.49	-0.6	1.06	54.329
Manjeri	-1.21	-2.5	-0.42	-12.992	-0.84	-4.667	-0.93	-0.353	-0.77	-17.38
Nilambur	0.14	0.36	-0.14	-0.278	-0.49	-2.869	-1.53	-1.086	0	-0.335









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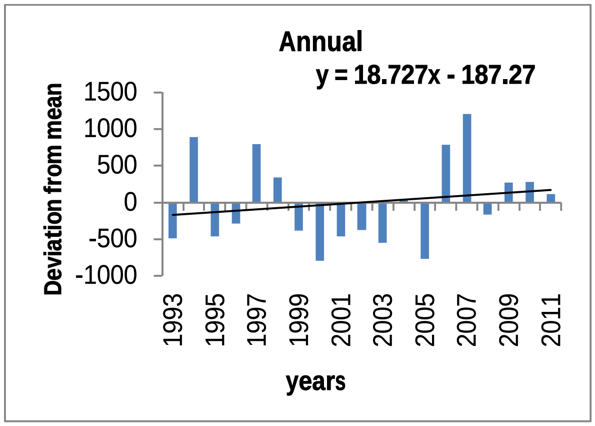

Figure 2: Rainfall Trend of Ambalavayal Station

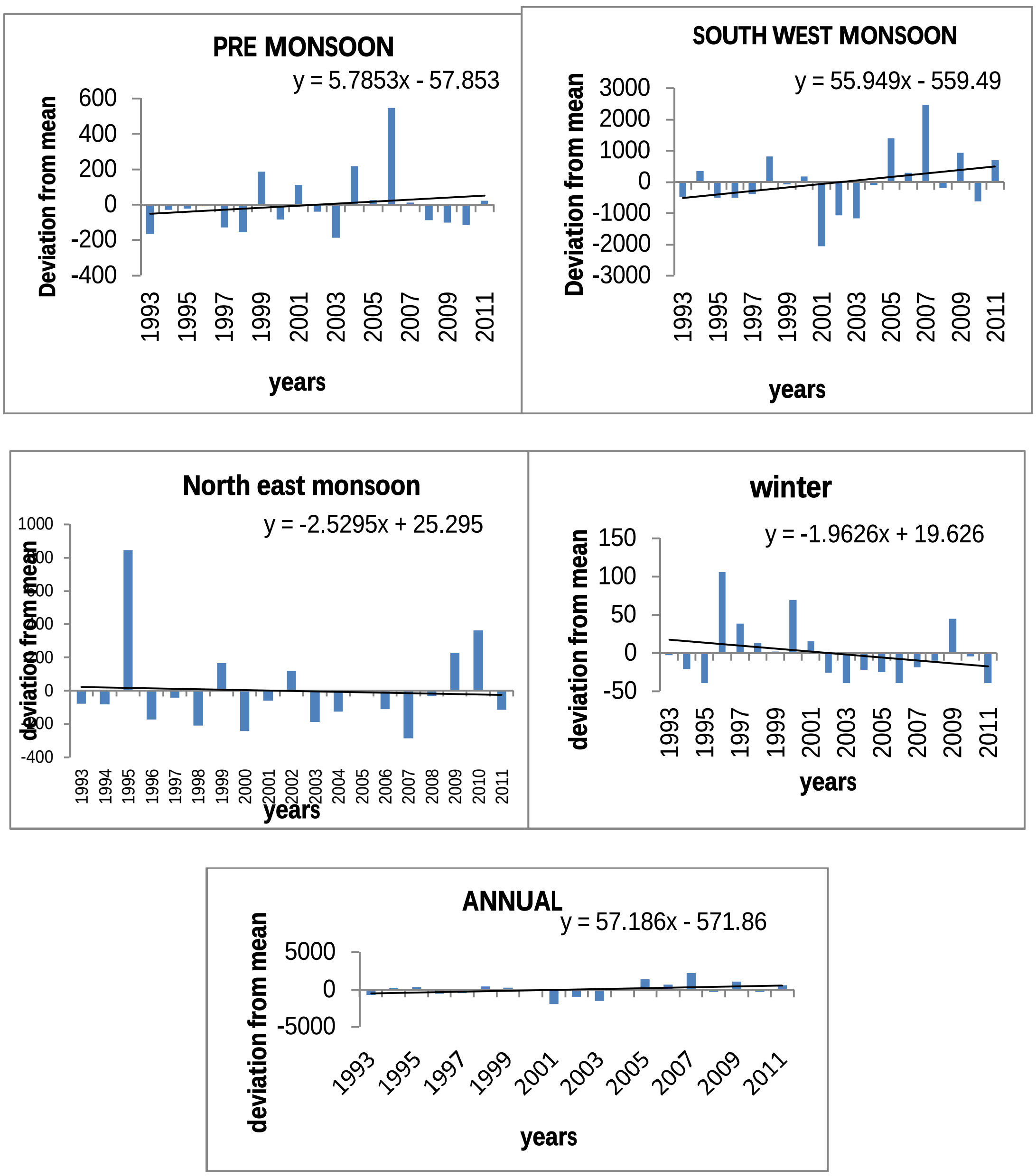

Figure 3: Rainfall Trend of Kalladi Station

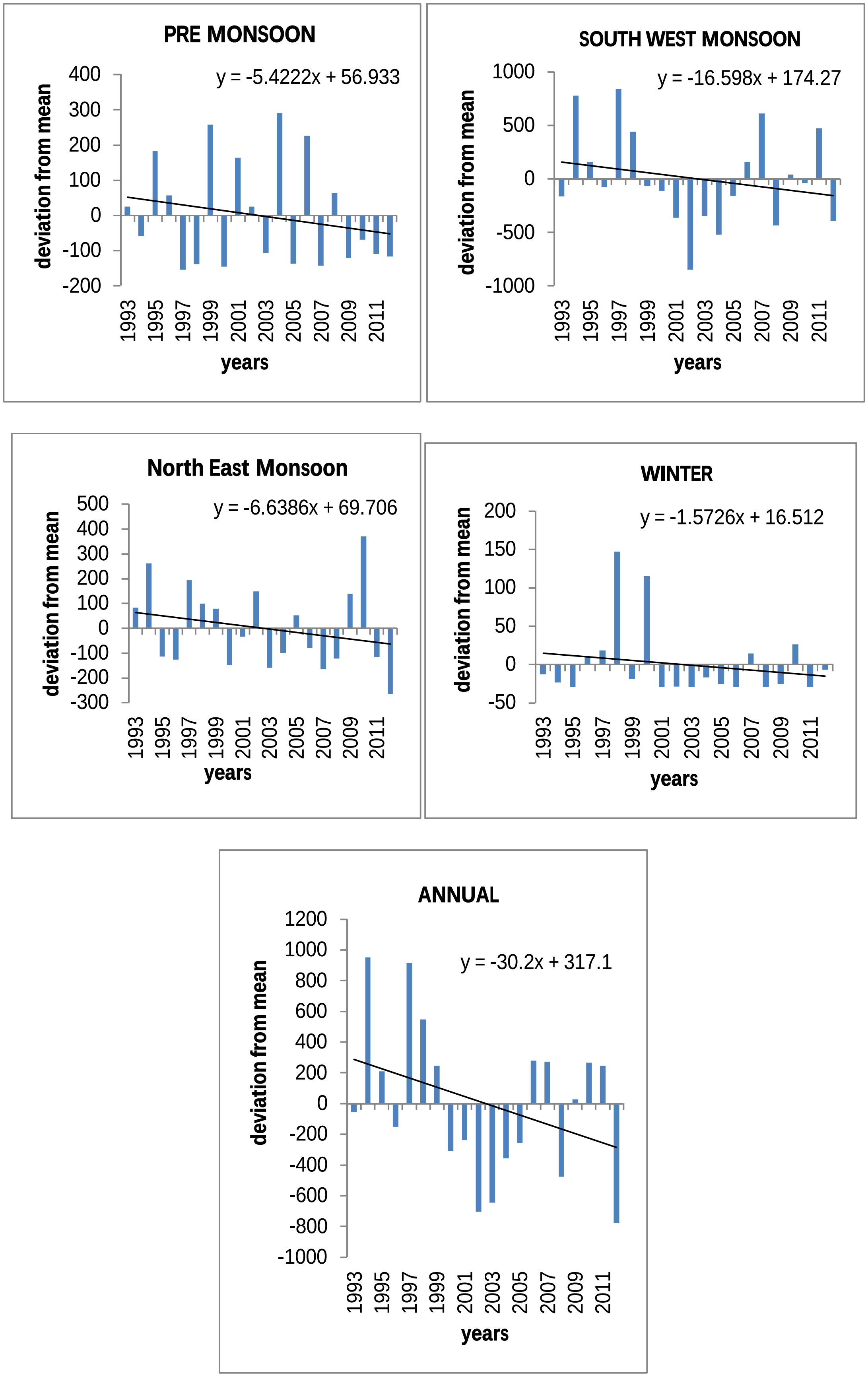

Figure 4: Rainfall trend of Manjeri station

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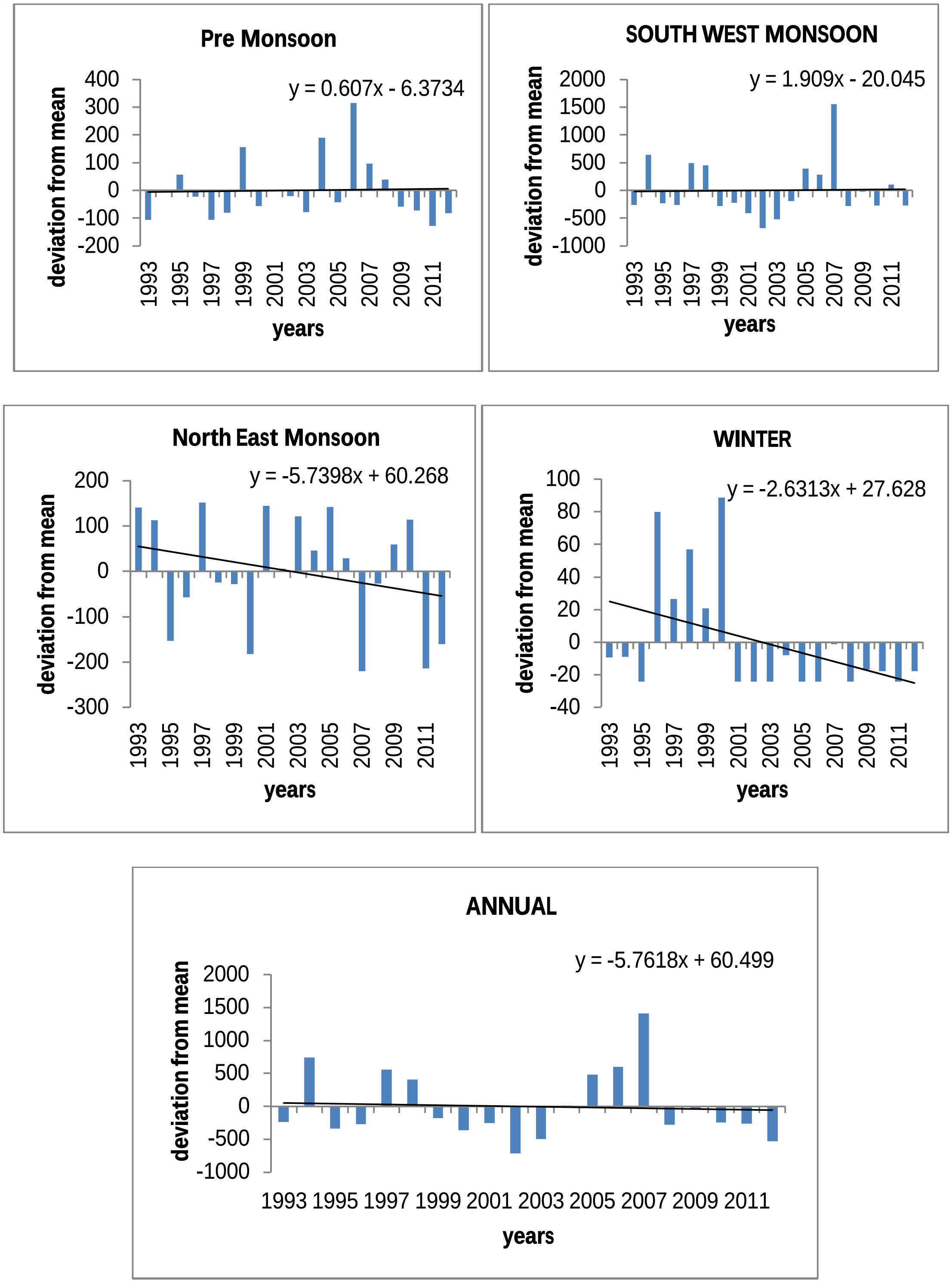

Figure 5: Rainfall trend of Nilambur station

V. CONCLUSION

The meteorological analysis comprising of rainfall variability trends and drought characterization were carried out for Chaliyar basin. Any change in rainfall and its pattern highly influences stream flow downstream. Thus detection of trend and the magnitude of variation is essential. Thus an investigation of the spatial and temporal variation of rainfall and its trends are essential for optimal planning and management of water resources of a region. The rainfall trend analysis conducted at four different stations in the basin at monthly, seasonal and annual scales using non-parametric tests (Mann Kendall & Sen slope) showed an increasing and decreasing trends for the period of 1993 to 2011, even though statically insignificant at 95 % level of confidence . On the other hand Parametric test (Regression analysis) identified some negative and positive trend for all the four stations at seasonal and annual scale. These trend analysis results are very important for effective water resources Planning and management.

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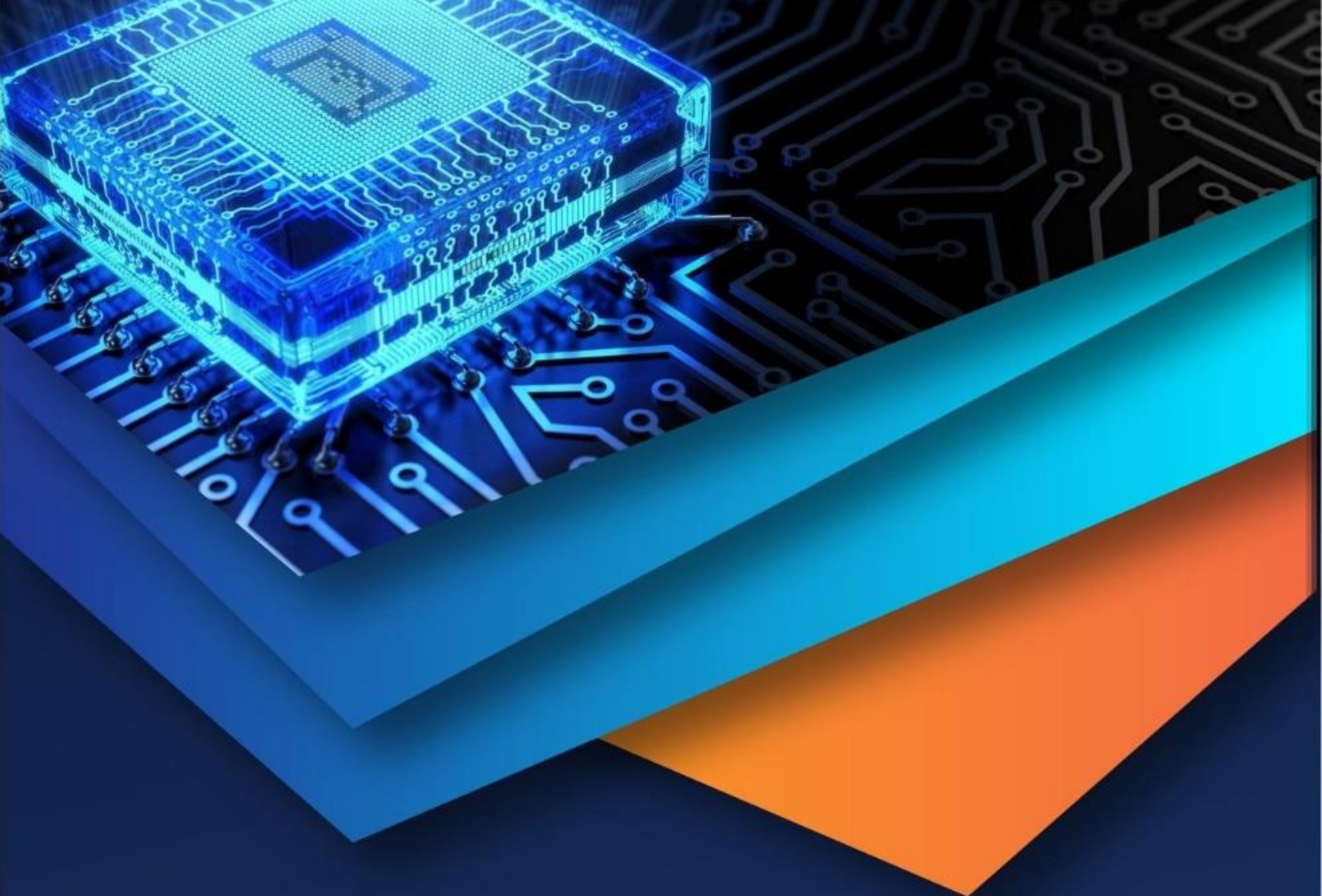

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