QUANTITATIVE ASSESSMENT OF CLIMATE CHANGE IN KERALA

THESIS

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STATISTICS

By

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CERTIFICATE

This is to certify that the work presented in this thesis entitled "QUANTITATIVE ASSESSMENT OF CLIMATE CHANGE IN KERALA" submitted to the University of Calicut for the award of the degree of Doctor of Philosophy in Statistics is a bonafide research work carried out by Ajitha T.K under my supervision and guidance in the Department of statistics, Farook College, Kozhikode. The results embodied in this thesis have not been included in any other thesis submitted previously for the award of any degree or diploma.

Dr. P. AnilKumar
(Research Guide)

DECLARATION

I hereby declare that embodied in this thesis entitled “Quantitative assessment of climate change in Kerala” is the result of investigations carried out by me in the Department of Statistics, Farook college, Kozhikode, University of Calicut under the supervision and guidance of Dr. P. Anilkumar, Associate Professor, Department of Statistics, Farook college, Kozhikode . The thesis contains no material which can be accepted for award of any degree or diploma in any of the University or Institution and to the best of my knowledge and belief, it contains no material previously published by any other person, except where the due references are made in the text of the thesis.

Farook   Ajitha T. K.
10- 04 - 2018

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AJITHA T.K

Dedicated to my Parents

and my lovely

grand daughters

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1 INTRODUCTION

Climate change is one of the major issues being faced by our planet. Main reason for this is presence of greenhouse gases viz., carbondioxide, methane and nitrous oxide which leads to global warming. Burning of fossil fuels, mainly by automobiles and in thermal plants for power generation, contributes the major share of these gases. Role of massive deforestation also is considerable in increasing the changes in climate (Saha, 2012). In order to face it, India has announced a National action plan on climate change in 2008. Two of the important fields in this were National Water Mission and National Mission on climate change for Strategic knowledge.

For the last 20 years, discussions are progressing on the impacts of climate change, worldwide. Recent observations reveal that global warming and changes in climate are at a faster rate, now. Scarcity of fresh water, increase in sea level, vector-borne diseases, change in flowering time and uncertain agricultural productions etc. are some obvious examples of this change.

Climate change can affect agriculture in many ways such as productivity in terms of quality and quantity of crops, agricultural practices, changes in irrigation conditions and usages of fertilizers, herbicides and insecticides, environmental effects like frequency and intensity of soil drainage, erosion and reduction of crop diversity, adaptation i.e., development of more competitive organisms such as flood resistant or salt resistant varieties of rice and so on (Saha, 2012).

A warmer climate may change the intensity and timing of rainfall. Since air at higher temperature can contain more moisture, evaporation of surface moisture will increase which can result in increasing the rainfall and snowfall events. Decrease in soil moisture will increase temperature due to solar radiation which in turn will cause longer and more severe drought. Decrease in rainfall and global warming will certainly affect the ground water table because of reduction in water recharge. Decrease in winter precipitation will reduce the total seasonal precipitation being received during December-February and can impose greater water stress. Intense rain for a few days will result in increased frequency of floods. Monsoon rain also will be lost as direct run-off. This will decrease the ground water recharging potential. Increased rainfall amounts and intensities will lead to greater rates of soil erosion.

Thus Climate change, which is a present reality, would seriously affect earth's atmospheric system. To overcome this crisis and adopt suitable preventive measures, an estimate of magnitude of climate change is essential. The only tool available in the present situation is to quantify the climate change using climate models. These models can mimic and project the future climate scenarios according to the efficiency of the model selected and applied. (Chakrapani, 2014)

A comprehensive basis for the climate change scenario is available in the reports of inter-governmental panel for climate change (IPCC 2007). According to these reports, mean air temperature is likely to be increased by $2.5^{o}C$ during the next century. The probable sea level rise is about one meter. The impacts of the climate change are very severe and produce significant ill effects to the whole earth and living beings. So, a correct assessment of climate change is a need of the hour.

The climate change can be studied globally or locally. But, to have more realistic adaptive measures, State-wise or region-wise studies are required. The main difference between a weather and climate model is that the weather forecast can be driven by the basic dynamics of the system. Whereas the long term climate system is realized from the changes in the radiation forcing such as increase in the greenhouse gases, changes in the land use pattern, deforestation, changes in the snow cover etc. Ocean which is a second source of energy to the earth's atmospheric system through latent heat release is an important forcing of the climate system. Thampi (2012) has reported that studying the changes in the mean or variability of the properties of the state of the climate persisting for an extended period is referred to as climate change.

To make an assessment of the climate change, usually two important variables viz., temperature and precipitation in an area are considered (Sindhu and Chandralekha, 2014) as they influence the ecosystem severely. The South-West monsoon contributing about 80% of the total precipitation over the country is a critical factor to be analysed.

Singh *et al*. (2012) has opined that the quantity of precipitation and its distribution in time and space affects the availability of water resources. As the distribution of rainfall is highly variable according to time and space, storage of water to meet the future requirements of different sectors throughout the year are required. Intensification of the global hydrological cycle and several impacts on regional water resources are results of climate change. Since water resources affects many aspects of the human society, it is ideal to detect the possible impacts of climate change of hydrological extremes at the regional and the local levels.

For proper management of water resources and agricultural systems the quantification of hydrological responses to rising concentrations of atmospheric CO_2 and other greenhouse gases is very important. The changes produced in temperature and precipitation due to climate change would influence the spatial and temporal distribution of water resources (IPCC, 2007).

The weather pattern in Kerala is very unique because of the peculiar geographic orientation with Arabian Sea as the western boundary. Even though the annual variability of climatic changes is small there exists large spatial variation in the state (Joseph,1990). Kerala is known to be the “gateway of the monsoon” to the country and a wet place in the humid tropics. Kerala receives about 2816 mm average annual rainfall. There are 44 rivers, sufficient back waters, streams, canals and other inland water bodies. Rich bio diversity and tropical rainforests are peculiar in Kerala. Because of the North - South orientation of the Western Ghats, the state receives plenty of rainfall during the South West monsoon season.

Kerala’s economy is highly dependent upon agriculture which is very much influenced by weather factors. Subini (2017) has reported that there was an increase of $0.49^{o}C$ in annual mean temperature in a period of 103 years (1901 – 2003) in Kerala. The rainfall has become uncertain in the current decade. The summer droughts and floods during the rainy season has become common events here. There is an increasing trend for temperature from 1956 to 2009 with more significance since 1981 onwards. The temperature hike was prominent across the high ranges like Wayanad when compared to the other regions of the state.

In Kerala, according to the Malayalam calendar, Thiruvathira Njattuvela is an important period for the crops because it assures steady rain with enough sunshine hours. Erratic monsoon and long lasting dry spells have made this balance skewed in the present climate scenario. The changes in the climate have put the farmers in trouble. Because of the unpredictable climatic conditions prevailing in Kerala, the farmers are unable to make use of their traditional skills to judge the pattern of weather, observing the clouds, environment and soil. The time of sowing, type of crops etc., were easily managed by the farmers in olden days from their experience to get a successful harvest. But now things have changed and nothing is predictable.

The current situation in Kerala demands the scientists to take immediate steps to observe the history of climatic variation through several decades, study the trend and quantify the changes so that future climate scenarios can be projected using the past realisations. Rainfall and surface temperature are the most important climatic factors that affect our ecosystem. Juan- Carlos *et al.* (2009) has reported rainfall to be a highly variable element in spatial and temporal scale with respect to daily, decadal and long term fluctuations.

In view of the importance of impacts of climate change on environment, living beings and earth as a whole, a study was carried out for the quantitative assessment of climate change in Kerala with the following objectives.

1. To Study the variations in onset of South-West monsoon in Kerala and to develop a stochastic model to predict it.
2. To study the spatial and temporal variations of rainfall in Kerala.
3. To explore the capabilities of probability distributions in fitting climatic variables.
4. To navigate through the pentads of climatic variables – a case study of Vellanikkara, Thrissur district.
5. To investigate the impact of climate change on reservoirs of Kerala - a case study of Idamalayar reservoir inflow.

Brief Description of the work done

A detailed study of the onset of South-West monsoon in Kerala has been done using the dates of onset for 147 years for the period from 1870 - 2016. A suitable probability distribution has been fitted to the onset dates. Short term forecasts were made through a meteorological approach using pre monsoon rainfall peak and long term forecasting have been tried using a univariate weighted least square regression model with heteroscedasticity correction to predict onset dates using its own significant auto correlated lags.

To examine the existence of trend in the monthly, seasonal and annual rainfall series in Kerala for 146 years from 1871- 2016, the non-parametric Mann-Kendall test has been applied. The dry years and wet years have been identified. Decadal variations in rainfall and their significance also have been studied. The expected estimates of rainfall depths or intensity of rainfall for a specific probability with respect to a reference period denoted by probability of exceedance and return period for a particular rainfall event have been computed by standard methods given by Weibull, Sevruk and Geiger etc. Rainfall depths have been estimated for selected probabilities using probability plot.

District wise average, C.V etc. were found out using the rainfall data of 14 districts of Kerala for the period from 1990 – 2016. The normal years, flood years and drought years with respect to each district have been identified. The monthly and seasonal rainfall distribution and their percentage contribution to the annual rainfall have been worked out. Exploratory analysis to get finer details of the rainfall variation in each district have been performed and compared. The temporal variations of rainfall for individual selected stations of KSEB Ltd. also have been done.

To forecast the frequency of occurrence of different quantities of rainfall in certain intervals, probability distributions have been fitted to the onset data and for monthly, seasonal and annual rainfall series. The peak rainfall series of Kerala, peak inflow series of Idamalayar Reservoir, the series of rainy pentads in Vellanikkara region etc. have been subjected to probability distribution fitting. Fisher Tippett (2), Lognormal, Logistic, GEV, Beta 4, Gamma (2), Exponential, Normal, Negative Binomial distributions have been identified as the best fitting models in different situations.

In agriculture and water management studies, finer details of the climatic variables play a very important role. So a pentad wise analysis of climatic variables viz., rainfall, maximum and minimum temperature, relative humidity, sunshine hours and wind velocity have been made. The rainy pentads have been identified month wise and season wise. The existence of trend in 73 pentads of the climatic variables for the Vellanikkara region taking the data for 34 years from 1983 -2016 has been studied.

Considering the importance of impact of climate change on water resources, an attempt have been done to observe the temporal variations of reservoir inflow and the relationship of inflow with rainfall received for the current and previous months. For a precise estimate of reservoir yield, simulation models have been developed. First order stationary Markov models for yearly inflow and the same model addressing the non- stationarity for monthly inflow have been developed. Apart from the long term simulation models, short term forecasting models also have been developed to predict reservoir inflow. The inflow data for the period from 1989 –'90 to 2016 – '17 of Idamalayar Reservoir have been used for the study. Multiple linear regression and ARIMA models have been tried for the purpose.

The Thesis is organized in six chapters including the introduction. After introduction of the work, each objective is described furnishing the Literature review, materials and methods, results and discussions. The summary of each chapter is given at the end of the thesis.

2 ONSET OF SOUTH WEST MONSOON IN KERALA

2.1 INTRODUCTION

The economy of a nation is dependent on its GDP. In a country like India, the agricultural production plays the major role in its economy. Hence the Government gives great importance for growth in agricultural production for planning their economic strategies. The agriculture in India is highly dependent on monsoon. A good monsoon always results in high crop productivity. Hence, in each year the farmers in India are eagerly waiting to see the onset of South-West (SW) monsoon (contributing about 80% of the annual mean rainfall), which commences in Kerala in early June and progresses to other parts of the country.

Though the onset of monsoon in Kerala is normally considered as on 1st June, it is highly uncertain. In some years it commences by the first week of May and by last half of June in some other years. This brings up the importance of monsoon prediction. The most important factors to be included in prediction are the onset, quantum of rainfall and its distribution during that season and intensity of monsoon

Though several attempts were made, predictions failed due to the large air-sea interactions and the scientists were forced to modify their work and try for better alternative methods and models. The complexity of the monsoon of South Asia is not completely understood, making it difficult to accurately predict the quantity, timing and geographic distribution of the accompanying precipitation. These are the most monitored components of the monsoon and they determine the water availability for any given year.

As per IMD report the monsoon can be categorised into two branches based on their spread over the sub-continent viz., Arabian Sea branch and Bay of Bengal branch. Alternatively, it can be categorised into two segments based on the direction of rain – bearing winds – SW Monsoon and North East Monsoon. Based on the time of year that these winds bring rain to India, the monsoon can be categorised into two periods: Summer monsoon (June – September) and winter monsoon (October to November).

Meteorological seasons over India are: Winter season: January – February, Pre monsoon season: March –May, South West Monsoon season: June – September, Post Monsoon season: October – December.

The seasonal reversal of winds and the associated rainfall is called monsoon. This word is derived from the Arabic word “Mausim”. The annual oscillation in the apparent position of the Sun between the Tropics of Cancer and Capricon causes the annual oscillation in the position of the thermal equator (region of maximum heating) on the Earth’s surface. This is associated with the annual oscillation of temperature, pressure, wind, cloudiness, rain etc. This is the cause of the monsoon.

On the Earth’s surface, there are asymmetries of land and ocean. The differential heating of land and ocean cause variations in the intensity of the annual oscillation of the thermal equator and hence regional variations in the intensity of monsoon.

The SouthWesterly wind flow occurring over most parts of India and Indian seas give rise to SouthWest monsoon over India from June to September. The SW monsoon over the Indian Peninsula first arrives over the South Indian state of Kerala, widely known as the gateway of the Indian monsoon (Sooraj, 2004). During 1943, the normal onset and withdrawal dates of the summer monsoon was determined by IMD at 180 rain gauge stations across British India, Pakistan, Bangladesh, Myanmar and Sri Lanka from characteristic monsoon rise/fall in pentad rainfall and by preparing charts. Anantha Krishnan *et al*. (1967) suggested an objective criterion for determining onset over Kerala state as, “beginning from 10th May if at least five out of the seven stations report 24 hourly rainfall of 1mm or more for two consecutive days, the forecaster should declare on the second day that the monsoon has advanced over Kerala”. Later Ananthakrishhnan and Soman (1988) improved the criterion as “when rainfall on the day and mean rainfall in the following 5 days period exceeded 10mm”. Joseph *et al.* (2006) has reported that the IMD uses the following criteria for declaring operationally the arrival of monsoon over Kerala “if after 10th May, 60% of the available 14 selected stations viz., Minicoy, Amini , Thiruvananthapuram, Punalur, Kollam, Alapuzha, Kottayam, Kochi, Thrissur, Kozhikode, Thalassery, Kannur, Kasargode and Mangalore report rainfall of 2.5mm or more for two consecutive days, the onset of monsoon over Kerala may be declared on the second day, provided the following conditions are also met. “ Depth of Westerlies should be maintained upto 600 hpa, in the box equator to latitude 10^{o} N and longitude 55 ^{o} - 80^{o} E. The zonal wind speed over the area bounded by parallels 5^{o} N and 10^{o} N and meridians 70^{o} E and 80^{o} E should be of order of 15 - 20 knots at 925 hpa. INSAT derived OLR (outgoing long wave radiation) value should be less than 200 wm-2 over the area bounded by parallels 5^{o}N and10^{o}N and meridian 70^{o} E and 75^{o} E

Withdrawal of SW monsoon from extreme North – Western parts of the country should not be attempted before 1st September. The following major synoptic features should be considered for the first withdrawal from the Western parts of NW India. (i) Cessation of rainfall activity over the area for continuous 5 days , (ii) Establishment of anticyclone in the lower troposphere (850 hpa and below), (iii) Considerable reduction in moisture content as inferred from satellite water vapour imageries and epigrams

Considerable variability could be observed in the onset, duration and intensity of the monsoons. Different features of the summer monsoon showed large variation with respect to intra – seasonal to inter annual and inter decadal. In this context a detailed study of the onset in Kerala and different statistical approaches to predict the onset is undertaken to make the task of future predictions more reliable and fruitful.

2.2 REVIEW OF LITERATURE

Utilising daily mean rainfall from dense rain gauge networks, Ananthakrishnan and Soman (1988) have derived the dates of onset of the SW monsoon over South and North Kerala on the basis of objective criteria for the years 1901 to 1980. According to them the monsoon onset date for South Kerala was found to be 30th May and that for North Kerala , 1st June with S.D of about 9 days in both cases.

Baby and Prakash (1994) studied the usefulness of the temperature and moisture data from TIROS operational vertical sounder to obtain humidity parameters like mid and upper troposphere water vapour and scale height of water vapour to characterise the onset of SW monsoon over India. The study showed that about 8 to 10 days prior to the onset over Kerala coast, the pentad averaged values in the Western Indian Ocean showed an increase in scale height of water vapour and mid troposphere moisture. The correlation of moisture flux across the Indian ocean and the rainfall over Kerala coast showed that the gradient of middle level moisture was stronger in the case of rainfall deficit years.

Kumar (2004) used the Global precipitation and In situ gauge data for the period from March 21st to May 31st for the years 1979 to 2001 to identify the pre monsoon rainfall peak (PMRP) during the period from 1st April to 10th May. In Kerala the PMRP was found to exist about six pentads prior to the onset of monsoon. Using the pre monsoon rainfall estimate from the satellite data, the onset dates of SW monsoon in Kerala were predicted by using regression of onset dates on PMRP dates.

Sooraj (2004) was of the opinion that about three weeks in advance of the onset of monsoon a consistent dramatic reversal in wind direction over the Western Arabian Sea would occur. A large increase in the wind speed would coincide with the onset of monsoon. The findings showed the dominant role of sea surface winds to establish the monsoon circulation and the importance of cross equatorial current phenomenon after the onset of monsoon.

Joseph *et al*. (2006) found that two ISO cycles were needed for the ASM onset processes. During this period large scale convection occur systematically at different locations of a big area in which the vertically IWV upto 300 hpa pumped up by convection increases steadily and reaches nearly 45 kg/m^2 around the date of MOK (Monsoon onset of Kerala). To determine the MOK an objective method with 3 steps was developed. First, the daily depth and strength of the monsoon current's Westerly (zonal) component in a box just South of Kerala bounded by latitudes 5^o N and 10^{o}N and longitudes 70^o E and 85^o E is to be monitored daily beginning on 5th May. At MOK the area mean wind should reach 6 m/s and 600 hpa. In the next step check the reliability of the MOK, if a possible MOK was found during the period 5th May to 25th May by examining the spatial pattern of OLR and 850 hpa wind field. In the next step a Hovmuller diagram averaging OLR between longitudes 65^{o}E and 80^o E was used to confirm that the data chosen was the real MOK observed by the slow and steady movement of organised convection and rainfall from the equatorial area to the latitudes of Kerala.

Dunxin and Leijiang (2008) examined the correlation between the South China sea summer monsoon onset and heat content in the upper layer of the warm pool in the Western pacific ocean using the Scripps institution of oceanography dataset for the period of 1953-1998 and used it for onset prediction. Inter decadal variability of the SCSSM onset was demarcated by 1970 with the largest correlation coefficient in the area West of the warm pool rather than near its centres which implied certain effect from other factors besides ENSO.

Pham *et al.* (2009) determined the summer monsoon onset over Southern Vietnam through a criterion based on in situ daily rainfall at six selected stations in Vietnam and the zonal component of wind at 1000 hpa. Clear changes was observed in the zonal wind strengthened over the Bay of Bengal and changed from negative to positive over South Vietnam and in convection in association with an identification of the meridional gradients of sea level pressure at 1000 hpa and of moist static energy at 2m over South East Asia.

Goswami and Gouda (2010) were of the opinion that even though the standard deviation in date of onset over the past hundred years was only 7 days, nearly 50% of the cases show large (> 1 S.D) deviations . The lack of predictability might be due to the noise introduced by local synoptic processes. To meet the special requirements of forecasting date of monsoon, a general circulation model (GCM) with a special feature, variable resolution and an objective de biasing of daily rainfall forecast was used.

Ajit *et al*. (2011) has revised the older data set using the new mean pentad precipitation data of 569 stations in India spread over the country, from 1971 – 2000. The date of onset of monsoon over Kerala was 1 June with a standard deviation ranging between 7 to 14 days.

A simple Index based on empirical orthogonal function of precipitation anomalies was employed by Charles *et al.* (2012) to characterise onsets, duration and amplitudes of South American monsoon system. Probabilistic forecasts of onset had 16.5 % improvement over climatological forecasts.

Kumar *et al*. (2013) attempted to predict the start date and the duration of breaks in the summer monsoon rain using multi – model super ensemble. High resolution daily gridded rainfall dataset of IMD in addition to rainfall estimates from tropical rainfall microwave mission satellite and the CPC morphing technique were used. Results of the prediction of onset and duration of the breaks in the summer monsoon rains showed that the prediction of a dry spell could be done around a week in advance

Monsoon prediction Algorithm has been developed by Suhas (2013) using satellite images of South West monsoon. The entire algorithm consisted of three stages. The first stage included image data from a span of 4 years. In the second stage the data set was segregated into multiple clusters and in the third stage the image data set was compared with centroids of clusters created in the second stage. Monsoon onset is predicted using K–NN algorithm.

Anonymous (2016) has reported that the normal monsoon onset over Kerala is 1st June. Since 2005, IMD has been using an indigenously developed statistical model to forecast the date of monsoon onset over Kerala with a model error of ± 4 days. The six predictors used in the model were minimum temperature over North – West India, pre monsoon rainfall peak over South peninsula, outgoing long wave radiation over South China Sea, lower tropospheric zonal wind over South West Indian ocean, upper tropospheric zonal wind over the East equatorial Indian Ocean and outgoing long wave radiation over the South West pacific region.

2.3 MATERIALS AND METHODS

The dates of onset of SW monsoon for 147 years for the period from 1870- 2016 published by IMD were collected and used for the study. Daily meteorological variables viz., rainfall, maximum temperature, minimum temperature, relative humidity, sunshine hours and wind velocity for 33 years for the period from 1984 to 2016 from the meteorological observatories in the College of Horticulture, Vellanikkara (bounded by 10^0 31'; $76^0$13'), under Kerala Agricultural University were also used to identify the pre-monsoon rainfall peak and to construct prediction equations for onset of SW monsoon.

The prediction of dates of onset was made using a meteorological and a statistical approach. To accomplish the prediction using meteorological approach, the daily observations on different climatic variables have been converted to pentad averages (five day mean). The correlation between these pentad average values with the pentad average rainfall during the onset pentad was computed. The pentad corresponding to pre monsoon rainfall peak (PMRP) was identified for each year. A simple linear regression of onset dates on PMRP was fitted and used for prediction of onset of SW monsoon.

In the statistical approach, General linear model (GLM) univariate analysis and a non-contiguous regression model by regressing onset values on its own past values using the weighted least square method with heteroscedasticity correction has been applied which will account for the auto correlations present in the univariate series of onset data. The dates of onset were quantified to an index for the ease of computation. The index 518 denotes June 1. It is an arbitrarily assumed value attached to June 1. In MS Excel dates can be stored as serial values so that they can be subjected to algebraic operations.

2.3.1 GLM univariate Analysis

The GLM univariate procedure provides regression analysis and analysis of variance for one dependent variable by one or more factors or variables. The factor variables divide the population into groups. Using this procedure, the null hypothesis about the effects of other variables on the means of various groupings of a single dependent variable can be tested. For regression analysis, the independent variables are specified as covariates.

2.3.2 Regression model with heteroscedasticity correction

When heteroscedasticity is present in the form of an unknown function of the regressors which can be approximated by a quadratic relationship, regression model by means of weighted least squares with heteroscedasticity correction offers the possibility of consistent standard errors and more efficient parameter estimates as compared with OLS. The procedure involves (a) OLS estimation of the model of interest, followed by (b) an auxiliary regression to generate an estimate of the error variance, then finally (c) weighted least squares, using weight as the reciprocal of the estimated variance. In the auxiliary regression (b) regress the log of the squared residuals from the first OLS on the original regressors and their squares. The log transformation is performed to ensure that the estimated variances are all non-negative. Denoting the fitted values from this regression u*, the weight series for the final WLS is then formed as 1/exp(u*).

2.4 RESULTS AND DISCUSSION

To characterise the internal structure of the onset data for 147 years from 1870-2016, the summary statistics were computed. The average date of onset of SW monsoon was found to be June 1st (518) with a S.D of 7.08 ≈ 7 days. The results showed that the onset dates ranged between as early as 11th May (497) in 1918 to as late as June 18th (535) in 1972.

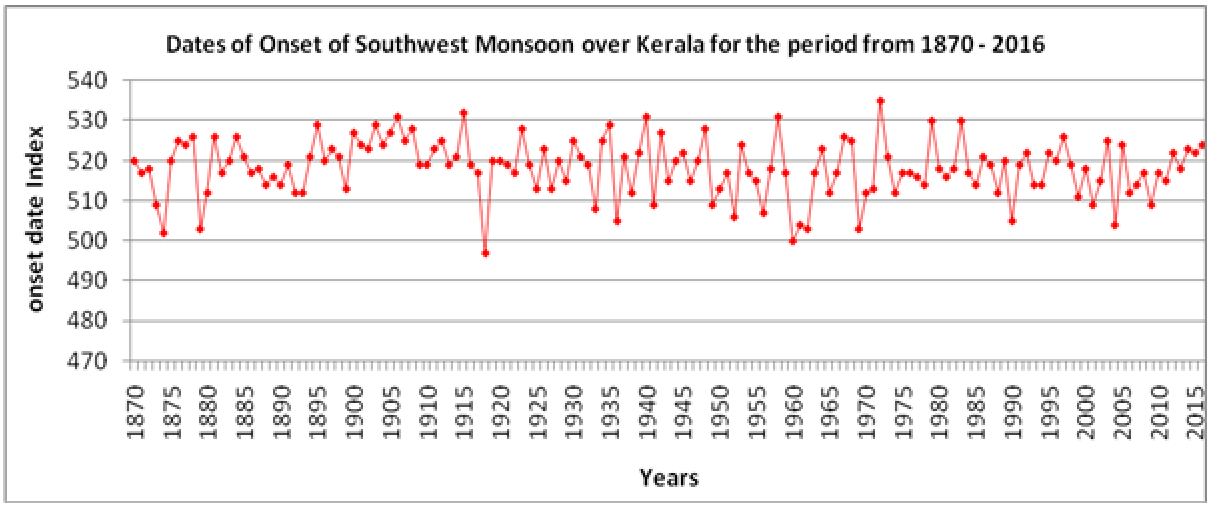


Fig. 2.4.1

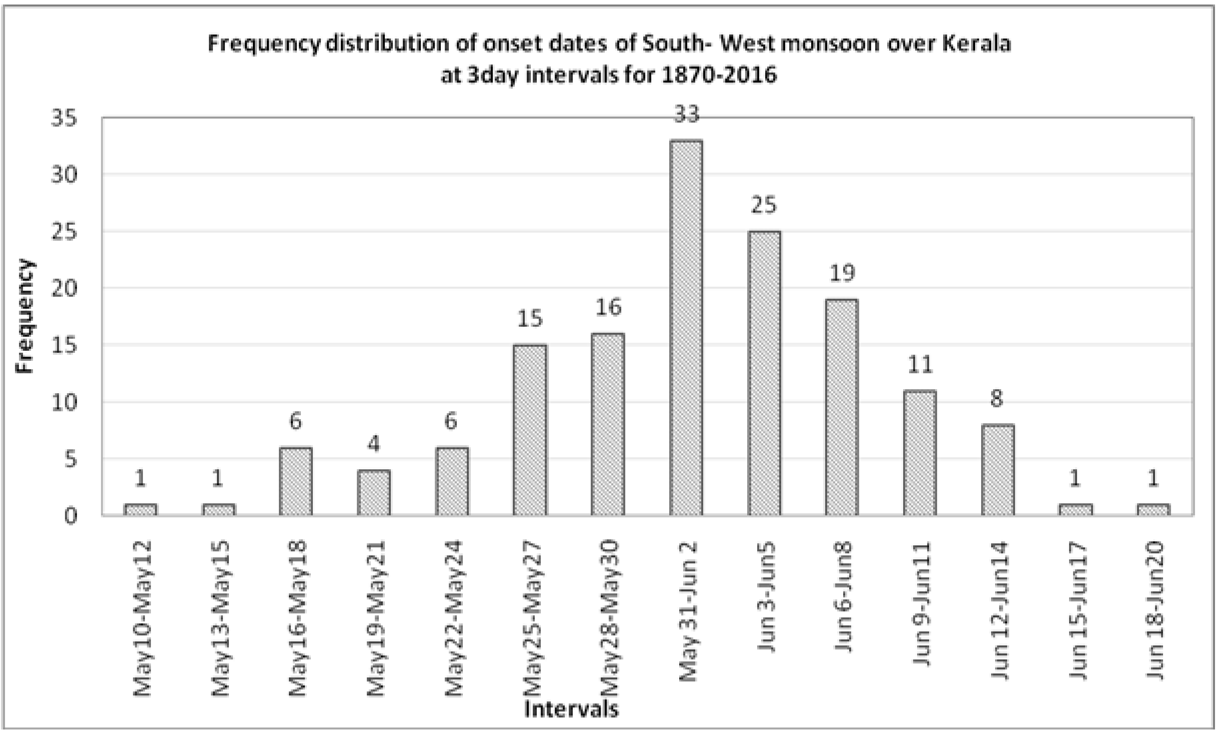


Fig. 2.4. 2

Out of the 147 data points of onset dates, 74 percentage were in the range of 518 ± 1S.D *i.e.*, between 25th May – 8th June. Twelve percentage (12%) of the cases were before 25th May and 14 percentage of them were beyond 8th June.

Table 2.4.1: Frequency distribution of onset dates according to ±1S.D limit

Date of Onset	Frequency	Percentage
Before 25th May	18	12
25th May – 8th June	108	74
After 8th June	21	14
Total	147	100

Goswami and Gouda (2010) were of the opinion that even though the standard deviation in date of onset over the past hundred years was only 7 days, nearly 50 percentage of the cases show large (> 1 S.D) deviations. The lack of predictability might be due to the noise introduced by local synoptic processes. To meet the special requirements of forecasting dates of monsoon a general circulation model (GCM) with a special feature, variable resolution and an objective de biasing of daily rainfall forecast has been used.

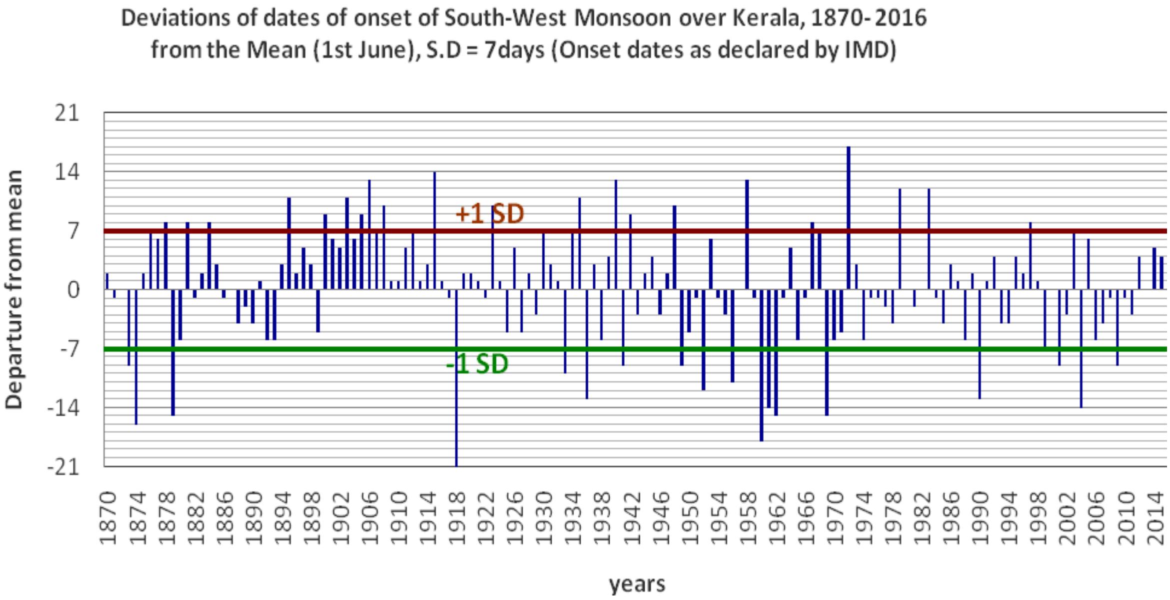


Fig. 2.4.3

2.4.1 Decadal variations in onset dates of SW monsoon in Kerala

To comprehend the variations in the onset dates of SW monsoon in Kerala, a one way ANOVA was done taking the decadal onset dates for 147 years.

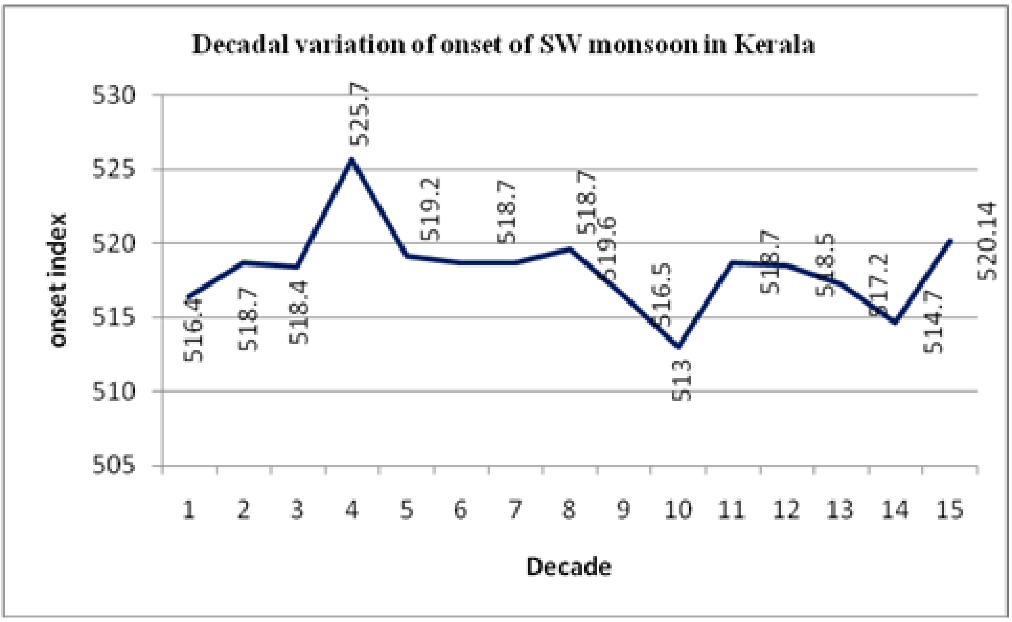


Fig. 2.4.1.1

Table 2.4.1.1: Decadal variations in onset dates of SW monsoon in Kerala

Decade	No. of observations	Mean	S.D	S.E	Min.	Max.
I	10	516.4	8.78	2.78	502	526
II	10	518.7	4.64	1.47	512	526
III	10	518.4	5.58	1.77	512	529
IV	10	525.7	3.43	1.09	519	531
V	10	519.2	8.9	2.82	497	532
VI	10	518.7	4.6	1.45	513	528
VII	10	518.7	7.85	2.48	505	529
VIII	10	519.6	7.66	2.42	509	531
IX	10	516.5	7.34	2.32	506	531
X	10	513	9.98	3.16	500	526
XI	10	518.7	7.86	2.49	512	535
XII	10	518.5	4.86	1.54	512	530
XIII	10	517.2	6.20	1.96	505	526
XIV	10	514.7	6.63	2.10	504	525
XV	7	520.14	3.44	1.30	515	524

Table 2.4.1.2: One way ANOVA to test the decadal variation of onset

Sources	Sum of squares	D.f	Mean square	F	Sig.
Between decades	1093.81	14	78.13	1.66	0.07
Within decades	6222.86	132	47.14		
Total	7316.67	146			

The results of the one way ANOVA from Table (2.4.1.2) shows that there was no significant variation between the decades with respect to onset dates. The within variations were found to be very high in this respect.

2.4.2 General Linear Model to forecast onset of SW Monsoon

The dates of onset of SW monsoon for 140 years from 1870 to 2009 were grouped into two by defining a covariate. The covariate X assumed the value 1 if the onset date was on or before June 1 and X = 2, if the onset date was after June 1.GLM for univariate analysis was performed and resulted in the following regression equation,

$$Y = 501.63 + \underset{(0.74\ S.E)}{\overset{**}{10.95}}\,X$$ giving an adjusted $R^2 = 60\%$.

When x=1, Y = 512 and when x=2, Y = 523. In general the onset of SW monsoon in any year can be expected to occur in between May 26th – June 6th (512 -523). For the remaining years which were not included for fitting the regression, the onset dates were within this interval except for one year.

Table 2.4.2.1: Actual and predicted onset dates for the years 2010 – 2016

Year	Index for actual onset date	Predicted Interval	Year	Index for actual onset date	Predicted Interval
2010	517	512-523	2014	523	512-523
2011	515	512-523	2015	522	512-523
2012	522	512-523	2016	524	512-523
2013	518	512-523			

Table 2.4.2.2: Frequency distribution of the actual onset dates for 147 years according to the covariate grouping

Onset dates	Frequency	Percentage
Before May 26^{th} (512)	19	13
Between May 26^{th} – June 6^{th}	94	64
After June 6^{th}(523)	34	23
Total	147	100

Table (2.4.2.2) shows that the frequency of delayed onsets were more than very early onsets.

2.4.3 Meteorological approach to predict the onset of SW monsoon in Kerala

According to several forecasting studies, pentad averages (five day mean) seemed to be a better representation of the distribution of rainfall. Hence in the meteorological approach of prediction of onset date, the pentad average of the daily climatic variables viz., rainfall, maximum temperature, minimum temperature, relative humidity, sunshine hours and wind velocity were computed from March 2^{nd} to onset date for 30 years from 1984 - 2013. The correlation coefficients of pentad averages for each climatic variable were computed with the pentad average rainfall during the onset period. A significant correlation coefficient of 0.46 was obtained between the quantity of rainfall at 8 pentads before onset and the quantity of rainfall at the onset pentad. The correlation coefficient was not significant for other climatic variables except in the just previous pentad before onset. Joseph *et al*. (2006) have found that, eight pentads before the monsoon onset over Kerala, a spatially large area of deep convection would form near the equator, South of Bay of Bengal, which would move to South East Asia marking the onset of South China Sea monsoon for many years. Eight pentads before MOK, a warm pool was located over central Bay of Bengal and an area of active convection would form to its South near the equator in the region of large sea surface temperature gradient.

Table 2.4.3.1: Descriptive statistics of mean pentad rainfall from 1 to 15 pentads before onset at Vellanikkara, Thrissur district

X pentad before onset	Mean	S.D	N	Correlation with mean rainfall at onset pentad	Significance
-15	0.68	2.76	30	-0.22	0.25
-14	0.26	0.90	30	-0.07	0.71
-13	0.50	1.08	30	-0.23	0.22
-12	2.29	4.00	30	0.03	0.89
-11	0.99	2.10	30	-0.27	0.16
-10	1.54	2.79	30	-0.07	0.72
-9	3.17	4.46	30	-0.01	0.96
-8	4.05	7.10	30	0.46**	0.01
-7	3.13	5.37	30	-0.13	0.50
-6	3.5	8.87	30	-0.24	0.20
-5	4.04	5.86	30	-0.02	0.92
-4	2.28	4.2	30	-0.12	0.54
-3	4.74	7.07	30	-0.24	0.21
-2	6.39	10.07	30	0.11	0.58
-1	3.77	3.44	30	0.37*	0.05
0	21.28	19.36	30	1	

* denotes significance at 5% level and ** denotes significance at 1 % level

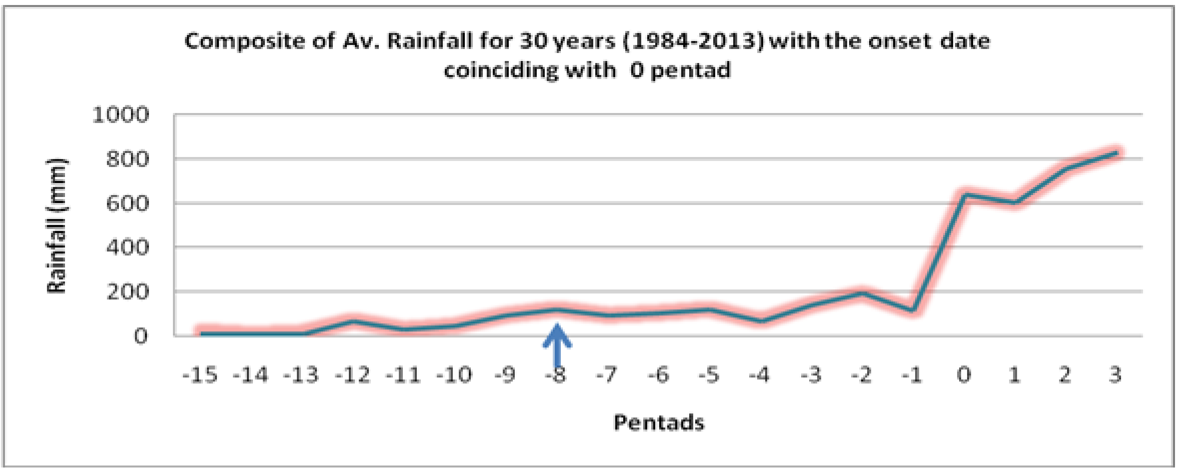


Fig. 2.4.3.1

The composite values over the years 1984-2013 of the rainfall data were computed using the pentad average values in such a way that the monsoon onset over Kerala (MOK) would coincide with the zero pentad. The intensity of rainfall was observed at -15 pentads to + 2 pentads with respect to the composite values. Fig. (2.4.3.1) shows the existence of a PMRP around 8 pentads before the onset of monsoon. For every year during the period from April 1st to May 10th, the mid-day of the pentad with rainfall peak was identified and recogonised as PMRP. The occurrence of PMRP was marked as on day1, day2 etc., if it has realised on April 1st, April 2nd and so on. A scatter diagram was drawn taking PMRP (x days) and the actual onset dates (y days). A correlation coefficient of 0.59 was obtained between the dates of PMRP and onset dates which was highly significant. The regression of y on x was as follows which can be used for the prediction of onset dates for the future.

$Y = 48.54 + 0.52^{**} X$ with a S.E = 0.14 for the regression coefficient

Table 2.4.3.2: Yearly distribution of PMRP, MOK, estimated MOK and residuals for 1984 - 2016

Year	PMRP	MOK (A)	Estimated MOK (B)	Error (A-B)	Year	PMRP	MOK (A)	Estimated MOK (B)	Error (A-B)
1984	23	61	61	0	2001	23	53	61	-8
1985	13	58	55	3	2002	23	59	61	-2
1986	33	65	66	-1	2003	23	69	61	8
1987	23	63	61	2	2004	18	48	58	-10
1988	18	56	58	-2	2005	23	68	61	7
1989	23	64	61	3	2006	13	56	55	1
1990	18	49	58	-9	2007	23	58	61	-3
1991	23	63	61	2	2008	28	61	63	-2
1992	23	66	61	5	2009	18	53	58	-5
1993	18	58	58	0	2010	28	61	63	-2
1994	13	58	55	3	2011	28	59	63	-4
1995	33	66	66	0	2012	38	66	68	-2
1996	23	64	61	3	2013	18	62	58	4
1997	33	70	66	4	**2014***	**28**	**67**	**63**	**4**
1998	28	63	63	0	**2015***	**33**	**66**	**66**	**0**
1999	18	55	58	-3	**2016***	**23**	**68**	**61**	**7**
2000	18	62	58	4	**2017***	**14**	**60**	**56**	**4**

*Validation of the regression model

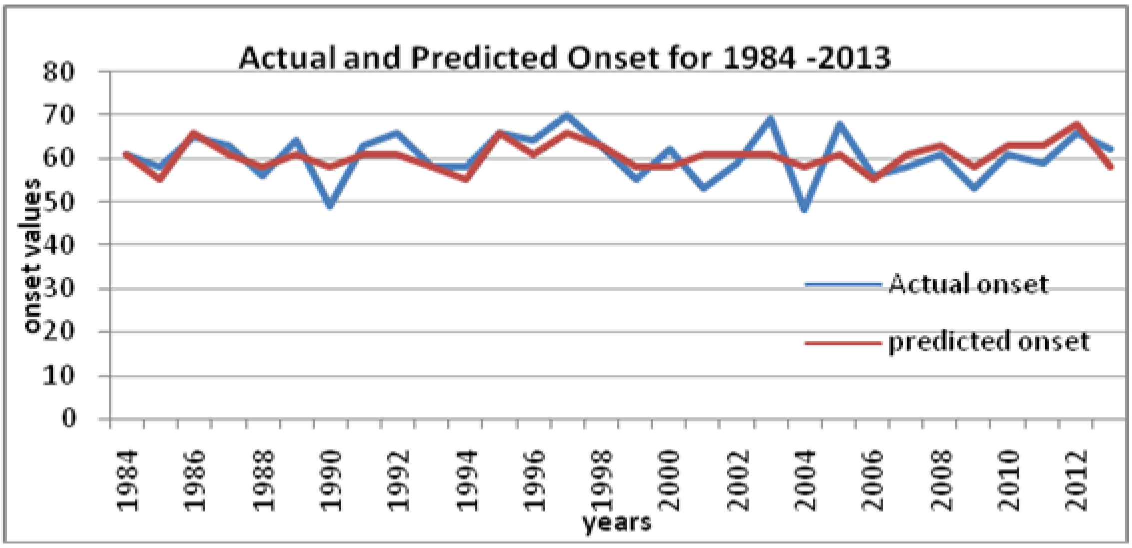


Fig. 2.4.3.2

Table 2.4.3.3: Runs Test for the Residuals

Test value	-2
Cases < Test value	7
Cases >= Test value	23
Total cases	30
Number of Runs	15
Z	1.46
Asymp. Sig. (2 tailed)	0.15

a.mode

The actual and estimated monsoon onset dates obtained using the regression of onset dates on PMRP are shown in Table (2.4.3.2). The regression model was validated by computing the predicted onset dates for 4 independent years, 2014 –2017 which were not included for the model fitting. In 2015 the error of prediction has turned out to be zero. The actual and predicted onset dates are graphically shown in Fig. (2.4.3.2). It could be observed that the predictability of the model is adequate except for some odd years where there were too early or too late onset events. The insignicant Z value in the Runs test in Table (2.4.3.3) shows that the errors of forecasts were randomly distributed. So this model can be recommended for predicting the arrival of SW monsoon in Kerala, especially in the particular locality of study as the errors were negligibly small for the concerned region.

Kumar (2004) has stressed the potential of satellite data to predict the onset of SW monsoon and used the Global precipitation and In Situ gauge data for 23 years from 1979 – 2001 and PMRP was identified around six pentads before the monsoon onset. In their study the correlation coefficient between the dates of PMRP and onset dates was 0.64. Even though the correlation coefficient between dates of PMRP and onset dates of SW monsoon was 0.59 in the present study, the PMRP was realised 8 pentads in advance of the onset as against the findings of the above author. The results of this study also show that the surface data is also equally capable as satellite data for predicting onset dates as against the existing belief.

2.4.4 Statistical approach to predict the onset of SW monsoon

In the meteorological approach already discussed, only short term predictions were tried. But a long term prediction is tried in the statistical approach. Time series forecasting is made use of to predict future onset dates based on its own previously observed values. If the current level of the dependent variable is heavily determined by its past levels or if the error terms are correlated across time it will generate autocorrelation in the Time series. In other words the present outcome of the model is greatly affected by the past errors. In such situation the assumption of homoscedasticity needed for BLUE (Best Linear Unbiased Estimator) is violated resulting in biased standard errors. A statistically valid estimation of the effect of the independent variables on the dependent variable cannot be made if the standard errors are biased.

Lagged dependent variables can be included as regressors in the model to make the results reliable by reducing the occurrence of autocorrelation arising from model misspecification. Here the correlation between the lagged dependent variable and the current disturbance are to be considered to estimate the parameters. This is a violation from the critical assumption of the classical linear regression model and due to inconsistency, the ordinary least square estimator become unacceptable. Hence the weighted least square method with heteroscedasticity correction has been made use of to predict the onset of SW monsoon. Keele and Kelly (2005) have opined that if lagged dependent variables are used to overcome the residual correlation present in the data, the coefficients for explanatory variables may be biased downward. Monte Carlo analysis can be used to assess the bias when a lagged dependant variable is used. Practical suggestions to use the lagged dependent variable in an appropriate manner have been suggested.

The dates of onset of SW monsoon for the period from 1870 - 2004 have been used to fit the regression model and validation of the model has been done using the data from 2005 – 2016. Predictions for 5 years from 2017 – 2021 have been made together with the confidence interval.

As a first step, the onset data was tested for the presence of trend. The results showed that there was no significant trend existing in the data. The trend equation for the onset data obtained is as follows,

$$Y = 519.67 - \overset{**}{0.02}t \text{ with } R^2 = 0.01$$

The stationarity of the onset data was tested using the Augmented Dickey fuller test.

Augmented Dickey-Fuller test: unit-root null hypothesis: a = 1
test with constant
model: $(1\text{-}L)y = b_0 + (a\text{-}1)*y(-1) + e$
estimated value of (a - 1): -0.925247
test statistic: tau_c(1) = -11.1109
p-value 3.555e-017

The null hypothesis of unit root has been rejected. So the series is stationary.

Table 2.4.4.1: Autocorrelation function for onset dates taking lag length = 37 (**, * indicate significance at 5% level and 10 % level)

LAG	ACF	PACF	LAG	ACF	PACF
1	0.0821	0.0821	19	0.1804 *	0.1509 *
2	-0.0746	-0.0819	20	0.0649	0.0466
3	0.0193	0.0331	21	-0.1636	-0.1076
4	0.0001	-0.0109	22	-0.1475	-0.1609 *
5	0.1711 **	0.1788 **	23	-0.0513	0.0066
6	0.0612	0.0288	24	0.0767	0.0206
7	-0.026	-0.0048	25	0.12	0.1128
8	0.1275	0.1326	26	-0.077	-0.0077
9	0.1313	0.1139	27	-0.0651	-0.0542
10	-0.0182	-0.0462	28	0.1271	0.1252
11	0.1085	0.1202	29	-0.0153	-0.0195
12	-0.1408	-0.1766 **	30	-0.0076	0.0178
13	0.0124	0.0292	31	-0.0198	0.0516
14	0.1069	0.0169	32	-0.0267	-0.0037
15	-0.0415	-0.0419	33	0.0341	-0.0732
16	0.0005	-0.0369	34	-0.0025	-0.0481
17	-0.0778	-0.0826	35	-0.0353	-0.0003
18	-0.0467	-0.0332	36	-0.0572	-0.0752
			37	-0.0081	0.0177

The results showed that the series was stationary with auto correlated lags. A regression model using 37 lags with heteroscedasticity correction was employed which has yielded an adjusted R^2 of 86% which was statistically significant at 1% level of significance. The other statistics based on the weighted data were as follows.

Table 2.4.4.2: Statistics based on the weighted data using 37 lags

Sum of squared residuals	122.32	S.E of regression	1.43
Log – likelihood	-149.92	Akaike criterion	375.83
Schwarz criterion	474.07	Hannan - Quinn	415.57
Rho	0.05	Durbin’s h	0.71

The Residual ACF and PACF for regression model using 37 lags

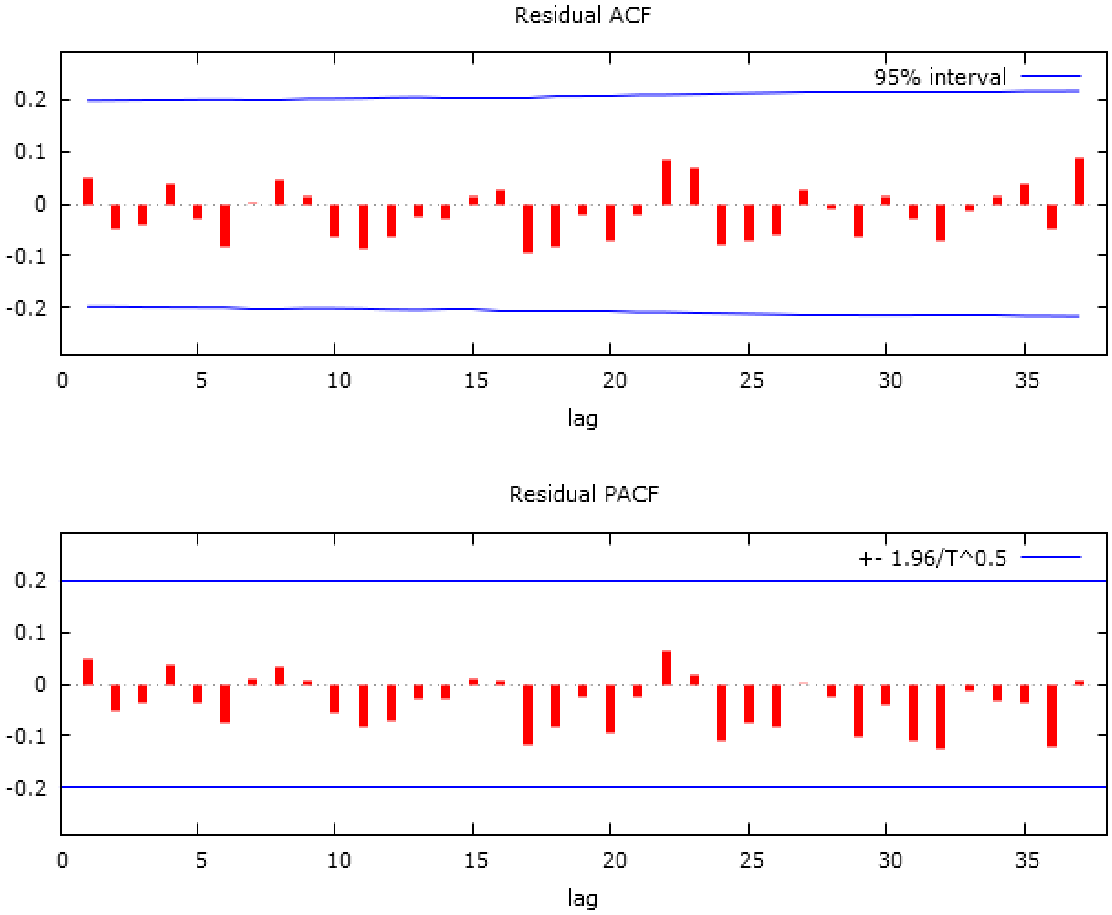


Fig. 2.4.4.1

Table 2.4.4.3: Runs Test for independence of errors

Test Value[a]	13.43[b]
Cases < Test Value	97
Cases >= Test	1
Total Cases	98
Number of Runs	3
Z	0.144
Asymp. Sig. (2-	0.885

a. Mode

b. There are multiple modes. The mode with the largest data value is used.

Test for normality of residuals in fitting regression using 37 lags

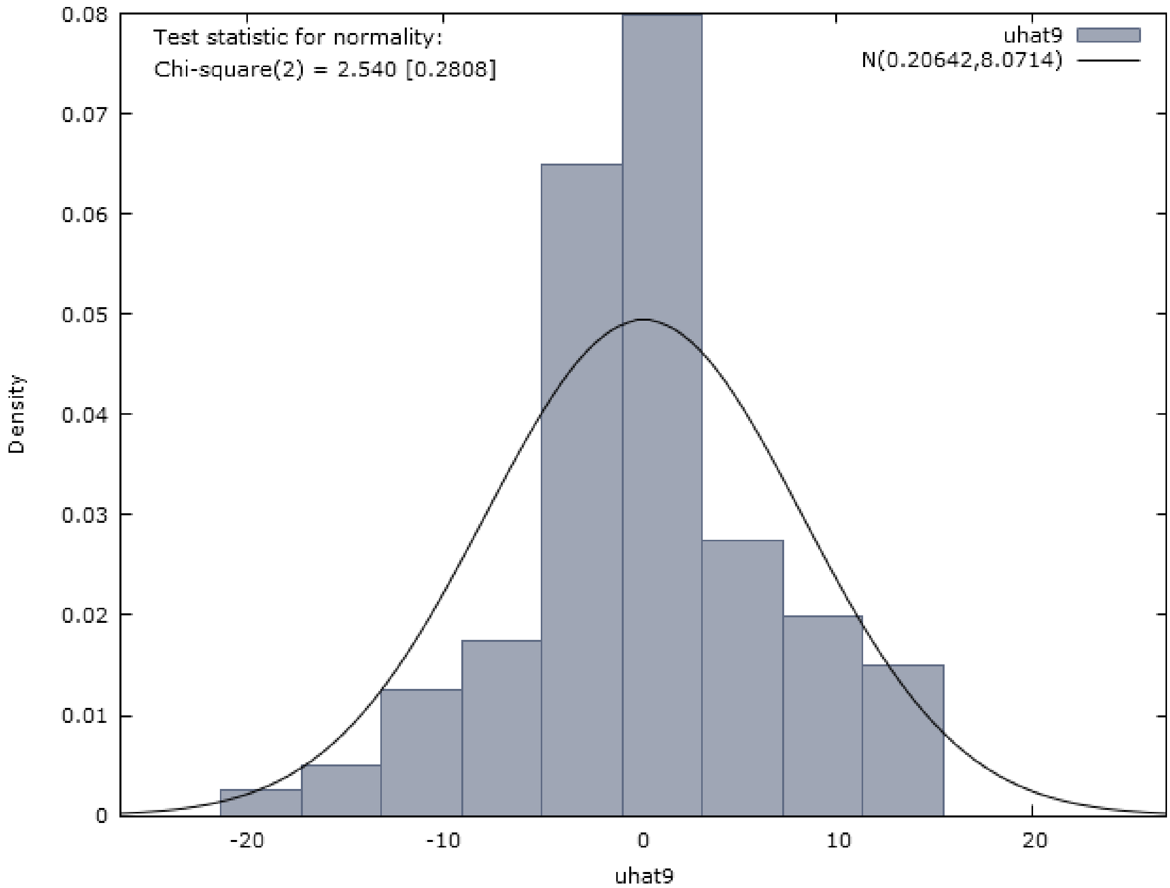


Fig. 2.4.4.2

The relative goodness of fit of statistical models are measured using several Information criteria. These are measures of the trade off between the uncertainty in the model and the number of parameters in the model. These tools are mainly used to attain much explanatory power with only a few parameters. The R – squared value would always increase when additional regression parameters are added. But the increase in accuracy would decrease the parsimony of the model. Practically, R – squared often increases dramatically for the first few added regression parameters and then levels off as more parameters are added. Therefore instead of fitting a model with 37 lagged variables involving insignificant regression coefficients, a non contiguous model considering the significant lags which is both parsimonious (does not over-fit the data with too many parameters) and accurate has been developed.

To capture the dynamic effects and to get rid of the autocorrelations present in the data, the significant auto correlated lags were first identified (Table 2.4.4.1) and a regression model with heteroscedasticity correction was fitted using the onset dates corresponding to the significant lags viz., 5, 12, 19 and 22 as the regressors. This model could predict the onset dates with minimum error when compared to the previous models discussed.

Table 2.4.4.4: Weighted Least Square Estimates used for prediction of onset of SW monsoon in Kerala

Estimates	Coefficient	Std. Error	t-ratio	P - value
Constant	452.39	105.33	4.29	<
b1 (Y_5)	0.19	0.09	2.04	0.04**
b2 (Y_12)	--0.12	0.09	--1.25	0.21
b3 (Y_19)	0.23	0.10	2.29	0.02**
b4 (Y_22)	--0.18	0.09	--1.87	0.06*

Table 2.4.4.5: Statistics based on the weighted data using 4 lags

Sum of squared residuals	588.62	S.E of regression	2.33
Log –likelihood	--253.59	Akaike criterion	517.18
Schwarz criterion	530.81	Hannan- Quinn	522.71
Rho	0.03	Durbin-Watson	1.90

Table 2.4.4.6: Runs test for randomness of errors

Test value	0.00
Cases < Test value	47
Cases >= Test value	66
Total cases	113
Number of Runs	57
Z	0.213
Asymp. Sig. (2 tailed)	0.831

Normality test for forecast errors

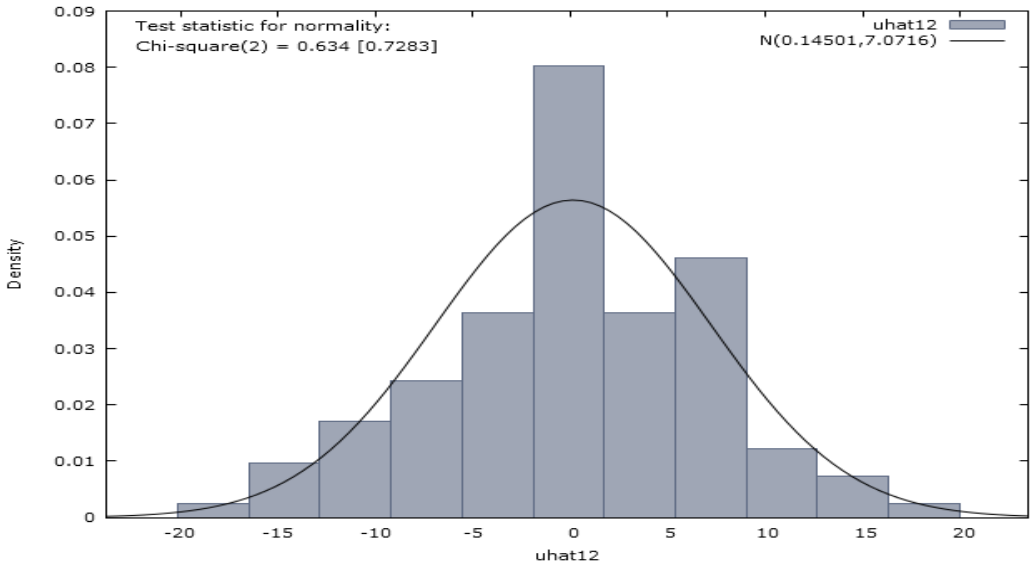


Fig. 2.4.4.3

Residual ACF and PACF for regression model using 4 lags

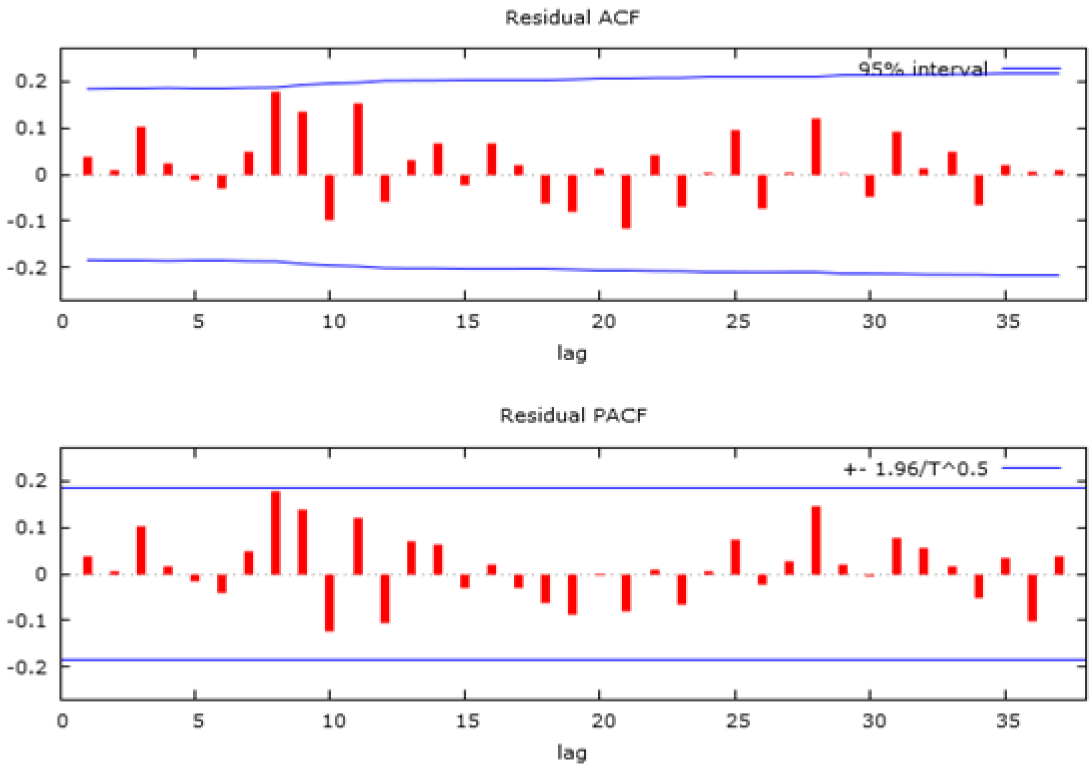


Fig. 2.4.4.4

The adequacy of the parsimonious model using the significant lags has been tested using the standard criterion on residuals. The errors satisfy the normality test (Fig.2.4.4.3) and peak of the curve corresponds to zero error. So it can be concluded that in most of the years the predictions can be done with zero error, that is with absolute accuracy as illustrated by the Runs test (Table 2.4.4.6) which shows that the modal value of error is zero. The non significant Z value of the Runs test indicate the acceptance of the Null Hypothesis that the errors of prediction were randomly distributed. The ACF (Auto correlation function) and PACF (Partial autocorrelation function) plots give a picture of white noise residual terms which shows that majority of the information content in the data has been extracted by the model and the residual series is not contaminated with any auto correlated terms. Long range forecasting of the Indian summer monsoon onset and rainfall in terms of antecedent upper air circulation have been attempted by Kung and Sharif (1982).

Table 2.4.4.7: Validation of the regression model (out of sample forecasts from 2005 - 2016) to predict the onset of SW monsoon

Year (1)	Actual dates of onset (2)	Predicted dates of onset using 37 lags (3)	Error in prediction (2) – (3)	Predicted dates of onset using significant lags 5,12,19,22 (4)	Error in prediction (2) – (4)
2005	524	517	7	517	7
2006	512	518	-6	517	-5
2007	514	519	-5	516	-2
2008	517	519	-2	519	-2
2009	509	512	-3	511	-2
2010	517	514	3	519	-2
2011	515	530	-15	519	-4
2012	522	515	7	519	3
2013	518	510	8	518	0
2014	523	522	1	517	6
2015	522	512	10	519	3
2016	524	516	8	523	1

From Table (2.4.4.7) it can be noticed that in almost all the years, the forecast errors are much lower in the case of predictions using regression model with selected significant lags as regressors when compared to the other models using 37 lags as well as the model using PMRP. The mean absolute error (MAE) used to compare the accuracy of prediction models turned out to be 3.08, 6.25 and 3.75 respectively for the models using 4 lags, 37 lags and using PMRP. The existing methods of monsoon onset forecasts make use of several variables of the current year and predictions are done for the particular year only. The recommended model (using 4 lags with lowest MAE = 3.08) in this study make use of the past values of a single variable viz., onset dates and the predictions can be done for several years in the future

Table 2.4.4.8: Forecasts of the onset of SW monsoon for the years from 2017 – 2021 using the parsimonious model (using lags 5,12,19,22)

Year	Prediction	Corresponding date of onset	S. E	95 % confidence interval
2017	518	1^{st}june	2.39	513.31 – 522.82
2018	516	30^{th} May	2.40	511.63 – 521.14
2019	517	31^{st} May	2.38	512.10 – 521.60
2020	516	30^{th} May	2.39	511.18 – 520.69
2021	521	4^{th}june	2.40	515.77 – 525.27

Table 2.4.4.9: Forecasts of the onset of SW monsoon for the years from 2017 – 2021 using the model with 37 lags

Year	Prediction	Corresponding date of onset	S. E	95 % confidence interval
2017	518	1^{st} June	1.58	514.90-- 521.22
2018	509	23^{rd} May	1.58	505.44-- 511.77
2019	515	29^{th} May	1.60	511.56-- 517.95
2020	517	31^{st} May	1.60	513.37-- 519.77
2021	516	30^{th} May	1.61	512.52-- 518.96

Onset predictions by IMD

The IMD uses three approaches to predict onset and strength of monsoon: statistical method, numerical weather prediction or dynamical method and dynamical cum statistical method. In all these methods several variables are used viz.,

i) Minimum Temperatures over North-West India, ii) Pre-monsoon rainfall peak over South Peninsula, iii) Outgoing Long wave Radiation (OLR) over South China Sea, (iv) Lower tropospheric zonal wind over South East Indian ocean, (v) upper tropospheric zonal wind over the East equatorial Indian Ocean, and (vi) Outgoing Long wave Radiation (OLR) over the South-West Pacific region.

The forecasts of the monsoon onset given by IMD for 2011-'15 were as follows

Table 2.4.4.10: Forecasts of the monsoon onset given by IMD for 2011-'15

Year	Actual Onset	Forecast of onset	Error
2011	29th May	31st May	-2
2012	5 th June	1 st June	4
2013	1st June	3rd June	-2
2014	6thjune	5thJune	1
2015	5thjune	30th May	6

2.4.5 Variation in quantity of SW monsoon rainfall with respect to onset dates

To study the linear relationship between the date of onset and the quantum of rainfall during SW monsoon, the total amount of rainfall received during the season was computed for the three stations viz., Vellayani (Thiruvananthapuram district), Vellanikkara (Thrissur district) and Pattambi (Palakkad district). The dates of onset were ranked in ascending order of magnitude. The corresponding total quantity of rainfall in each year during the SW monsoon period was computed from the date of onset to 30th September, *i. e*. the end of the SW monsoon period for each year. The daily data available from 1984 to 2013 (20years) were pooled to get the total quantity of rainfall for each year. The rainfall data were also ranked, giving 1st rank to the highest quantity. Now, the two sets of ranks, viz. ranks of onset dates for different years and ranks of the total quantity of rainfall were correlated. The Spearman's rank correlation coefficient was found to be + 0.35 for Vellanikkara which was significant at 5% level of significance. The correlation coefficients were 0.21 and 0.40 for Vellayani and Pattambi respectively. It can be understood that an early onset of monsoon can have profound effects on the quantity of SW monsoon rainfall.

3 SPATIAL AND TEMPORAL VARIATIONS OF RAINFALL IN KERALA

3.1 INTRODUCTION

The inter-annual variations of rainfall in Kerala can be annual, seasonal or spatial. In the State, though much variation is not felt in the first two, there is considerable distinction in the spatial variation. If investigations are done on short term and long term fluctuations, observe the spatial and temporal characteristics and study the methods to compensate it, engineers and hydrologists can make use of rainfall and produce maximum advantage out of it. The global climate, as well as the processes like agriculture, is sensitive to the annual variation in Monsoon. If, the variation is within 1 standard deviation of the long term mean it is considered as normal and wet\dry if it is above or below one standard deviation of the mean (Aype, 2005).

In general, agricultural production, water resources management and overall economy of the country are seriously affected by climatic changes. As rainfall is a highly variable element in spatial and temporal scale with respect to daily, decadal and long term fluctuations (Juan-carlos *et al* , 2009) a study was carried out to identify the monthly, seasonal and annual trend of rainfall in Kerala.

3.2 REVIEW OF LITERATURE

Spatial and temporal patterns of rainfall during mid-summer and their relationships to inter annual drought occurrences in Southern Africa have been studied using dry spell frequencies by Usman and Reason (2004)

The occurrence and distribution of rainfall and spatial and seasonal variations of rainfall pattern in Lower Bhavani river basin, Tamil Nadu has been made by Anantha Kumar *et al* (2008).

Singh and Ranade (2009) has opined that in this era of climate change scenario projections, characteristics of wet spells and intervening dry spells are extremely useful for water related sectors. The wet and dry spells for 19 sub regions across India have been studied using gridded daily rainfall available on 1^{o} latitude x 1^{o} longitude spatial resolution for the period

1951 – 2007. A continuous period with daily rainfall equal to or greater than (less than) daily mean rainfall of monsoon period over the area of interest is taken as the intra- annual variation. The rainfall due to wet spells contributes 68% and dry spells 17% to the respective annual total. In a majority of regions the actual and extreme wet spells are slightly shorter and thus rainfall intensity is higher in recent years/decades. But the actual and extreme dry spells are slightly longer with weaker rainfall intensity. A tendency for the first wet spell to start 6 days earlier and to end two days earlier was observed leading to larger duration of rainfall activities. In any of the 40 wet spell/dry spell parameters studied, a spatially coherent, robust long term trend was not found.

Pradeep (2012) carried out a study on the variation in temperature in the campus of CWRDM, Kozhikode, taking 27 years of data from 1983 – 2009 and revealed that there was not much variation in the average values of atmospheric temperature. No trend was observed in maximum, minimum and average temperature. It may be due to the total weather phenomenon like cloud coverage, rain, air- mass condition etc., minor variations in the values on different days were observed. The main reason for not having a considerable increase in temperature unlike in developed cities might be due to the fact that there was not much degradation of vegetative cover and greenery in the campus.

Rao *et al.* (2012) noticed warming Kerala in tune with global warming through analysis of the temperature data from 1956 – 2009. There was an increase of 0.72^{o}C in annual maximum temperature, 0.22^{o}C in minimum temperature and 0.47^{o}C in mean annual temperature over a period of 54 years. This was prominent since 1981 onwards. Increase in temperature, decline in rainfall, dryness within the humid climate, increase in aridity index and droughts were the major climate change indicators observed in Kerala State.

Chakraborty (2013) made use of modified Mann- Kendall and Spearman’s rho test to estimate trend in rainfall at Seonath sub basin in the Chattisgarh State using 49 years (1960 – 2008) rainfall data. Spatial and temporal variability of rainfall also have been studied using coefficient of variation. For annual and seasonal rainfall series, decreasing trend was noticed

Bibi *et al.* (2014) studied spatial-temporal variability of monthly amounts and frequency in rainfall and rainfall trends by analyzing 27 years (1980-2006) of gridded daily rainfall data obtained from a merged data set by National Centre for Environmental Prediction and Climate research Unit (NREP & CRU). Temporal variability was assessed using the percentage coefficient of variation and temporal trends in rainfall were assessed using maps of linear regression slopes for the months of May through October.

Sindhu and Chandralekha (2014) made a study on trend in monthly temperature using Mann-Kendall trend test and the predictions were made using Sen's slope and moving average method for an urban area of Thiruvananthapuram city.

Sushant *et al.* (2015) analysed the rainfall data of Cauvery river basin. The rainfall distribution, variability and trends during 1901 – 2002 were studied. The result showed that the coefficient of variation fluctuate significantly during the winter season than other seasons. Winter rainfall showed a significant decreasing trend and an increasing trend in the post monsoon season. Annual rainfall got a significant decrease during twentieth century.

Sivajyothi and Karthikeyan (2017) used Mann-Kendall test to assess the significance of monthly, seasonal and annual rainfall using the rainfall data for a period from 1901 to 2002 for 12 districts in Andhra Pradesh. No significant trend was noticed in the annual and seasonal rainfall in the entire State. In some of the districts, annual and monsoon precipitation have decreased and post monsoon and winter rain increased.

3.3 DATA AND METHODOLOGY

The monthly data of rainfall for a period of 146 years from 1871 to 2016 based on 306 stations were collected from the official website of Indian Institute of Tropical Meteorology Pune. A detailed analysis of the data was done to identify the existence of trend in the monthly, seasonal and annual data of rainfall for 146 years. The Non parametric Mann-Kendall test was applied for this purpose on the assumption that there was no serial dependence in the time series data. It is commonly employed to detect monotonic trends in series of environmental climatic and hydrological data. The Mann-Kendall statistic 'S', 'Senslope' and 'P value' were computed. The direction of trend can be assessed through the positive or negative values of 'S'. Senslope represents the rate of change of climatic parameters with respect to time. If a significant trend was noticed based on the level of significance, the future predictions of a climatic variable can be made using the Senslope value for that particular period.

The Mann Kendall statistic is given by,

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign\left(X_j - X_k\right)$$

$$\text{Sign}(x) = \begin{cases} 1 \; if \; x > 0 \\ 0 if \; x = 0 \\ -1 \; if \; x < 0 \end{cases}$$

The mean of S is E[S] =0 and the variance

$$\sigma^2 = \left\{ n(n-1)(2n+5) - \sum_{j=1}^{p} t_j\left(t_j - 1\right)\left(2\, t_j + 5\right) \right\} /18$$

Where p is the number of tied groups in the data set and tj is the number of data points in the jth tied group. The statistic S is approximately normally distributed provided that the following Z – transformation is employed:

$$Z = \begin{cases} \frac{S-1}{\sigma} if \;\; S > 0 \\ 0 if \;\; S = 0 \\ \frac{S+1}{\sigma} \; if \;\; S < 0 \end{cases}$$

Magnitude of Trend: Sen's slope

According to Sen's method the linear slope is calculated as

$$d_k = \frac{X_j \; - \; X_i}{j - i}$$

For ($1 \leq i < j \leq n$) where d is the slope, x denotes the variable, n is the number of data points and i, j are indices. Sen's slope is then calculated as the median from all slopes.

B= Median d_k. The intercepts are calculated for each time step t as $a_t = x_t - b^*t$.

3.4 RESULTS AND DISCUSSION

3.4.1 Temporal variations of rainfall in Kerala

A detailed investigation of the rainfall data for 146 years from 1871 to 2016 revealed that the long term average rainfall in Kerala was 2816.65 mm with a S.D of 415.06 mm and C.V=14.74 . The long term average for different months from January to December ranges from 10.77 mm in January to 679.61mm in June. In February, the average rainfall was 16.35 mm and in March 36.97 mm. For April & May it was 111.66 mm & 243.32 mm. A significant hike was observed in the average rainfall in June as 679.61mm and in July 633.45 mm. Again there were diminishing values as 375.81mm in August and 229.91 mm in September. Due to the North East monsoon, a slight increase was observed as 287.16 mm in October and a descend to 154.46 mm in November and a steep fall to 37.18 mm in December. The time series of monthly rainfall in Kerala for 146 years is given in Fig.3.4.1.1

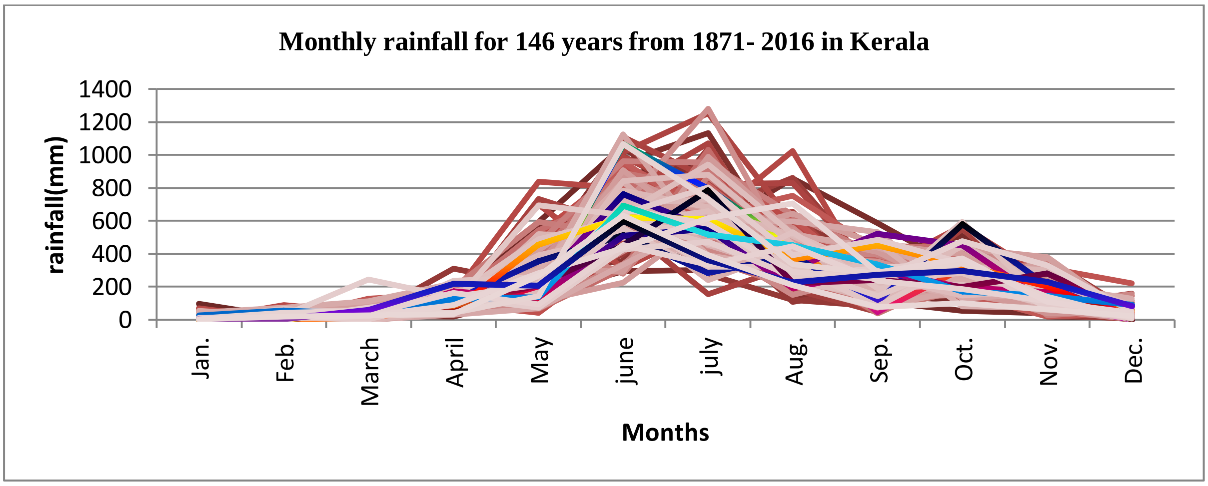


Fig. 3.4.1.1

Table 3.4.1.1: Mean, S.D and C.V of monthly, seasonal and annual rainfall for 1871-2016 in Kerala

Period	No. of years	Mean	S.D.	C.V.	Percentage contribution to the annual rainfall
January	146	10.77	16.36	151.88	0.38
February	146	16.35	18.65	114.05	0.58
March	146	36.97	31.99	86.52	1.31
April	146	111.66	52.09	46.65	3.96
May	146	243.32	156.14	64.17	8.64
June	146	679.61	192.95	28.39	24.13
July	146	633.45	205.57	32.45	22.49
August	146	375.81	156.16	41.55	13.34
September	146	229.91	122.14	53.12	8.16
October	146	287.17	108.69	37.85	10.20
November	146	154.46	83.92	54.33	5.48
December	146	37.18	37.65	101.25	1.32
Winter (J,F)	146	27.12	25.66	94.58	0.96
Pre Monsoon(MAM)	146	391.95	158.63	40.47	13.92
SW Monsoon (JJAS)	146	1918.79	374.09	19.50	68.12
Post Monsoon	146	478.81	148.65	31.04	16.99
Annual	146	2816.65	415.06	14.74	

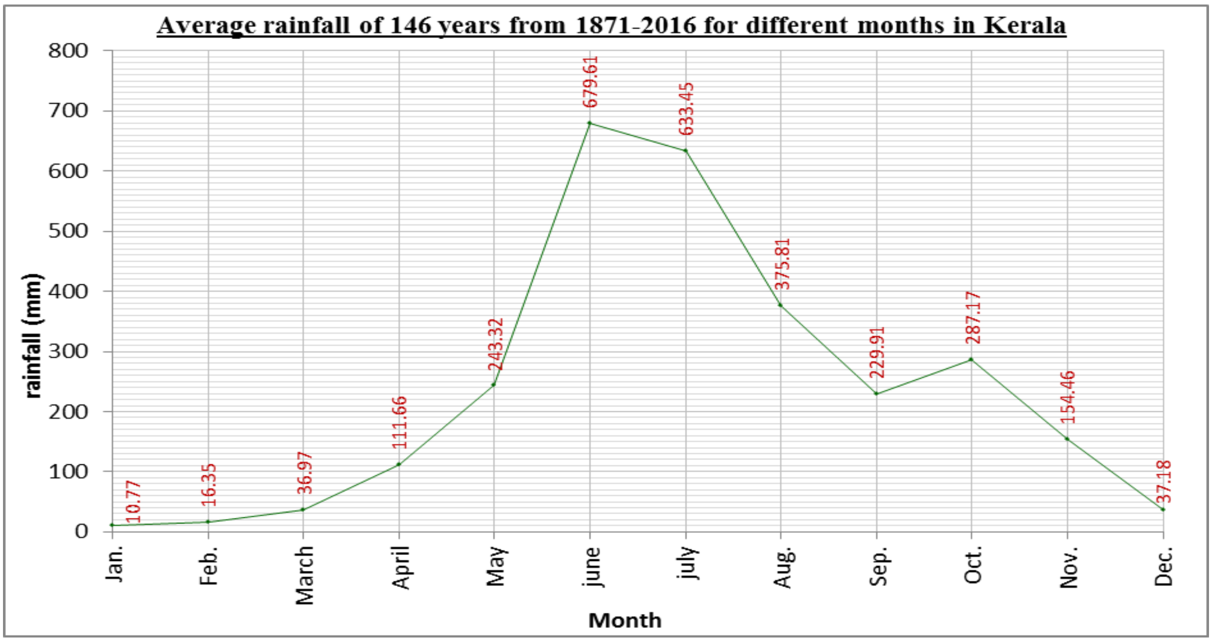


Fig. 3.4.1.2

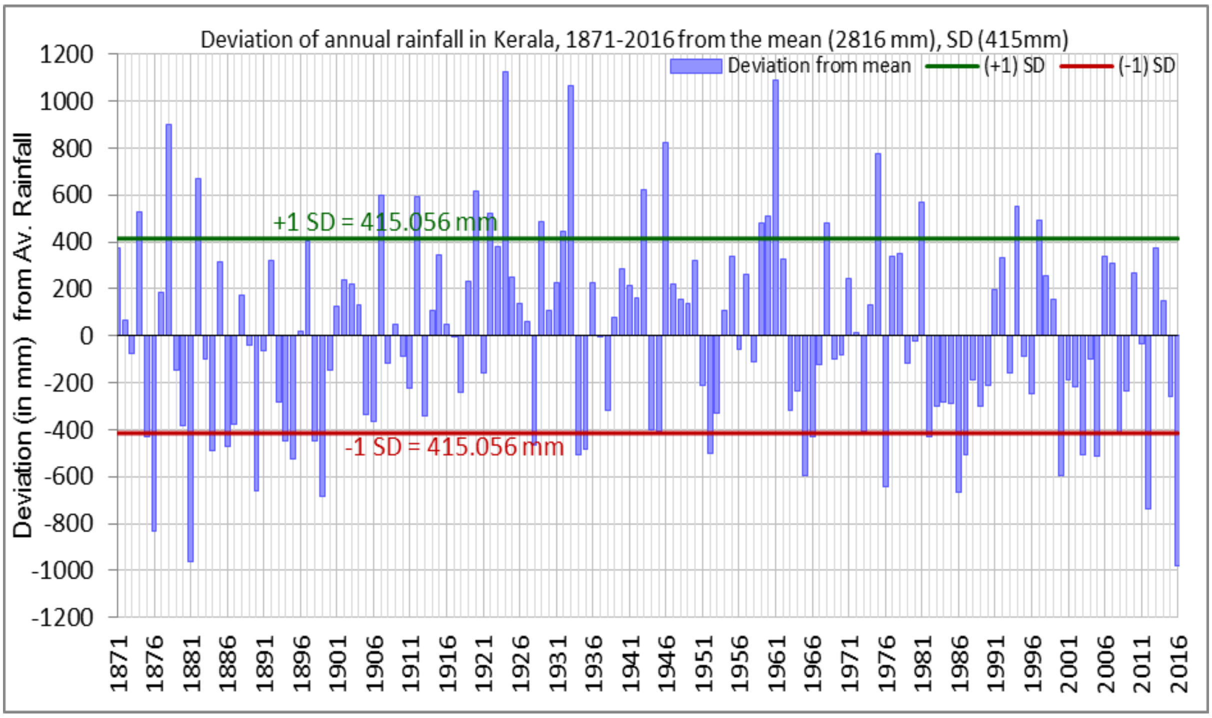


Fig. 3.4.1.3

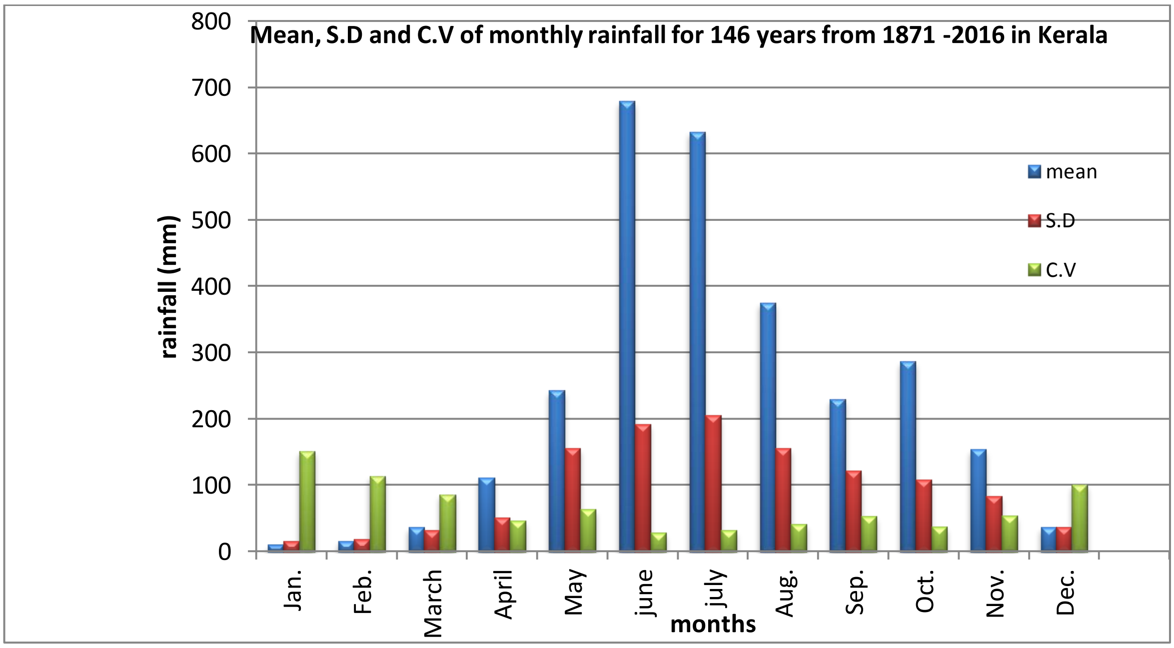


Fig. 3.4.1.4

The consistency in the amount of rainfall received during the month of June, July and October are more as revealed by the low values of percentage coefficient of variation. As it is evident, the CV% is very high in the month of December, January and February (Fig.3.4.1.4)

When the rainfall amount for different seasons namely, winter, pre- Monsoon, SW Monsoon and post Monsoon were considered, the average quantity of rainfall received in SW Monsoon was 1918.79 mm with a C.V of 19.49% followed by 478.81 mm in the post-monsoon period with a C.V of 31.04% and with a quantity of 391.95 mm during the pre-monsoon period with a C.V of 40.47% and the least contribution to the annual rainfall by an average amount of 27.12 mm as the winter rain with a C.V of 94.58%. About 24.13% of the annual rainfall was contributed through the showers in the month of June followed by 22.49% in July, 13.34% in August, and 10.2% in October and through the other months. When the season-wise data was considered, around 68.12% of the annual rainfall was contributed by SW monsoon followed by 16.99% by NE monsoon (post monsoon), 13.92% by pre-monsoon and a negligible amount of 0.96% by the winter rain.

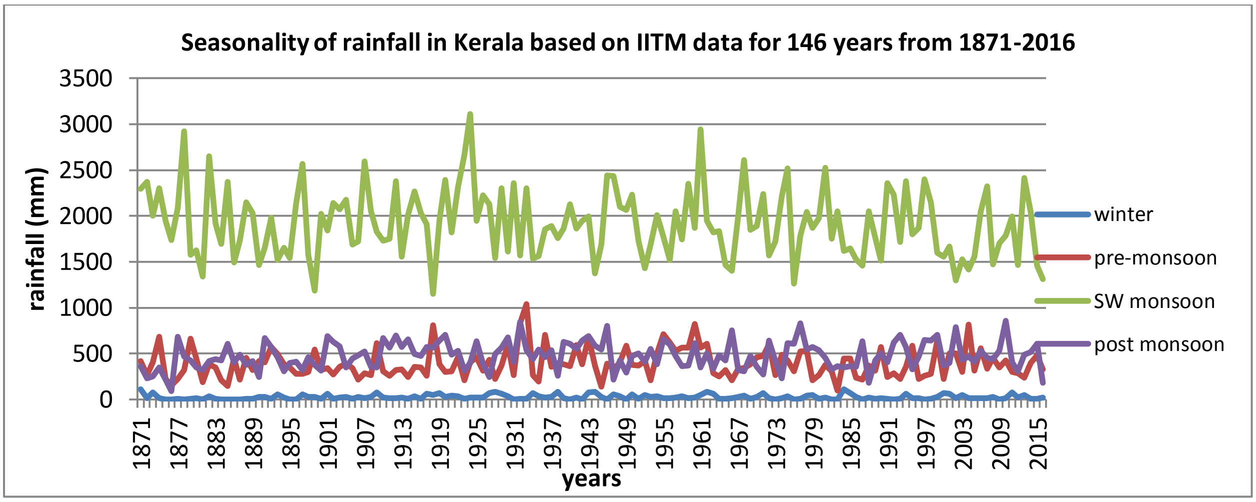


Fig. 3.4.1.5

Table 3.4.1.2: Monthly, seasonal and annual highest and lowest rainfall and the corresponding year of occurrence

Period	Year corresponding to occurrence of highest rainfall	Quantity of highest rainfall (mm)	Year corresponding to occurrence of lowest rainfall	Quantity of lowest rainfall (mm)
January	1871	96.9	*	0
February	1938	87.6	*	0
March	2008	242.8	*	0
April	1899	310.1	1881	18.3
May	1933	837.4	1945	41.2
June	1981	1123.7	1976	222.5
July	1968	1281.1	1918	152.5
August	1931	1023.5	1898	107
September	1878	586.1	1957	36
October	1999	593.2	1876	54.6
November	1977	379.8	1873	19
December	1946	221.1	1910	0
Winter (J,F)	1984	113.4	1973	0
PreMonsoon(MAM)	1933	1036.8	1983	100.2
SWMonsoon (JJAS)	1924	3115.3	1918	1150.2
Post Monsoon	2010	857.5	1876	93.2
Annual	1924	3944.9	2016	1837.4

* denote occurrence in more than one year

From 1871 – 2016, the year corresponding to the peak and pits of rainfall in each month, season and year is provided in Table (3.4.1.2). The peak value in January was 96.9 mm in 1871and the lowest value was 0 in several years. In February the highest value was 87.6 mm in1938 and the lowest value was 0 in several years. In March the maximum rainfall was 242.8 mm in 2008 and minimum 0 in several years. The highest and lowest values in April were 310.1 mm in 1899 and 18.3 mm in 1881. In May, the maximum value was 837.4 mm in 1933 and the minimum occurred in 1945 as 41.2 mm. Even though the average rainfall over 146 years was highest in June the highest of all the years was occurred in July. In June the highest value was1123.7mm in 1981and the minimum value 222.5 mm in 1976. The highest value was 1281.1 mm in July 1968 and the lowest value in July was 152.5 mm in1918. The range was 1023.5 mm to 107 mm in August during the years 1931 and 1898 respectively. In September, the maximum value was 586.1 mm in 1878 and a minimum of 36 mm in 1957. The peak value in October 1999 was 593.2 mm and 54.6 mm was the minimum in 1876. In November, the highest value was 379.8 mm in 1977 and the minimum 19 mm in 1873. In December, the range was 221.1 mm in 1946 and 0.0 mm in 1910.

When seasonal rainfall was considered, the peak winter rain was 113.4 mm in 1984 and the least was 0.0 mm in1973. The pre-monsoon peak was 1036.8 mm in 1933 and the minimum was 100.2 mm in 1983. In 1924 a maximum of 3115.3 mm rainfall was obtained during the South West monsoon season. The minimum monsoon rainfall was 1150.2 mm in 1918. The highest post monsoon rainfall was 857.5 mm in 2010 and the minimum was 93.2 mm in 1876.

The annual peak rainfall over 146 years, from 1871 to 2016, was 3944.9 mm in 1924. The year 2016 was a drought year pushing the annual rainfall downward to 1837.4 mm. Such an event of low rainfall has not occurred for the last 145 years of study.

Wet and Dry Years in Kerala for the period from 1871 - 2016

The monsoon rainfall is considered to be normal if it is within 1 standard deviation of the long term mean and wet/dry if it is beyond 1 standard deviation of the long term mean (Aype, 2005). Out of the 146 years under study, 99 years received normal rainfall, 21 years were wet and 26 years were dry. The same is depicted in Fig. (3.4.1.6). The number of years falling beyond ± 2 S.D limits were very rare.

Table 3.4.1.3: The dry and wet years in different decades, the gap between two consecutive dry/wet years and the quantity of rainfall received for the period 1871-2016

Decade	Dry years	Quantity of rainfall received (mm)	Gap between dry years	Decade	Wet years	Quantity of rainfall received (mm)	Gap between wet years
1(1871-1880)	1875	2389.2		1(1871-1880)	1874	3346.3	
1(1871-1880)	1876	1986.3	1	1(1871-1880)	1878	3716.9	4
2(1881-1890)	1881	1855.7	5	2(1881-1890)	1882	3486	4
2(1881-1890	1884	2326.9	3	4(1901-1910)	1907	3416.6	25
2(1881-1890	1886	2345.2	2	5(1911-1920)	1912	3410.7	5
2(1881-1890	1890	2153.2	4	5(1911-1920)	1920	3433.2	8
3(1891-1900)	1894	2366.7	4	6(1921-1930)	1922	3339.9	2
3(1891-1900)	1895	2291.2	1	6(1921-1930)	1924	3944.9	2
3(1891-1900)	1898	2367	3	6(1921-1930)	1929	3304.5	5
3(1891-1900)	1899	2131.4	1	7(1931-1940)	1932	3260.1	3
6(1921-1930)	1928	2351.5	29	7(1931-1940)	1933	3884	1
7(1931-1940)	1934	2307.6	6	8(1941-1950)	1943	3440.2	10
7(1931-1940)	1935	2334.7	1	8(1941-1950)	1946	3642.5	3
9(1951-1960)	1952	2313.2	17	9(1951-1960)	1959	3299.6	13
10(1961-1970)	1965	2218.2	13	9(1951-1960)	1960	3328.2	1
10(1961-1970)	1966	2387.7	1	10(1961-’70)	1961	3907.2	1
11(1971-1980)	1976	2172	10	10(1961-’70)	1968	3299.1	7
12(1981-1990)	1982	2389.2	6	11(1971-‘80)	1975	3593.9	7
12(1981-1990)	1986	2147.1	4	12(1981-‘90)	1981	3384.3	6
12(1981-1990)	1987	2306.7	1	13(‘91-2000)	1994	3368.5	13
13(1991-2000)	2000	2219	13	13(‘91-2000)	1997	3307.3	3
14(2001-2010)	2003	2311.7	3				
14(2001-2010)	2005	2300.7	2				
14(2001-2010)	2008	2395.5	3				
15(2011-2020)	2012	2078.4	4				
15(2011-2020)	2016	1837.4	4				

The wet years were 1874, 1878, 1882, 1907, 1912, 1920, 1922, 1924, 1929, 1932, 1933, 1943, 1946, 1959, 1960, 1961, 1968, 1975, 1981, 1994 & 1997. Among the wet years, in 6 years namely 1878, 1924, 1933, 1946, 1961 and in 1975 there was beyond 25% excess of the normal year rainfall and they were identified as flood years and 1924 was the most flooded year. The dry years were 1875, 1876, 1881, 1884, 1886, 1890, 1894, 1895, 1898, 1899, 1928, 1934, 1935, 1952, 1965, 1966, 1976, 1982, 1986, 1987, 2000, 2003, 2005, 2008, 2012 & 2016. Among the dry years, 1876, 1881, 2012 and 2016 were drought years which were having rainfall deficit more than 25% of the normal and the worst drought was hit in 2016 under the study period.

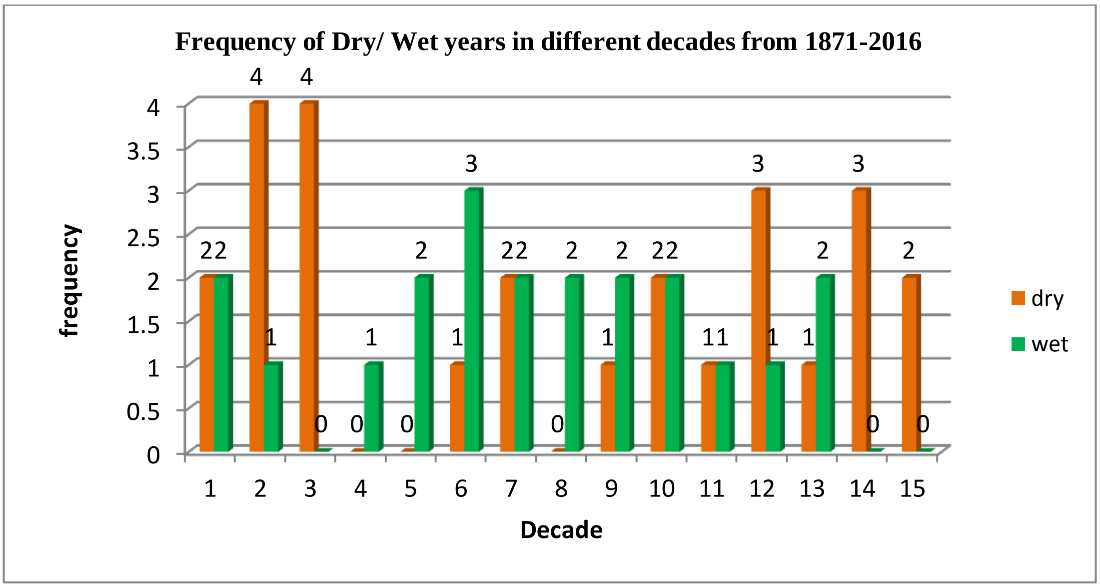


Fig. 3.4.1.6

The distribution of wet years and dry years over different decades are shown in Table (3.4.1.3), Fig. (3.4.1.6). There were 4 wet years in decade 2 & 3 followed by 3 dry years in 12th and 14th decade. There was no drought year during the 4th & 5th decade. In the 15th decade even though it included only 6 years, there were two drought years and 2016 was the worst drought year ever had in Kerala. Even the Government had for the first time ever, planned to impose a water ration system across households and industries as recommended by the Kerala State Disaster Management Authority (KSDMA). Irrigation across districts in the state was stopped. The state received a deficit of 33.7% rain from the SW Monsoon and NE Monsoon. The wind, between October and December, more or less deserted the state.

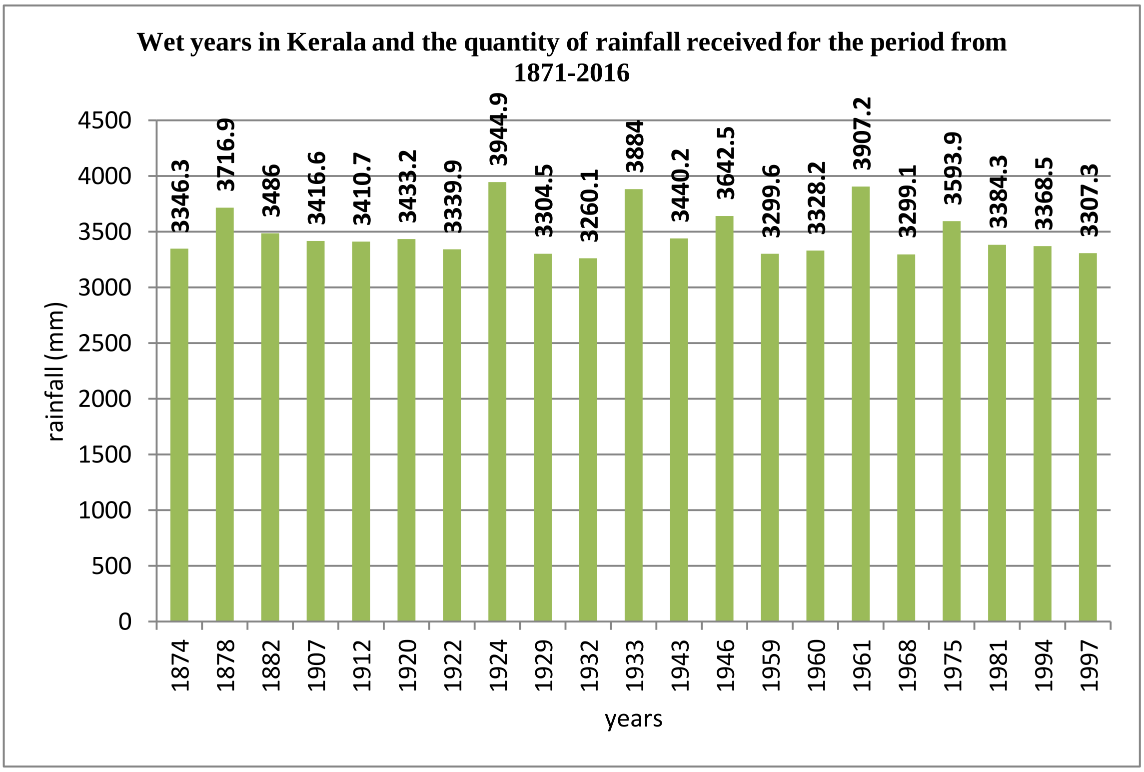


Fig. 3.4.1.7

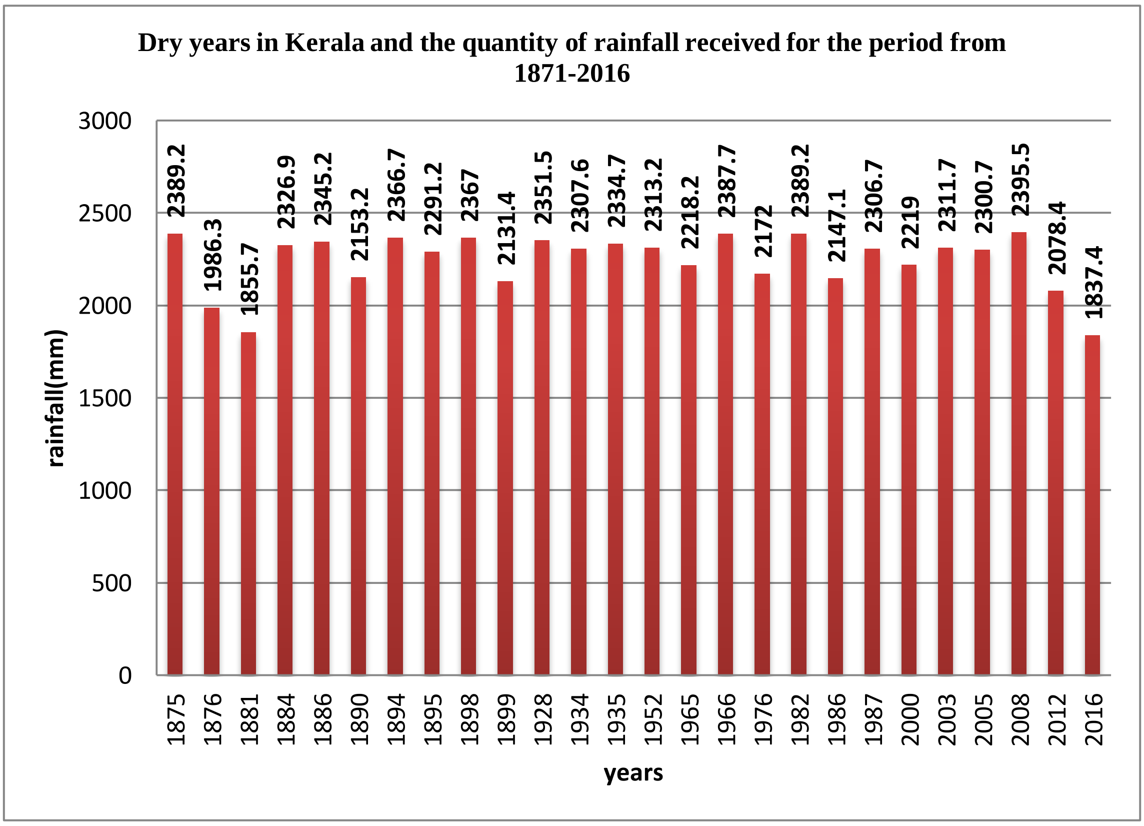


Fig. 3.4.1.8

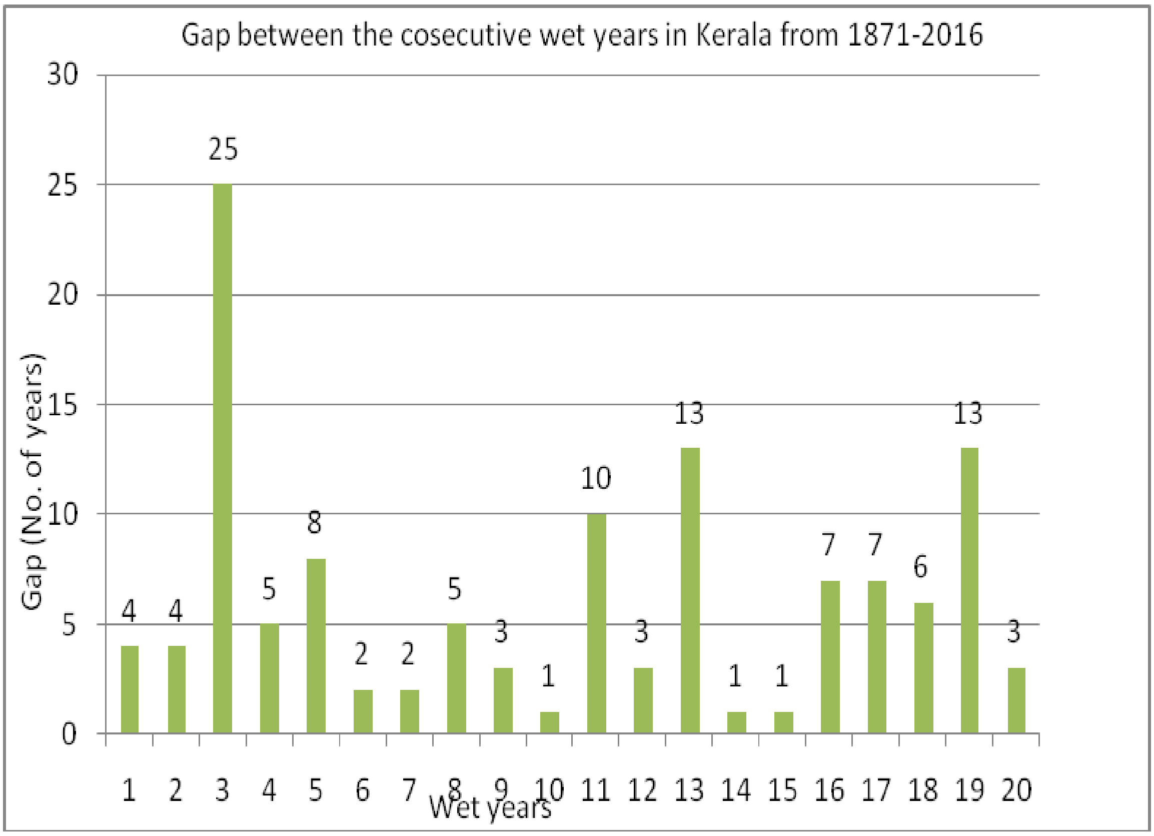


Fig. 3.4.1.9

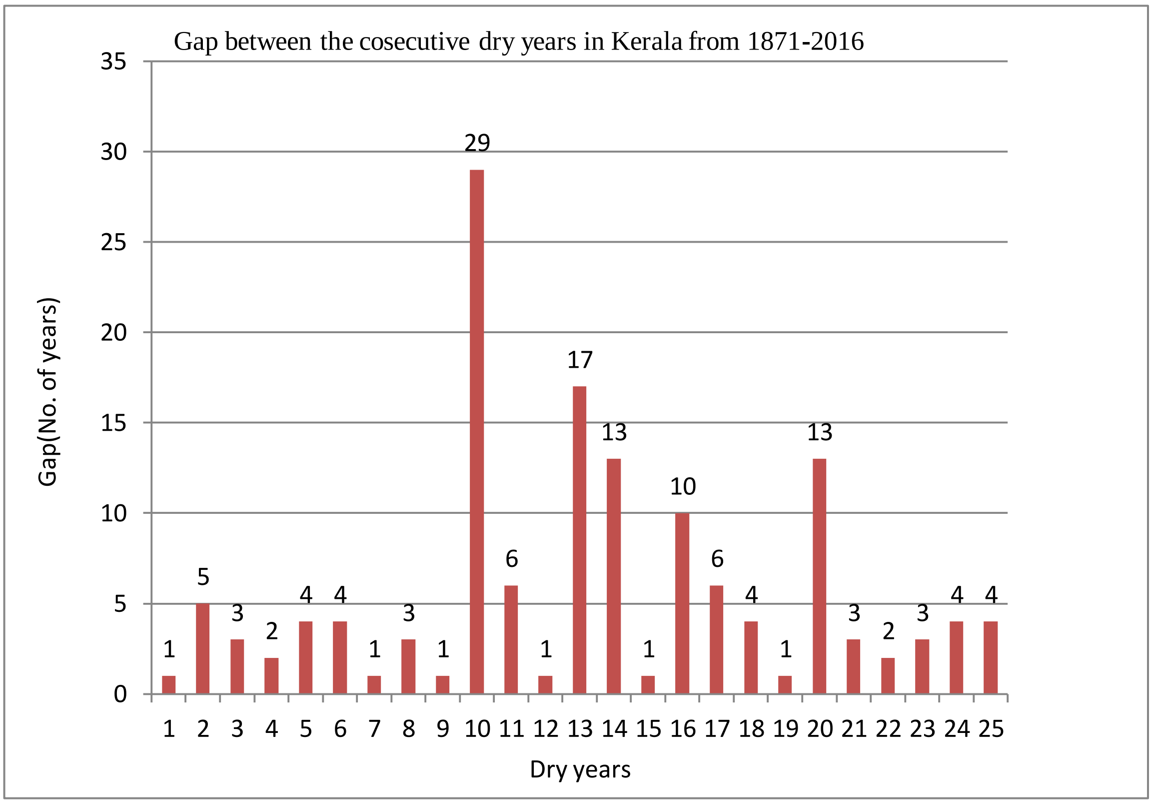


Fig. 3.4.1.10

The severity of occurrence of drought was very rare. From the year 1871 onwards there were 26 dry years in the State. But, none of them was as severe as the one in 2016. The 2012 drought was perhaps the worst one until 2016. Usually, the NE monsoon used to compensate for the deficiency in SW monsoon. But, in 2016 it didn't happen.

Consequences of severe flood and drought in Kerala

The worst affected years in Kerala due to flood and drought were 1924 and 2016 respectively. The actual consequences were as given below.

Flood in 1924

The most severe flood in the recent history of Kerala was occurred in July 1924, in Periyar river. Many parts of the districts viz., Idukki, Kottayam, Ernakulam, Alappuzha and Thrissur were submerged or seriously affected as heavy rain continued for about three weeks. As per the Malayalam calendar it was in the year 1099 M.E. Hence, the flood was popularly known as the "flood of 99". Major landslides occurred in many places and a mountain, 'Karinthirimala' almost washed away due to the flood along with the road to Munnar, lying at an elevation of about 1500 m from the sea level. A monorail system, which was unique in the subcontinent, constructed in 1902 connecting Munnar and Top station which was later replaced by light railway system in 1908 also washed away by the 1924 flood. The present road from Ernakulam to Munnar was constructed after this flood.

There was a belief without any substantial proof that the 1924 flood was caused by a major breech of Mullaperiyar Dam. Much more realistic information was given by Sri. Ranjith K., Asst. Manager, L & T that during the month of July 1924 three floods had been occurred in South India. And this could not be caused by a dam break. In the "Review of floods in India for the last 75 years" by Mr. C. Ramaswamy it has been mentioned that there was heavy rainfall with increased wind speed during the last week of July 1924 (Anonymous, 2017). The reasons for the heavy rainfall and flood were attributed to:

1. Off shore vortices along the west cost
2. Mesoscale factors in the lower layer of atmosphere in the hilly areas
3. Perturbations in the higher layer of troposphere in the form of waves in the easterlies.
4. Movement of high level easterly jet maxima

The total rainfall (mm) in 1924 distributed over different months and seasons was as follows

Table 3.4.1.4: The total rainfall (mm) in 1924 distributed over different months in Kerala

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
19	5.2	74.4	130.3	199.9	1014.5	1253.3	583.9	263.6	153.6	192.8	54.4

Table 3.4.1.5: The total rainfall (mm) in 1924 distributed over different seasons in Kerala

JF	MAM	JJAS	OND	ANN
24.2	404.6	3115.3	400.8	3944.9

The SW monsoon (3115.3 mm) was the heaviest of all the years under study and it contributed to the peak rainfall of 3944.9 mm during the year 1924.

The heavy flood of 1924 and the consequent landslides almost destroyed the nearby towns and submerged many places. It also claimed lives of many people, animals and destroyed many man-made structures along the banks of the river and neighbouring places and almost changed the shape of many places. Damages happened to the crops and properties were devastating. The flood was most destructive in Munnar where approximately 485 cm rainfall was reported during those few days. The Kundala valley narrow gauge railway line at Munnar was irreparably damaged and eventually abandoned. Our old generation, who witnessed the flood could remember that incident only with fear.

During those period most of the records pertaining to the locality were used to be kept by the Churches. Most of them were destroyed due to the flood and hence Church records now available are only from 1924 onwards (Anonymous, 2015).

Drought in 2016

Experts have opined that the State’s flora survived the dry months because the rains were wide spread even though it was scarce. The rainfall during the SW monsoon period and post monsoon period in different districts, for the year 2016 are depicted in Table (3.4.1.6) &

Table (3.4.1.7). The departure from the normal rainfall was negative for all the districts during SW as well as NE monsoon.

Table 3.4.1.6: South-West Monsoon Rainfall in 2016 for different districts of Kerala

District	Actual rainfall (mm)	Normal (mm)	Departure from Normal (%)
Thiruvananthapuram	572.3	871.3	-34
Kollam	950.9	1332.3	-29
Pathanamthitta	1095.4	1715.7	-36
Alappuzha	1134.8	1745.9	-35
Kottayam	1330.7	1897.3	-30
Idukki	1569.5	2276.2	-31
Ernakulam	1569.4	2065.0	-24
Thrissur	1219.6	2197.5	-44
Palakkad	1034.7	1572.7	-34
Malappuram	1251.2	2060.4	-39
Kozhikode	1887.3	2603.1	-27
Wayanad	1073.8	2632.1	-59
Kannur	1991.0	2669.0	-25
Kasaragode	2253.0	3007.5	-25

Table 3.4.1.7: Rainfall from 1st October to 31st December, 2016 in Kerala

District	Actual rainfall (mm)	Normal (mm)	Departure from Normal (%)
Thiruvananthapuram	112.4	511.2	-79
Kollam	406.8	627.9	-35
Pathanamthitta	425.8	614.9	-31
Alappuzha	208.4	564	-63
Kottayam	252.4	527.6	-52
Idukki	174.1	557	-69
Ernakulam	295.1	484.4	-39
Thrissur	152.1	464.9	-67
Palakkad	137.5	424.3	-68
Malappuram	118.2	447.3	-74
Kozhikode	74.6	418.2	-82
Wayanad	104.8	327.4	-68
Kannur	84.4	342	-75
Kasaragode	71.2	335.1	-79

Source: Kerala State Disaster Management Authority (KSDMA), www.firstpost.com and Economic review.

The consequences of such a drought are very severe like drying up of water bodies, wide spread wilting of vegetation and crops, heat wave, etc.

Though, the consecutive failure of monsoon is very rare, it will create severe adverse after effects on us. The ground water table also would go downwards. Though, our State is getting rain in more than 6 months in a year, its steep topography do not support to hold the water, and most of the water falling on the ground will escape to the Arabian sea easily unless, we get heavy rains at a prolonged interval. This requirement is satisfied by the arrival of North-East monsoon in October, which may extend to December. The ground water table went very much below the normal level since the NE monsoon was very weak in 2016. Water level in almost all the reservoirs were decreasing alarmingly which forced the Government to take stringent steps to control usage of remaining water in the reservoirs in the State. The State government introduced a 26 point agenda as suggested by the KSDMA, with the motto of 3'R's –Reduce, Reuse and Recycle water. It was also decided to fix an order of preference for the use of water as, drinking followed by house hold and then industrial use, till May 2017. The Government banned washing motor vehicles etc., using water supplied by its public water supply system. Industries which tap ground water were instructed to reduce the use to 75% till May 2017, by which summer rains were expected. It was also forced to take stringent measures, including provision of police protection for keeping the reservoirs free of pollution, considering water as the most precious commodity.

Since, the State power system depends on Hydro-power, the drought in 2016 had its adverse impact here also. Though, the annual requirement was 24000 million units, the internal generation was only 7100 MU. Due to the decrease in rainfall, available water in the reservoirs were sufficient only for about 5400 MU. That means, a deficit of about 2000 MU which would have to be additionally purchased from outside the State bearing large financial burden on the State Electricity Board. An assessment done on 22nd December 2016 comparing the power generation is as shown below.

Table 3.4.1.8: Comparative power generation capacity on 21st December (in million units) in Kerala

2012	2013	2014	2015	2016
1819.6	3646.08	3246.15	2754.15	1988.93

Source: KSEB Ltd.

During the earlier drought in 2012, the power generation was 1819.6 MU and KSEB was forced to implement frequent load shedding and power cuts and imposed a usage based hike in the electricity charges to its consumers, depending on their consumption slabs.

Gap between consecutive wet years and consecutive dry years

When the gap between the consecutive wet years was considered it could be observed that 3 wet years occurred at a gap of 4 years. The next wet year was seen after a long gap of 25 years. In the case of dry years also such a long gap of 29 years was observed. In general the gap of occurrence of dry years was small when compared to wet years. That means, in Kerala the frequency of occurrence of dry years were more than consecutive wet years. After 1997 a wet year has not occurred in Kerala whereas frequency of occurrence of dry years was increasing. From 2000 onwards, dry years occurred in Kerala with an average gap of 3 years. In 2016, the government declared the entire State drought hit, with all the 14 districts witnessing successive monsoon failures. Reservoir levels were at least 22% lower than the average.

Decadal variation of rainfall in Kerala

Climate is the weather of a place averaged over a period of time. Climate information includes the statistical weather information that tells us about the normal weather, as well as the range of weather extremes for a location. Climate change is expressed in terms of years, decades and centuries. In climate study, trends of cycles of variability in different weather variables is considered. A lot of changes can take place day to day in weather conditions but, usually the climate remains relatively constant. If it is not constant it can be named as climate change. Since the main objective of the study is to quantify the climate change, a decadal study was performed.

To study about the variations in rainfall between decades, the decadal mean for 15 years starting from 1871 to 2016 were computed and to test whether there was a significant difference between the decades with respect to rainfall, a one way ANOVA was performed and the following results were obtained. The results are given in Tables (3.4.1.9) –(3.4.1.10)

Table 3.4.1.9: Decadal variation of rainfall from 1871-2016 (Monthly, Seasonal & Annual) in Kerala

Decadal variation of rainfall in January, 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	10.36	30.43	293.76	97	0
2	4.36	10.87	249.40	35	0
3	4.46	5.26	117.88	19	0
4	16.66	20.38	122.34	67	0
5	15.81	20.62	130.44	54	0
6	16.85	10.70	63.49	39	0
7	11.87	21.78	183.53	69	0
8	19.04	21.88	114.93	60	0
9	7.1	8.09	113.98	27	0
10	13.72	12.57	91.59	34	1
11	6.31	14.57	230.94	47	0
12	12.71	19.27	151.61	55	0
13	5.3	5.95	112.27	19	0
14	7.55	8.42	111.50	26	0
15	8.567	8.74	102.01	26	3

Decadal variation of rainfall in February, 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	13.8	23.29	168.74	78	0
2	4.43	7.41	167.25	25	0
3	19.31	16.97	87.87	53	0
4	13.22	11.40	86.22	36	1
5	15.27	17.19	112.56	62	3
6	23.68	25.05	105.78	74	0
7	15.84	26.29	165.98	88	0
8	18.45	19.48	105.57	59	1
9	16.76	12.54	74.85	46	3
10	19.84	18.85	95.03	51	0
11	17.92	15.88	88.64	44	0
12	15.27	22.25	145.72	73	0
13	15.95	22.00	137.94	66	0
14	15.31	17.74	115.89	51	0
15	22.87	20.70	90.52	54	6

Decadal variation of rainfall in March, 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	21.15	17.98	85.00	54	1
2	19.74	17.86	90.45	58	0
3	44.13	36.13	81.88	107	6
4	34.55	22.66	65.58	61	1
5	27.76	19.23	69.28	77	11
6	51.59	24.66	47.80	89	15
7	39.77	31.91	80.23	115	0
8	49.01	41.92	85.53	129	2
9	40.33	27.73	68.76	103	10
10	43.48	29.81	68.56	103	12
11	28.37	24.70	87.06	89	3
12	35.92	30.60	85.18	113	0
13	24.84	15.54	62.56	53	0
14	55.69	69.55	124.88	243	3
15	39.133	14.54	37.16	60	24

Decadal variation of rainfall in April, 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	99.86	41.57	41.63	165	44
2	77.47	50.03	64.58	183	18
3	154.7	81.62	52.76	310	65
4	98.38	37.06	37.67	158	49
5	87.27	50.92	58.35	202	35
6	105.3	56.92	54.06	213	41
7	130.8	50.39	38.52	226	55
8	112.1	32.91	29.36	159	63
9	147	35.19	23.94	195	87
10	100.6	36.84	36.58	166	44
11	119.3	36.71	30.75	173	67
12	103.4	59.32	57.36	221	29
13	95.72	45.66	47.70	179	48
14	131.2	49.13	37.42	234	59
15	111.3	71.46	64.19	218	34

Decadal variation of rainfall in May, 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	259.2	181.37	69.97	591	75
2	216.95	108.15	49.85	381	92
3	194.39	77.59	39.91	327	99
4	205.35	114.96	55.98	474	80
5	247.23	179.66	72.67	731	70
6	222.42	125.62	56.48	441	73
7	309.04	276.56	89.49	837	43
8	264.97	173.96	65.65	520	41
9	344.59	167.94	48.74	593	64
10	231.85	148.85	64.20	502	76
11	262.58	146.16	55.66	507	110
12	200.28	131.83	65.82	520	69
13	212.06	130.39	61.49	489	80
14	268.94	188.97	70.27	693	74
15	187.68	76.93	40.99	283	91

Decadal variation of rainfall in June, 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	799.49	167.54	20.96	1054	471
2	742.22	258.95	34.89	1069	293
3	701.22	156.64	22.34	906	357
4	668.07	200.94	30.08	1075	398
5	754.28	198.57	26.33	1111	517
6	714.56	174.88	24.47	1015	479
7	601.6	168.94	28.08	886	314
8	728.39	182.71	25.08	961	498
9	698.72	176.17	25.21	893	309
10	552.02	191.75	34.74	961	277
11	617.9	236.10	38.21	909	223
12	681.62	209.73	30.77	1124	332
13	706.06	166.13	23.53	1066	505
14	568.82	85.80	15.08	672	428
15	645.67	230.38	35.68	1068	434

Decadal variation of rainfall in July, 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	666.07	189.42	28.44	945	264
2	600.42	249.00	41.47	1131	300
3	583.99	199.13	34.10	1002	274
4	729.2	193.52	26.54	1040	450
5	615.81	220.35	35.78	856	153
6	741.27	278.95	37.63	1253	371
7	664.64	179.63	27.03	987	329
8	654.05	108.36	16.57	818	431
9	600.76	240.08	39.96	1030	343
10	745.85	252.82	33.90	1281	424
11	667.87	134.67	20.16	989	509
12	470.08	128.35	27.30	656	238
13	673.87	186.54	27.68	944	277
14	539.36	170.67	31.64	804	283
15	491.93	159.27	32.38	734	333

Decadal variation of rainfall in August, 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	366.83	210.38	57.35	855	155
2	350.68	137.18	39.12	553	128
3	351.57	174.55	49.65	632	107
4	359.6	182.69	50.80	860	228
5	328.25	107.91	32.87	512	184
6	456.99	202.23	44.25	829	244
7	419.67	235.70	56.16	1024	273
8	393.87	180.13	45.73	752	166
9	310.69	90.51	29.13	421	152
10	418.58	150.33	35.91	637	150
11	403.49	123.27	30.55	645	239
12	384.68	118.29	30.75	595	231
13	393.1	122.04	31.05	532	209
14	310.99	67.89	21.83	390	191
15	396.32	184.34	46.51	708	209

Decadal variation of rainfall in September, 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	254.72	161.55	63.42	586	111
2	191.97	105.54	54.98	420	84
3	147.25	66.64	45.25	303	81
4	229.26	83.72	36.52	426	114
5	243.09	140.41	57.76	469	46
6	254.63	101.08	39.70	399	85
7	198.04	119.81	60.50	410	40
8	238.64	123.88	51.91	424	82
9	207.1	148.91	71.90	450	36
10	261.87	89.95	34.35	398	139
11	231.42	134.22	58.00	459	67
12	255.31	164.90	64.59	530	77
13	233.43	136.42	58.44	523	47
14	261.54	133.45	51.02	485	80
15	247.45	89.10	36.01	335	78

Decadal variation of rainfall in October, 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	211.24	130.73	61.89	506	55
2	247.41	84.59	34.19	395	112
3	294.12	102.71	34.92	471	188
4	310.91	70.01	22.52	410	183
5	340.19	114.85	33.76	552	165
6	267.74	97.16	36.29	409	118
7	326.89	122.35	37.43	570	160
8	266.32	88.30	33.16	426	157
9	301.83	99.67	33.02	457	180
10	275.1	101.40	36.86	440	148
11	277.75	101.91	36.69	433	149
12	228.74	92.41	40.40	356	82
13	351.17	133.12	37.91	593	148
14	346.4	115.93	33.47	581	195
15	244.7	106.92	43.70	372	101

Decadal variation of rainfall in November, 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	102.44	63.91	62.38	217	19
2	137.19	48.77	35.55	223	65
3	111.42	54.10	48.56	192	32
4	153.97	102.38	66.49	369	25
5	202.19	95.24	47.10	339	85
6	165.8	59.87	36.11	278	89
7	170.78	82.29	48.19	317	64
8	192.19	95.18	49.53	313	20
9	163.53	93.25	57.03	362	41
10	107.49	63.37	58.96	263	25
11	213.71	130.18	60.92	380	37
12	134.2	50.40	37.55	209	72
13	155.88	76.14	48.84	300	90
14	165.49	89.51	54.09	331	71
15	131.35	56.27	42.84	228	59

Decadal variation of rainfall in December, 1871-2016

Decad	Mean	SD	CV %	Max	Min
1	30.54	22.20	72.68	75	2
2	29.4	29.56	100.54	103	3
3	24.26	21.36	88.03	66	2
4	43.49	45.77	105.25	146	0
5	52.56	44.42	84.51	157	14
6	40.5	31.79	78.50	103	7
7	29.13	31.91	109.54	114	6
8	64.98	71.18	109.55	221	0
9	27.01	22.57	83.56	68	4
10	48.36	44.75	92.52	154	2
11	35.7	31.12	87.16	114	3
12	33.16	39.45	118.95	128	0
13	38.97	38.18	97.98	89	0
14	19.59	21.31	108.79	51	0
15	42.083	35.87	85.23	91	9

Decadal variation of rainfall in Winter, 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	24.16	38.50	159.36	112	0
2	8.79	11.90	135.38	35	1
3	23.77	19.34	81.35	55	1
4	29.87	22.50	75.33	77	7
5	31.07	22.78	73.32	68	7
6	40.52	24.05	59.34	86	9
7	27.71	29.65	107.02	88	0
8	37.49	31.14	83.07	87	2
9	23.86	12.75	53.43	49	7
10	33.56	26.60	79.25	84	7
11	24.23	24.13	99.61	73	0
12	27.98	36.65	130.97	113	0
13	21.25	25.65	120.73	73	0
14	22.86	19.87	86.93	65	2
15	31.433	27.69	88.09	80	10

Decadal variation of rainfall in Summer, 1871-2016

Decad	Mean	SD	CV %	Max	Min
1	380.21	180.09	47.37	684	157
2	314.15	114.90	36.58	456	146
3	393.23	109.12	27.75	574	277
4	338.26	108.36	32.03	612	217
5	362.26	162.91	44.97	807	245
6	379.31	118.37	31.21	600	211
7	479.61	279.14	58.20	1037	193
8	426.08	156.14	36.65	680	143
9	531.92	174.45	32.80	825	209
10	376.01	130.02	34.58	606	213
11	410.33	136.01	33.15	602	213
12	339.61	135.31	39.84	573	100
13	332.62	154.39	46.41	644	222
14	455.92	154.87	33.97	819	301
15	338.15	88.94	26.30	485	236

Decadal variation in SW Monsoon, 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	2087.1	408.00	19.55	2925	1577
2	1885.3	423.48	22.46	2653	1339
3	1784	394.02	22.09	2567	1186
4	1986.1	281.17	14.16	2595	1687
5	1941.4	384.21	19.79	2395	1150
6	2167.4	478.78	22.09	3115	1543
7	1884	298.38	15.84	2361	1536
8	2015	326.91	16.22	2445	1374
9	1817.3	267.42	14.72	2349	1432
10	1978.3	470.48	23.78	2943	1405
11	1920.7	362.30	18.86	2522	1261
12	1791.7	330.75	18.46	2526	1457
13	2006.4	334.13	16.65	2401	1553
14	1680.7	308.66	18.36	2322	1296
15	1781.4	434.83	24.41	2416	1309

Decadal variation in Post Monsoon, 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	344.21	163.04	47.37	684	93
2	413.99	95.58	23.09	608	246
3	429.78	117.71	27.39	670	311
4	508.37	133.88	26.34	694	347
5	594.91	78.86	13.26	707	474
6	474.03	137.51	29.01	679	247
7	526.8	156.32	29.67	848	256
8	523.48	178.10	34.02	806	217
9	492.37	109.38	22.21	655	360
10	430.93	136.22	31.61	757	306
11	527.13	177.69	33.71	828	233
12	396.09	118.81	30.00	633	185
13	546.02	141.79	25.97	704	328
14	531.46	161.12	30.32	858	397
15	418.13	154.16	36.87	606	182

Decadal variation of Annual rainfall , 1871-2016

Decade	Mean	SD	CV %	Max	Min
1	2835.7	507.01	17.88	3717	1986
2	2622.2	491.99	18.76	3486	1856
3	2630.8	361.59	13.74	3222	2131
4	2862.7	287.30	10.04	3417	2452
5	2929.7	336.70	11.49	3433	2473
6	3061.3	430.64	14.07	3945	2352
7	2918.1	473.04	16.21	3884	2308
8	3002	382.97	12.76	3643	2410
9	2865.4	348.36	12.16	3328	2313
10	2818.8	500.82	17.77	3907	2218
11	2882.4	404.42	14.03	3594	2172
12	2555.3	325.77	12.75	3384	2147
13	2906.3	358.22	12.33	3369	2219
14	2691	328.35	12.20	3156	2301
15	2569.1	522.61	20.34	3189	1837

Table 3.4.1.10: ANOVA – Decadal variation of monthly rainfall in Kerala, 1871-2016

Month	Between decades Sum of squares	Within decade sum of squares	Between decades mean sum of squares	Within decade mean sum of squares	F	Significance
January	3367.64	35428.13	240.55	270.44	0.89	0.57
February	2694.14	47751.22	192.44	364.51	0.53	0.91
March	16847.53	131523.38	1203.40	1003.99	1.20	0.28
April	64764.95	328677.9	4626.07	2508.99	1.84*	0.04
May	261247.54	3273630.16	18660.54	24989.54	0.75	0.72
June	682754.31	4715554.09	48768.17	35996.60	1.36	0.19
July	911826.72	5215944.65	65130.48	39816.37	1.64	0.08
August	243321.45	3292464.60	17380.10	25133.32	0.69	0.78
September	141513.94	2021576.99	10108.14	15431.89	0.66	0.81
October	257089.74	1455723.83	18363.55	11112.40	1.65	0.07
November	156072.55	865119.64	11148.04	6603.97	1.69	0.07
December	19703.79	185845.87	1407.41	1418.67	0.99	0.47

* Significant at 5% level

Table 3.4.1.11: ANOVA – Decadal variation of seasonal rainfall in Kerala, 1871-2016

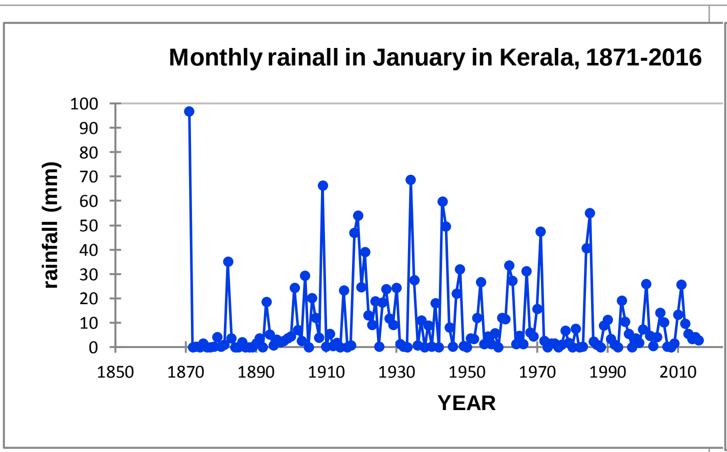
Season	Between decades Sum of squares	Within decade sum of squares	Between decades mean sum of squares	Within decade mean sum of squares	F
Winter	7915.43	87524.32	565.39	668.13	0.85
Summer	512371.78	3136405.14	36597.99	23942.02	1.53
SW monsoon	2306649.42	17985115.50	164760.67	137290.96	1.2
Post monsoon	645490.22	2558337.99	46106.45	19529.30	2.36**
Annual	3277054.30	21702326.87	234075.31	165666.62	1.41

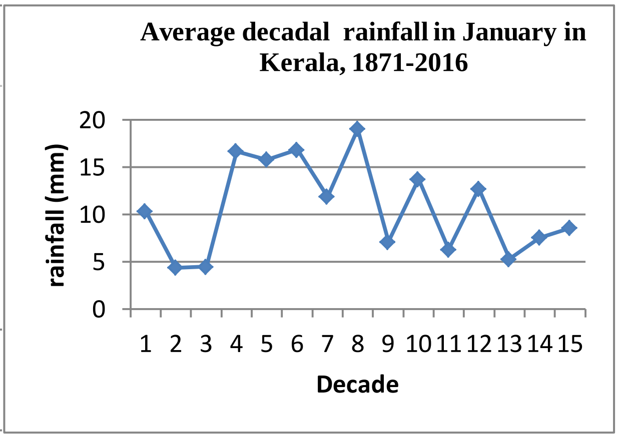
The one way ANOVA to compare the different decades with respect to the monthly, seasonal and annual rainfall showed that even though there was no significant variation between the annual rainfall in different decades starting from 1871 to 2016, there was a significant decadal variation in the post monsoon period (significance at 0.01 level). This might be due to the significant decadal variation ($\alpha = 0.10$) in the month of October and November. There was a significant decadal variation ($\alpha = 0.05$) in the month of April also. There existed high within decadal variation also which might have masked to some extend the between decadal variations. The maximum average rainfall in April was 154.71 mm in the 3rd decade and minimum average rainfall was 77.47 mm in the 2nd decade.

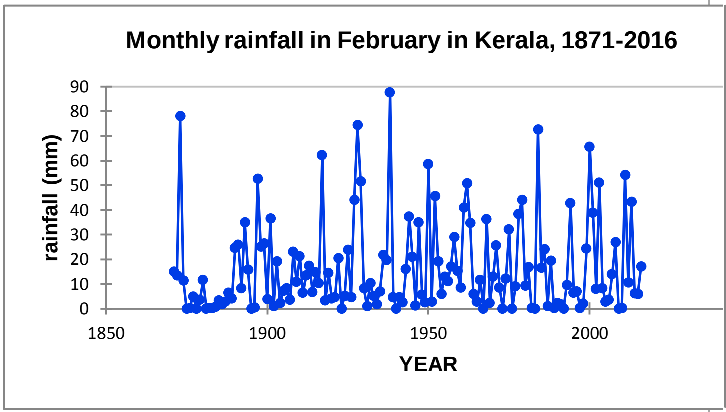
The average annual rainfall was maximum (3061.32 mm) in the 6th decade (1921-1930) and this might be the consequence of the severe flood occurred in 1924 and 1922 was also a wet year. The average minimum rainfall (2555.34 mm) was in the 12th decade (1981-1990). There were 3 dry years namely 1982, 1986 and 1987 in this decade.

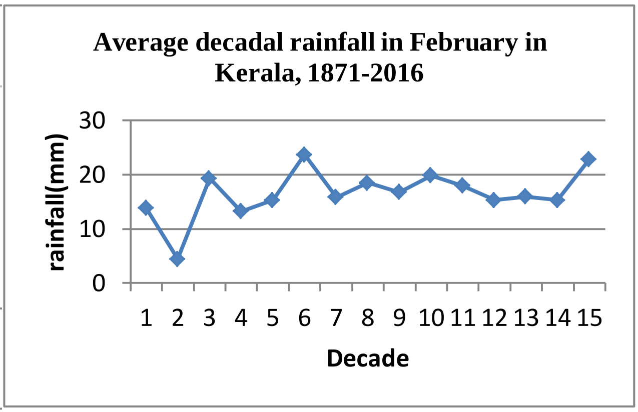
A comparison of the yearly versus average decadal monthly, seasonal and annual rainfall in Kerala (Table 3.4.1.11) has revealed the highly intensive within decadal variation hidden in the data and how it was smoothened when the decadal averages were computed. This type of frequent within decadal variations *ie* the year to year variation has brought huge values of within group sum of squares for the one way ANOVA for the comparison of decadal rainfall and masked the actual variations existed between decades.

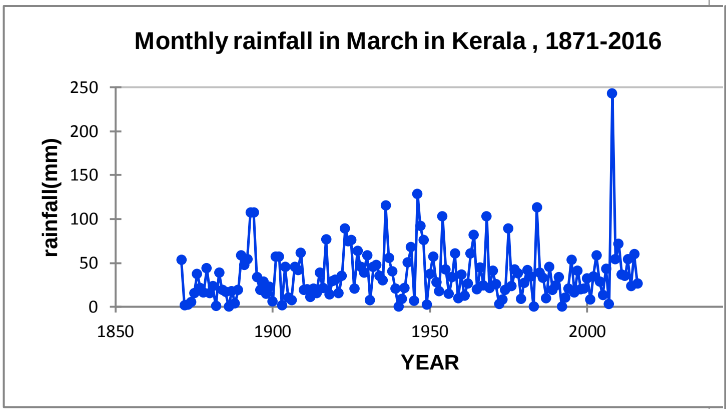
Comparison of yearly vs. decadal monthly, seasonal and annual rainfall in   Kerala, 1871-2016

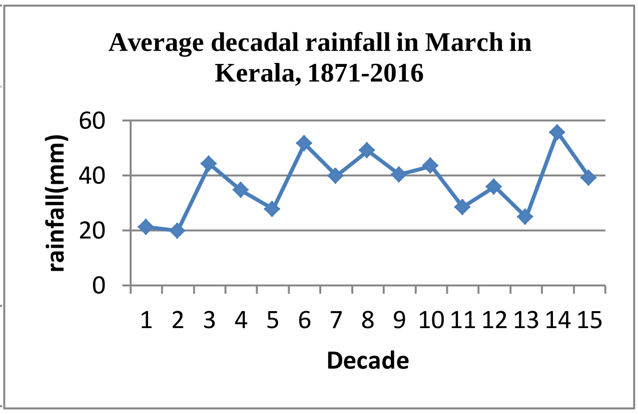




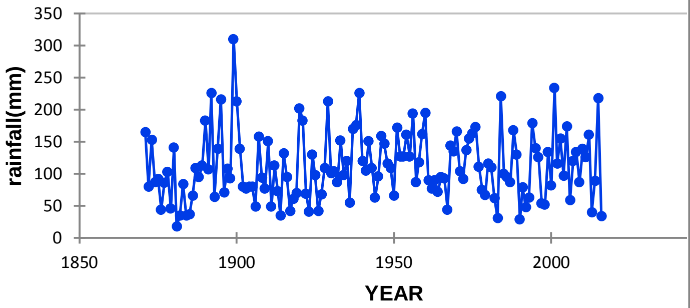




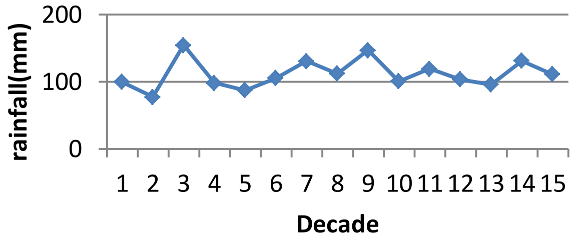




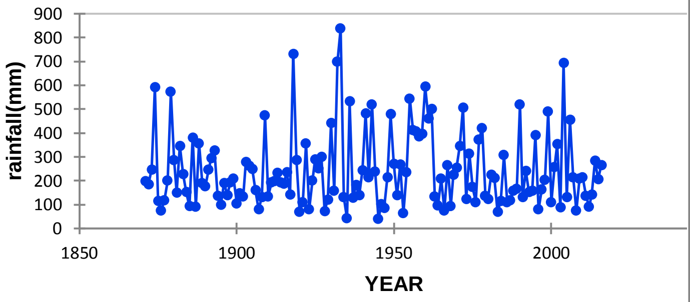
Monthly rainfall in April in Kerala, 1871-2016



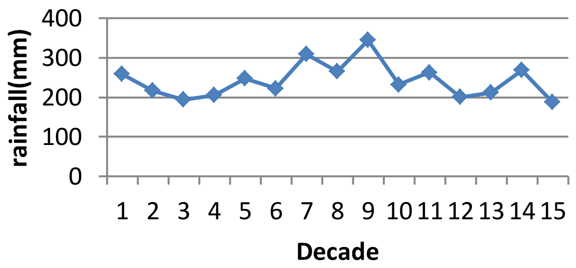
Average decadal rainfall in April in Kerala, 1871-2016



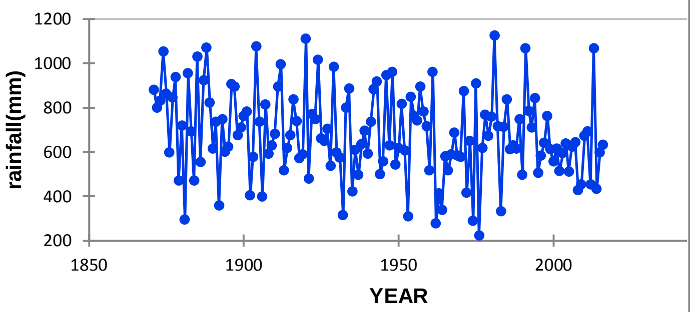
Monthly rainfall in May in Kerala,1871-2016



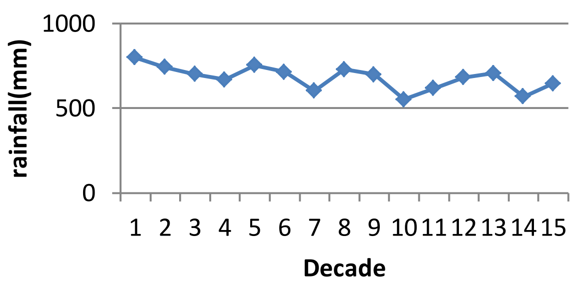
Average decadal rainfall in May in Kerala, 1871-2016



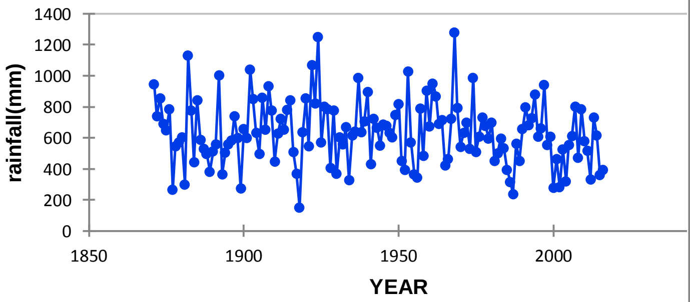
Monthly rainfall in June in Kerala, 1871-2016



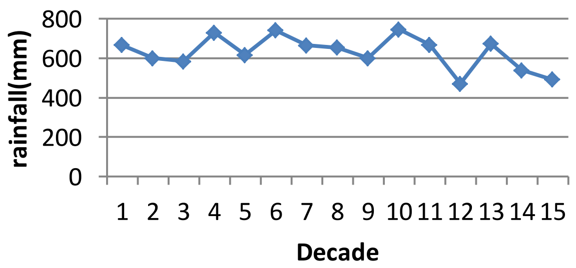
Average decadal rainfall in June in Kerala, 1871-2016

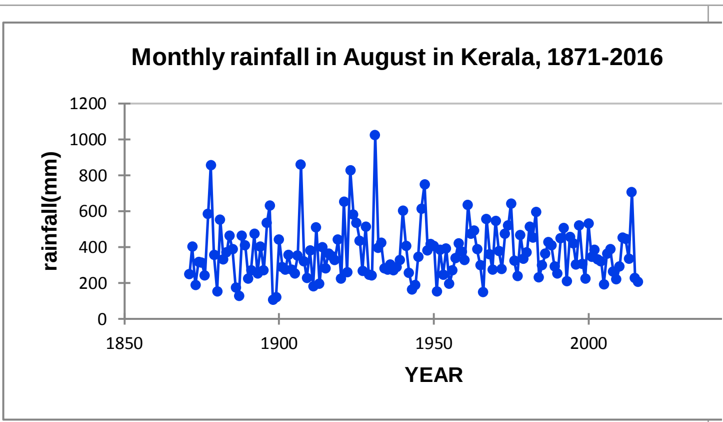


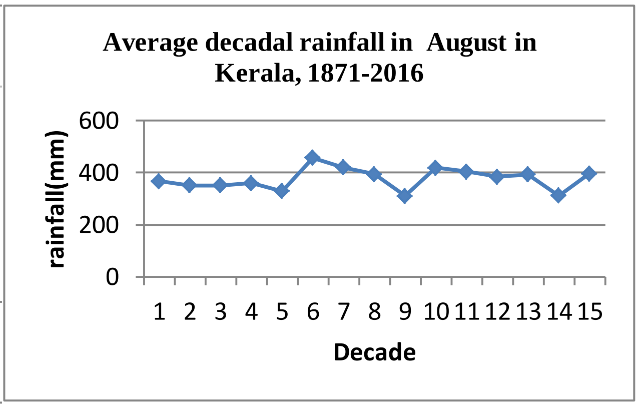
Monthly rainfall in July in Kerala, 1871-2016

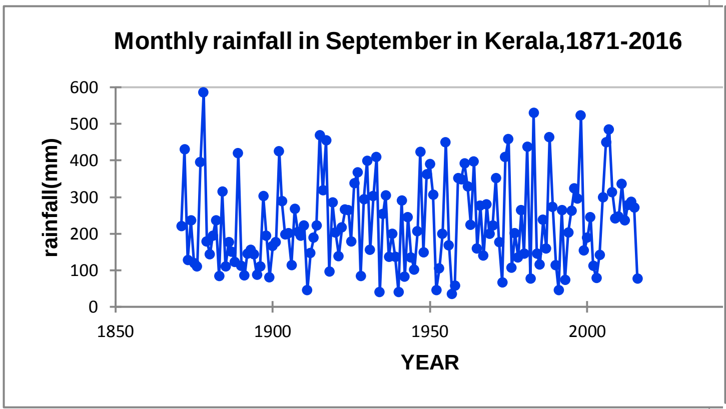


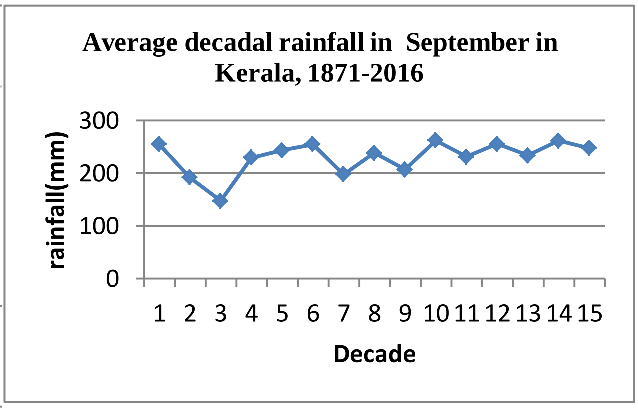
Average decadal rainfall in July in Kerala, 1871-2016

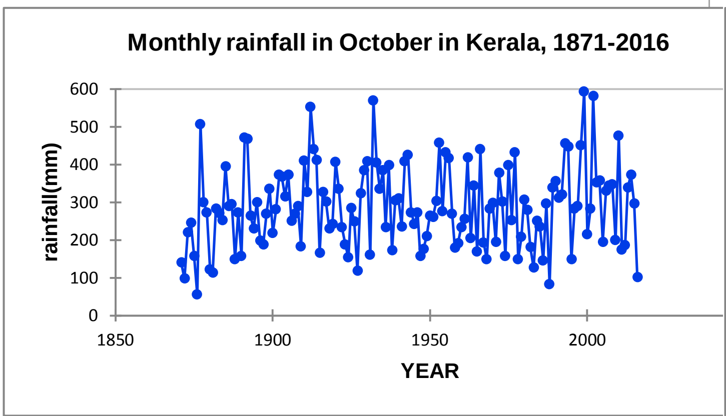


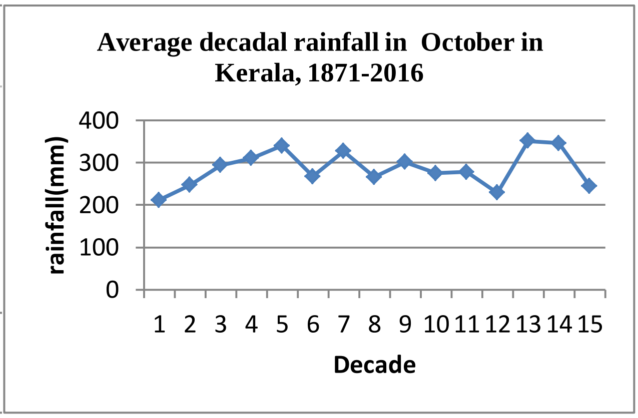

Monthly rainfall in August in Kerala, 1871-2016
rainfall(mm)
1200
1000
800
600
400
200
0
1850
1900
1950
2000
YEAR

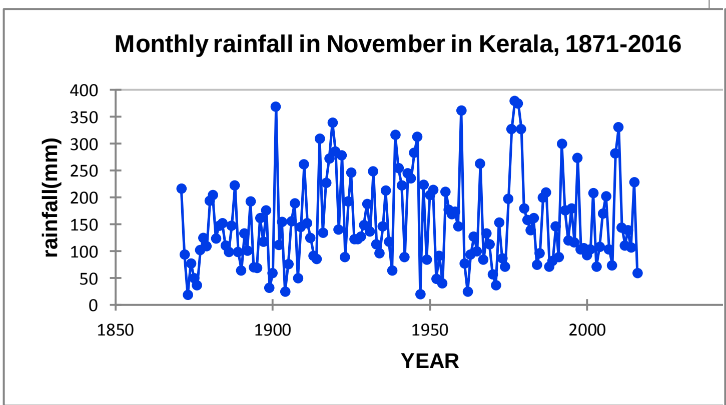

Average decadal rainfall in August in Kerala, 1871-2016
rainfall(mm)
600
400
200
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Decade

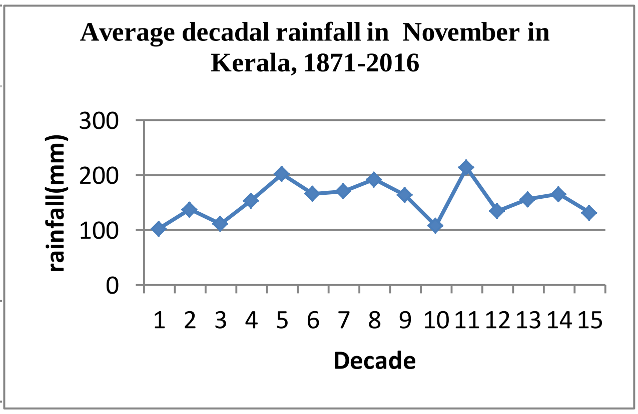

Monthly rainfall in September in Kerala,1871-2016
rainfall(mm)
600
500
400
300
200
100
0
1850
1900
1950
2000
YEAR

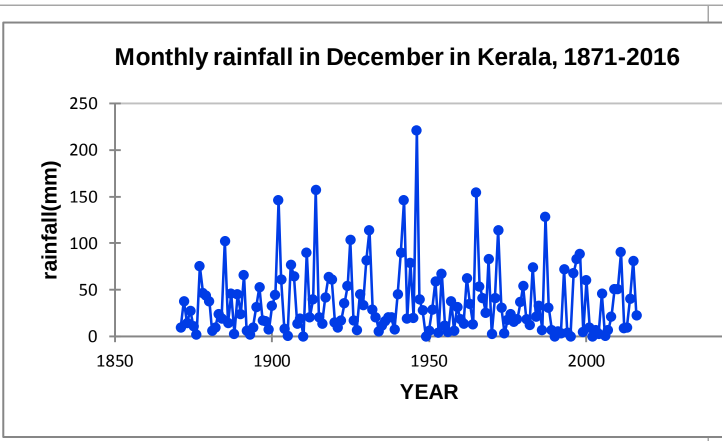

Average decadal rainfall in September in Kerala, 1871-2016
rainfall(mm)
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Decade

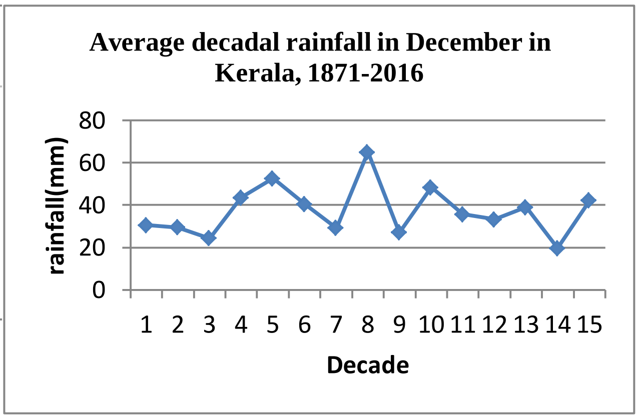

Monthly rainfall in October in Kerala, 1871-2016
rainfall(mm)
600
500
400
300
200
100
0
1850
1900
1950
2000
YEAR

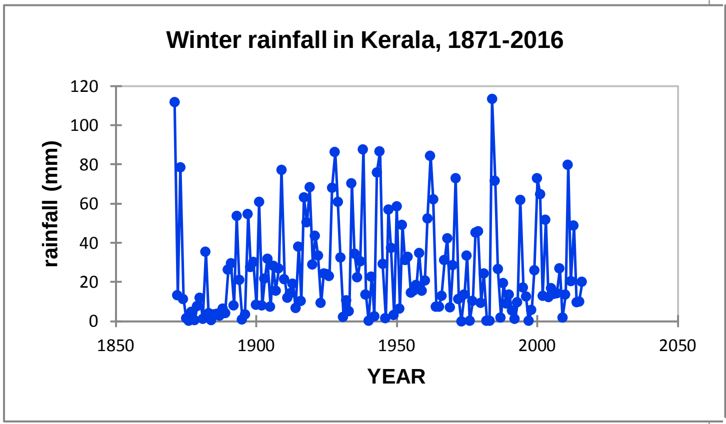

Average decadal rainfall in October in Kerala, 1871-2016
rainfall(mm)
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Decade

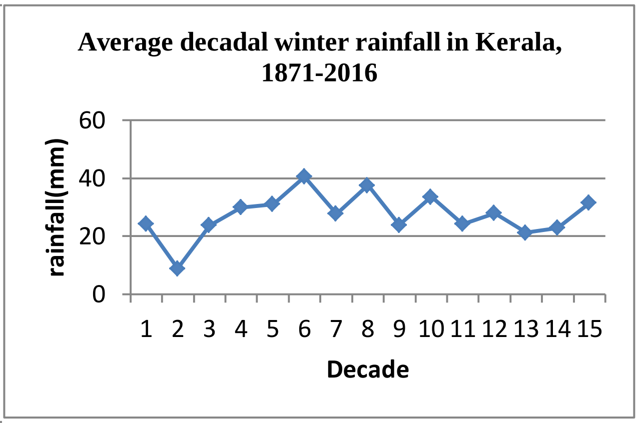

Monthly rainfall in November in Kerala, 1871-2016
rainfall(mm)
400
350
300
250
200
150
100
50
0
1850
1900
1950
2000
YEAR

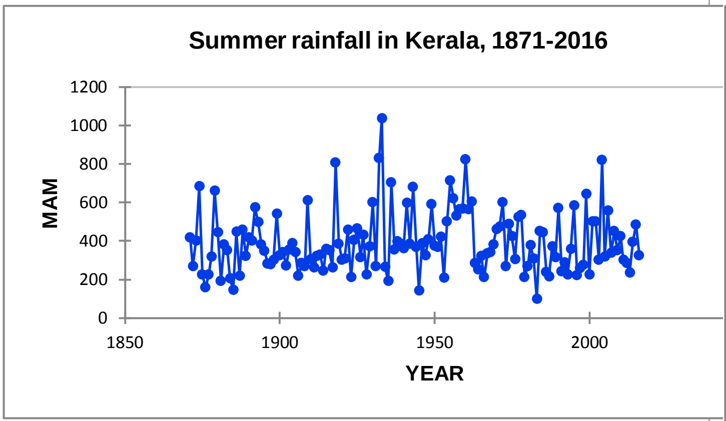

Average decadal rainfall in November in Kerala, 1871-2016
rainfall(mm)
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Decade

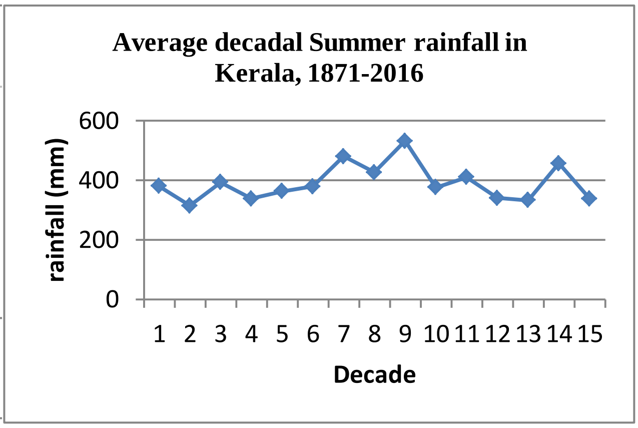

Monthly rainfall in December in Kerala, 1871-2016
rainfall(mm)
250
200
150
100
50
0
1850
1900
1950
2000
YEAR

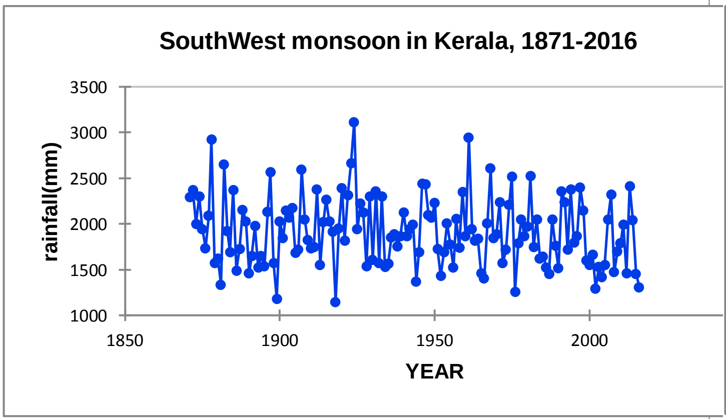

Average decadal rainfall in December in Kerala, 1871-2016
rainfall(mm)
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Decade

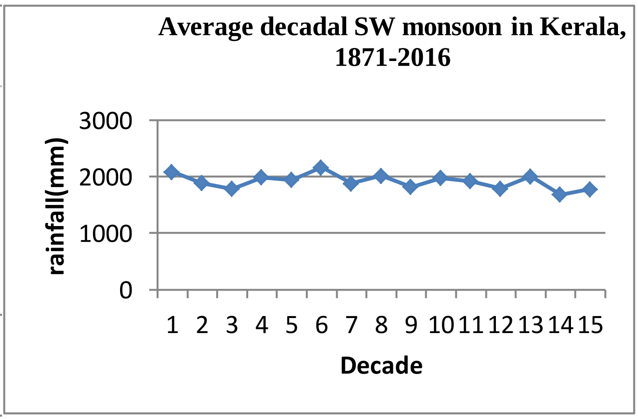

Winter rainfall in Kerala, 1871-2016
rainfall (mm)
120
100
80
60
40
20
0
1850
1900
1950
2000
2050
YEAR


Average decadal winter rainfall in Kerala, 1871-2016
rainfall(mm)
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Decade


Summer rainfall in Kerala, 1871-2016
MAM
1200
1000
800
600
400
200
0
1850
1900
1950
2000
YEAR


Average decadal Summer rainfall in Kerala, 1871-2016
rainfall (mm)
600
400
200
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Decade


SouthWest monsoon in Kerala, 1871-2016
rainfall(mm)
3500
3000
2500
2000
1500
1000
1850
1900
1950
2000
YEAR


Average decadal SW monsoon in Kerala, 1871-2016
rainfall(mm)
3000
2000
1000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Decade

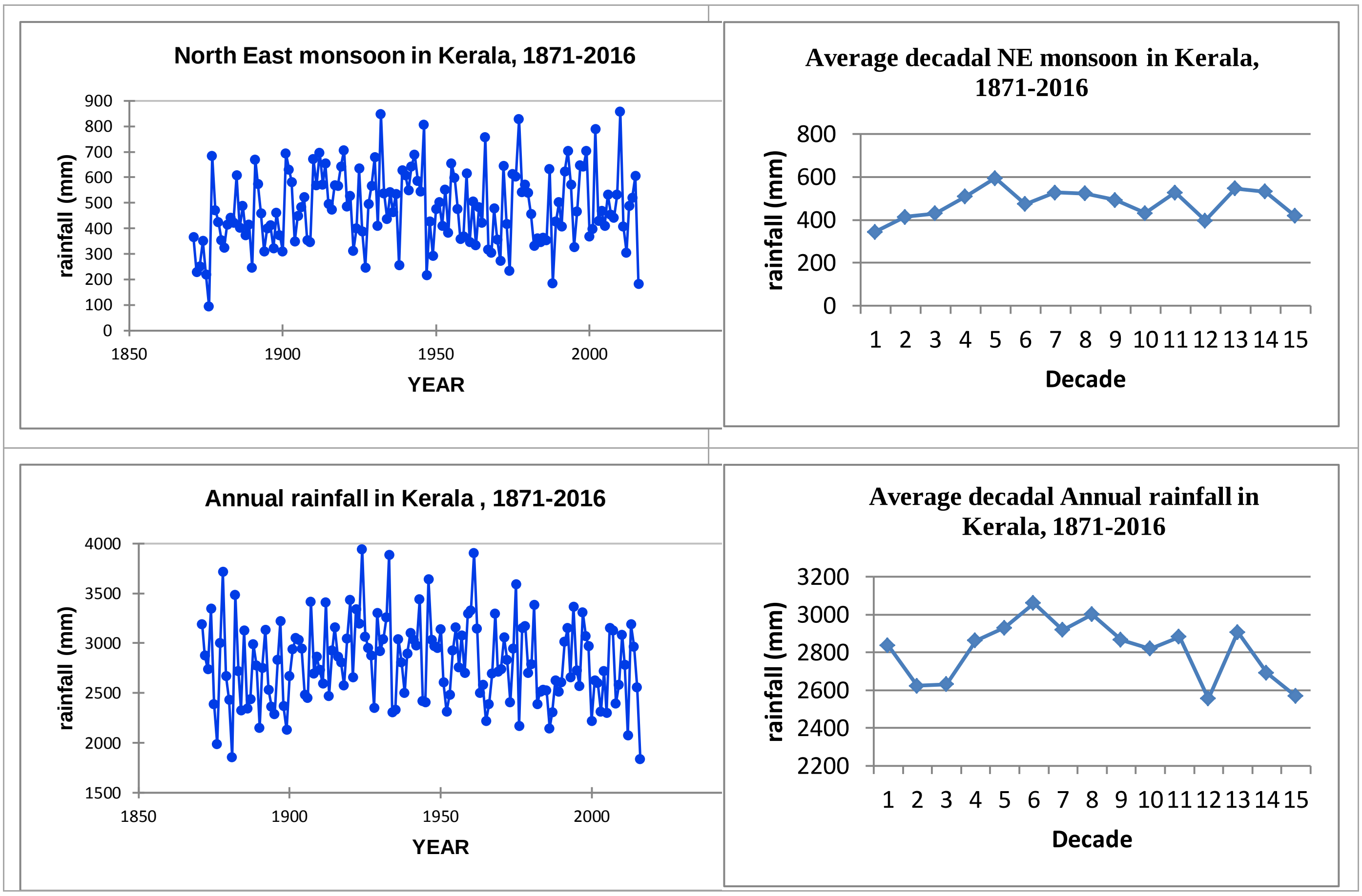

North East monsoon in Kerala, 1871-2016
rainfall (mm)
YEAR
Average decadal NE monsoon in Kerala, 1871-2016
rainfall (mm)
Decade
Annual rainfall in Kerala , 1871-2016
rainfall (mm)
YEAR
Average decadal Annual rainfall in Kerala, 1871-2016
rainfall (mm)
Decade

Fig 3.4.1.11

Table 3.4.1.12: Summary statistics of yearly and decadal average rainfall in Kerala, 1871-2016

Period	146 yrs' Mean	15 av. Decade's Mean	146 yrs' S.D	15 av. Decade's S.D	146 yrs' Min.	15 av. Decade's Min.	146 yrs' Max.	15 av. Decade's Max.
January	10.77	10.71	16.36	4.92	0.0	4.36	96.9	19.04
February	16.35	16.53	18.65	4.52	0.0	4.43	87.6	23.68
March	36.97	37.03	31.99	10.98	0.0	19.74	242.8	55.69
April	111.66	111.65	52.09	21.51	18.3	77.47	310.1	154.71
May	243.32	241.84	156.14	44.18	41.2	187.68	837.4	344.59
June	679.61	678.71	192.95	70.06	222.5	552.02	1123.7	799.49
July	633.45	629.68	205.57	84.08	152.5	470.08	1281.1	745.85
August	375.81	376.35	156.16	41.83	107	310.69	1023.5	456.99
September	229.91	230.38	122.14	31.93	36	147.25	586.1	261.87
October	287.17	286.03	108.69	43.43	54.6	211.24	593.2	351.17
November	154.46	153.84	83.92	33.61	19	102.44	379.8	213.71
December	37.19	37.32	37.651	11.89	0.0	19.59	221.1	64.98
Winter	27.12	27.24	25.66	7.55	0.0	8.79	113.4	40.52
Summer	391.95	390.51	158.63	61.16	100.2	314.15	1036.8	531.92
SW monsoon	1918.78	1915.11	374.09	130.39	1150.2	1680.71	3115.3	2167.44
NE monsoon	478.80	477.18	148.65	68.65	93.2	344.21	857.5	594.91
Annual	2816.65	2810.05	415.06	158.47	1837.4	2555.34	3944.9	3061.32

Trend in Kerala rainfall

The significance of the trend existing in monthly, seasonal and annual rainfall data have been studied and presented in Table (3.4.1.13)

Table 3.4.1.13: Summary statistics to test the significance of trend (1871-2016) in monthly, seasonal and annual rainfall in Kerala

Period	Kendall's tau	p-value	Sen's slope
January	0.080	**0.052**	0.008
February	0.071	0.204	0.024
March	0.080	0.131	0.060
April	0.077	0.171	0.150
May	0.004	0.950	0.021
June	-0.154	**0.006**	-1.122
July	-0.087	**0.034**	-0.642
August	0.043	0.446	0.214
September	0.091	**0.086**	0.396
October	0.072	0.201	0.280
November	0.057	0.211	0.165
December	-0.025	0.568	-0.020
Winter	0.051	0.481	0.033
Summer	0.048	0.394	0.238
SW monsoon	-0.097	**0.084**	-1.283
NE monsoon	0.078	0.135	0.442
Annual	-0.028	0.504	-0.446

From Table (3.4.1.13) it could be noticed that there was no significant trend for the annual rainfall in Kerala. But when the individual months were studied in detail there exists a significant negative trend for the occurrence of rainfall in the month of June (Sen's slope = -1.122 significant at 0.01 level of significance) and July (sen's slope = -0.642, significant at 0.05 level of significance) both these have resulted in a significant negative trend for the SW monsoon as a whole (Sen's slope = -1.283, significant at 0.10 level of significance). In contrary to this, a significant positive trend was found in the month of January (Sen's slope = 0.008, significant. at 0.01 level of significance) and in September (Sen's slope = 0.396, significant at 0.10 level of significance).

From the above results, it could be inferred that there was a slight shift realised in the occurrence of rainfall in a long period of time owing to the significant negative trends of rainfall in June, July and significant positive trends in January, September and no significant trend in annual rainfall.

3.4.2 Dependable rainfall and return period

In general the variability in annual rainfall received at a location for a given period will be more if the climate is dry. Similarly, if a shorter period is considered, the annual variability of rainfall seems to be high.

Annual rainfall recorded for a period of 146 years from 1871 to 2016 in Kerala

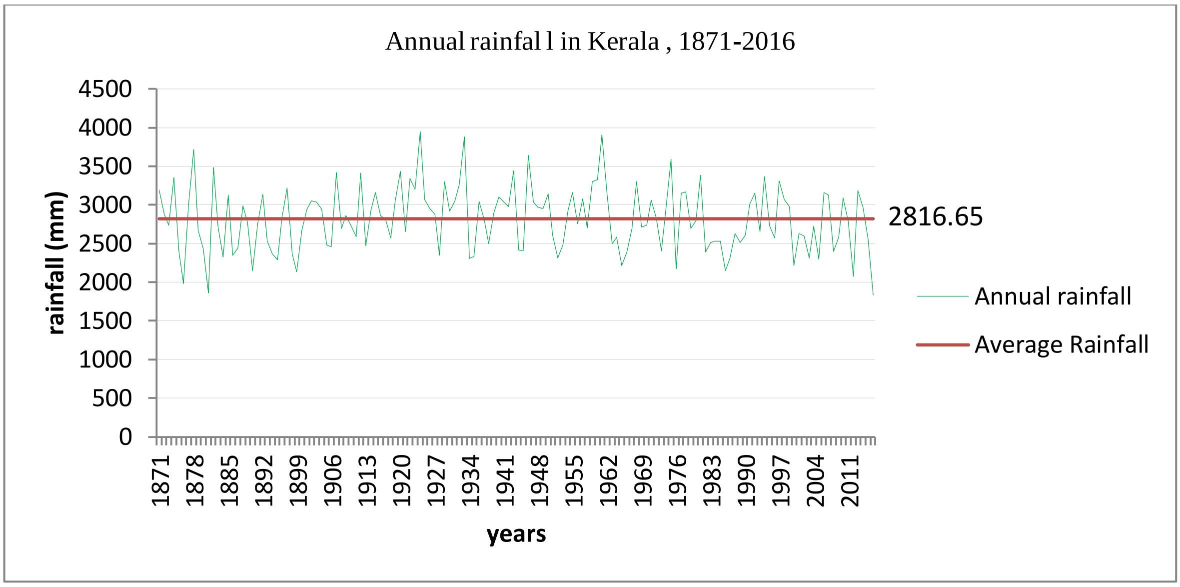


Fig 3.4.2.1

The annual rainfall varied from 1837.4 mm in 2016 to 3944.9 mm in 1924. The average annual rainfall received was 2816.7 mm with a S.D = 415.06 for a period of 146 years from 1871 to 2016. Normal rainfall expected is given by the long term average. The departure of total rainfall received in a particular year, from the normal can be found to have a comparison between different years as well as decades.

Since there exists considerable variability in the annual rainfall received in different time periods, the management of irrigation, water supply and operations related to reservoirs are done not based on the long term average of rainfall records but on particular rainfall depths that can be expected for a specific probability or a return period. To obtain these rainfall depths a thorough analysis of the long term time series of historical rainfall data is required. (Leuven and Raes , 2004). Even though a time series data can be characterized using their mean and standard deviation, they cannot be blindly applied to find out the rainfall depths which can be expected with a specific probability or return period. Sometimes the actual characteristics of the data may be ignored and so the results may be misleading. To overcome these type of errors, the exact distribution which the data follows is to be checked before proceeding to the estimation of rainfall depths.

It is obvious that longer the time series, more similar, the frequency distribution will be to the probability distribution. Accurate determination of rainfall depths with respect to selected return period is not possible for data of shorter period. When return period exceeds the observation period, the estimates of dependable rainfall are less reliable. The error in estimates of expected rainfall can be reduced by increasing the number of observations of the study period. Usually a period of 30 years or more is treated as a satisfactory period. If extreme event of rainfall is to be studied more number of years are required.

Before the computations, the data is to be checked for randomness, normality and trend. When hydrological data sets are considered outliers are to be excluded from the analysis unless they carry some essential historical information.

Probability of exceedance and return period

The expected estimates of rainfall depths (Xp) or intensity of rainfall for a specific probability with respect to a reference period (hour, day, week, month, year etc.) are essential for the management of irrigation and drainage projects. The above mentioned probability refers to the probability of exceedance and gives the likelihood that the actual rainfall during that particular period will be equal to or higher than the estimated rainfall depth Xp. It is also called the 'dependable rainfall' in irrigation science as it is the maximum amount of rain one can rely on during the reference period.

In this context, the probability of occurrence of a rainfall depth greater than some given value Xp is termed as the probability of exceedance Px. It is expressed as a fraction or a percentage. The period or number of years in which the actual observation is expected to return is referred to as the occurrence interval or return period Tx. It is the reciprocal of Px. i.e. $Tx = \frac{1}{Px}$

The probability of exceedance is fixed depending upon the damage that may be caused because of the excess or shortage of rainfall, the risk associated with it and the lifetime of the project. Selecting a higher level of dependable rainfall may result in lower risk, but in bigger canals or larger pipes. Thus it deals with an economic parameter and selection involves the benefits in relation to the cost involved (Leuven and Raes , 2004).

Frequency analysis and probability plotting

To obtain the rainfall depths for selected probabilities or return periods, the historical data on rainfall is collected first. As the next step, the data is ranked such that the highest value of rainfall in a year gets the first rank, the next higher value gets the second rank and so on. After arranging rank 'r' to each year, compute probability of exceedance using one of the standard methods given in Table (3.4.2.1). Then a probability plot is drawn taking rainfall quantity along X-axis and probability of exceedance along Y-axis.

For management and planning purposes information on the rainfall depth that can be expected in a specific period under various weather conditions are required. The weather condition in a period is said to be dry if the probability of exceedance is 80% or more and normal if there is 50% of probability of exceedance and humid if it is 20% or less.

The Weibull, Sevruk and Geiger and the Gringorten methods of finding the probability of exceedance are found to be theoretically sound.

Methods for estimating probabilities of exceedance of ranked data where 'r' is the rank and 'n' the number of observations.

Table 3.4.2.1: Standard methods to compute probability of exceedance

Method	Estimate of probability of exceedance (%)
California State dept. 1923	$\frac{r}{n}$ X 100
Hazen, 1930	$\frac{(r-0.5)}{n}$ x 100
Weibull, 1939	$\frac{r}{(n+1)}$ x100
Gringorten, WMO, 1983	$\frac{(r-0.44)}{(n+0.12)}$ x100
Sevruk& Geiger, 1981	$\frac{(r-\frac{3}{8})}{(n+\frac{1}{4})}$ x100

Table 3.4.2.2 A sample of Probabilities of exceedance of ranked annual rainfall estimated using various methods

Year	Ranked rainfall (mm)	Rank no.	Estimate of probability of exceedance Px				
			California state dept. 1923	Hazen	Weibull	Gringorten	Sevruk& Geiger
			(r/n) x 100	(r-0.5/n) x 100	(r/(n+1) x 100	(r-0.44)/(n+0.12) x 100	(r-3/8)/(n+1/4) x 100
1924	3944.9	1	0.68	0.34	0.68	0.38	0.43
1961	3907.2	2	1.37	1.03	1.36	1.07	1.11
1933	3884.0	3	2.05	1.71	2.04	1.75	1.79
1878	3716.9	4	2.74	2.40	2.72	2.44	2.48
1946	3642.5	5	3.42	3.08	3.40	3.12	3.16
1975	3593.9	6	4.11	3.77	4.08	3.81	3.85
1882	3486.0	7	4.79	4.45	4.76	4.49	4.53
1943	3440.2	8	5.48	5.14	5.44	5.17	5.21
1920	3433.2	9	6.16	5.82	6.12	5.86	5.90
1907	3416.6	10	6.85	6.51	6.80	6.54	6.58
1912	3410.7	11	7.53	7.19	7.48	7.23	7.26
1981	3384.3	12	8.22	7.88	8.16	7.91	7.95
1994	3368.5	13	8.90	8.56	8.84	8.60	8.63
1874	3346.3	14	9.59	9.25	9.52	9.28	9.32
1922	3339.9	15	10.27	9.93	10.20	9.96	10.00
1960	3328.2	16	10.96	10.62	10.88	10.65	10.68
1997	3307.3	17	11.64	11.30	11.56	11.33	11.37
1929	3304.5	18	12.33	11.99	12.24	12.02	12.05
1959	3299.6	19	13.01	12.67	12.93	12.70	12.74
1968	3299.1	20	13.70	13.36	13.61	13.39	13.42
1932	3260.1	21	14.38	14.04	14.29	14.07	14.10
1897	3222.0	22	15.07	14.73	14.97	14.75	14.79
1923	3198.6	23	15.75	15.41	15.65	15.44	15.47
1871	3190.9	24	16.44	16.10	16.33	16.12	16.15
2013	3188.5	25	17.12	16.78	17.01	16.81	16.84
1978	3169.5	26	17.81	17.47	17.69	17.49	17.52

Estimating rainfall amounts for selected probabilities

The rainfall corresponding to various probabilities of exceedance can be obtained by plotting an appropriate curve of trend on the plotted points. The goodness of fit can be evaluated by the coefficient of determination (R^2).

Probability plot

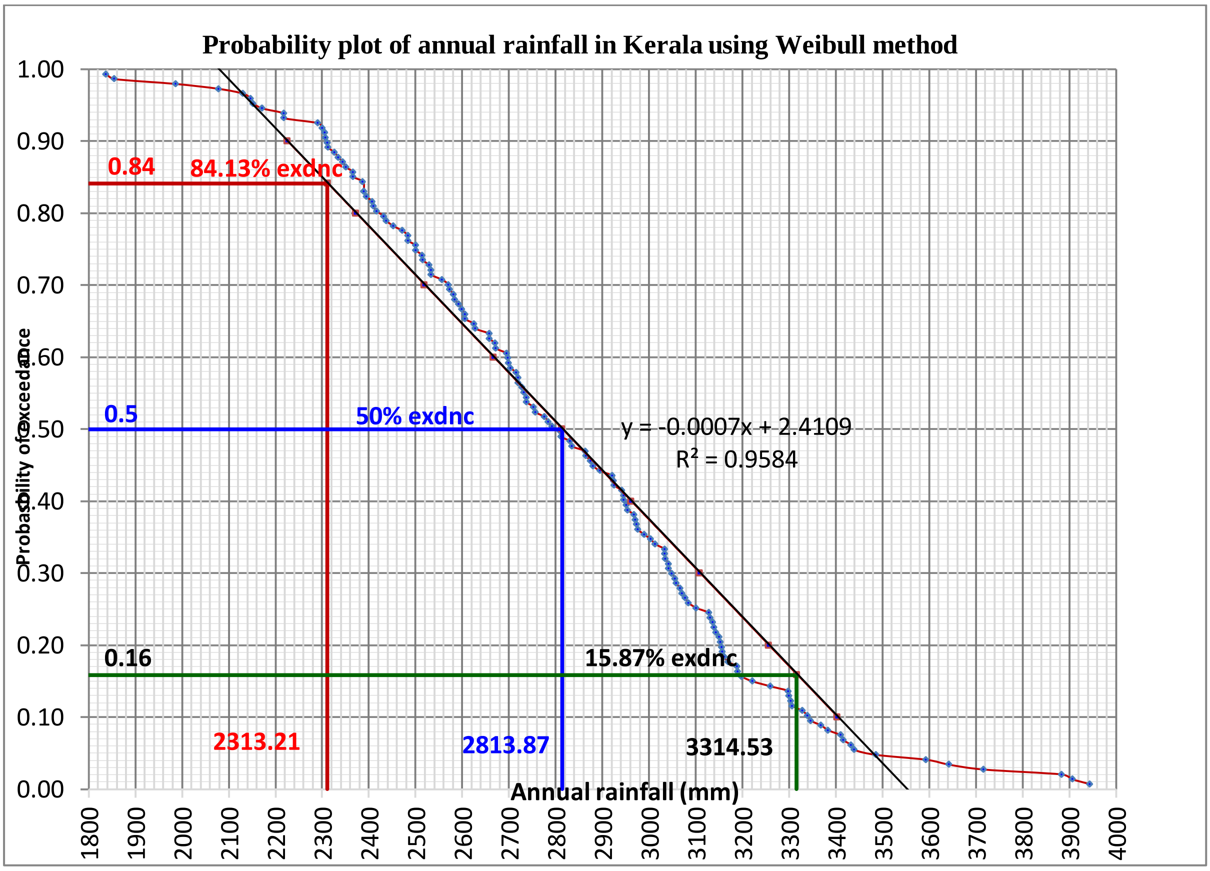


Fig. 3.4.2.2

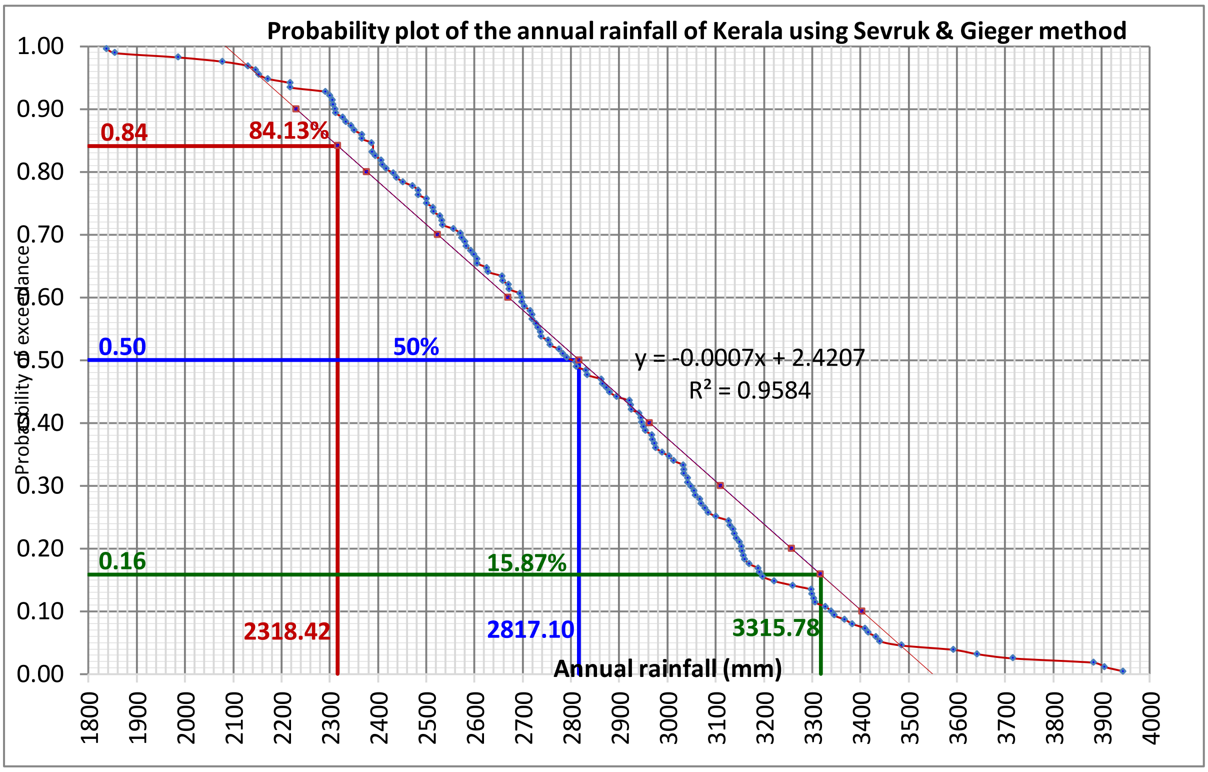


Fig. 3.4.2.3

Table 3.4.2.3: Estimated annual rainfall for Kerala for selected probabilities and return periods derived from the plotted line in the probability plot.

Probability of exceedance Px	Return period Tx	Estimated annual rainfall Xp	Probabilities of non-exceedance(100-Px)	Return period
(%)	(Yrs)	(mm)	(%)	(Yrs)
10	10	3402.89	90	1.11
20	5	3255.63	80	1.25
30	3.33	3108.38	70	1.43
40	2.5	2961.13	60	1.67
50	2.00	2813.87	50	2
60	1.67	2666.62	40	2.5
70	1.43	2519.36	30	3.33
80	1.25	2372.11	20	5
90	1.11	2224.86	10	10

Probability of exceedance would be smaller for higher rainfall amounts.

<u>Numerical Solution</u>

In the case when the rainfall data is perfectly normal, the probability plot would exactly fall on the normal line. Then the mean corresponds to the 50 percent probability of exceedance, mean + s (standard deviation) corresponds to 15.87% and mean – s with 84.13% probability of exceedance. Since mean and s are the parameters of a Normal distribution they can be used to estimate rainfall for selected probabilities or return periods

$Xp = \bar{X} \pm ks$ where Xp is the rainfall depth having a specific probability of exceedance, $\bar{X}$ is the sample mean, s the standard deviation and k a frequency factor. The sign of k changes according to the probability of exceedance.

Table 3.4.2.4: Estimated annual rainfall in Kerala through numerical solution

Probability of exceedance Px (%)	Estimated annual rainfall (mm)	Return period Tx (years)
10	3347.9	10
20	3165.3	5
30	3036.6	3.33
40	2922.5	2.5
50	2816.7	2.0
60	2710.8	1.67
70	2596.7	1.43
80	2468.0	1.25
90	2285.4	1.11

Table 3.4.2.5: Comparison of estimated annual rainfall through Weibull, Sevruk-Geiger and numerical methods

Probability of exceedance	Annual rainfall (mm)		
	Weibull	Sevruk & Geiger	Numerical method
0.10	3402.89	3403.78	3347.9
0.20	3255.63	3257.11	3165.3
0.30	3108.38	3110.44	3036.6
0.40	2961.13	2963.77	2922.5
0.50	**2813.87**	**2817.10**	**2816.7**
0.60	2666.62	2670.43	2710.8
0.70	2519.36	2523.76	2596.7
0.80	2372.11	2377.09	2468.0
0.90	2224.86	2230.42	2285.4

From Table (3.4.2.5) it could be followed that the estimated rainfall corresponding to Px = 0.5 through Sevruk & Geiger method exactly coincide with the actual mean (≈2817mm) of the rainfall series and coincides with the value at Px = 0.5 in the numerical method.

3.4.3 Spatial variability of rainfall in Kerala

Kerala is a narrow strip of land of about 580 km length and 35 to 120 km width, located at the Southern tip of Indian sub - continent with the Western Ghats on the Eastern side and the Arabian Sea on the Western side. The terrain is comparatively steep from East to West. The peculiar orientation of the State makes the weather pattern, unique with large North - South and East - West gradients in its annual rainfall pattern. The Western Ghats, obstructing the path of the South-West monsoon current causes the place to experience heavy rainfall. Along the plains, the annual rainfall increases from about 150 cm in the extreme South to about 350 cm in the extreme North. Steep downward gradient is seen in the annual rainfall from the Eastern parts towards West, with the Lakshadweep islands receiving only 150 cm annual rainfall (Joseph – 1990).

Fig. 3.4.3.1: Source www.mapsofindia.com

A typical approach for acquiring an enhanced view of the spatial and temporal variability in precipitation is the detailed analysis of historical rainfall data which will give adequate information on the intensity or spread of rainfall with respect to time and space for a region. The monthly rainfall data for the period from 1990 to 2016 pertaining to the 14 districts of Kerala were collected from “ Economic review” and “Indiastat.com”.

According to the summary statistics of the district wise rainfall data, it could be observed that the Idukki district was top in the case of average quantity of rainfall received (3645.91 mm) for the period from 1990 to 2016. Then came Kasaragode (3443.47 mm) and Kannur (3298.56). Kozhikode received an average rainfall of 3262.97 mm. Ernakulam (3258.61 mm), Kottayam (3037.04 mm) and Thrissur (2925.27 mm) were in the 5th, 6th and 7th positions. Pathanamthitta (2890.72 mm), Malappuram (2740.37 mm), Alappuzha (2685.74 mm) and Wayanad (2565.96 mm) were the next districts. The last 3 districts in the order of average quantity of rainfall received were Kollam (2507.67 mm), Palakkad (2199.85 mm) and Thiruvananthapuram (1833.63 mm). In all the districts, the average rainfall was below the normal rainfall. The corresponding normal rainfall for different districts were Thiruvananthapuram (1923mm); Kollam (2495 mm); (Pathanamthitta (2840 mm); Alappuzha (2999 mm); (Kottayam (3208 mm); Idukki (3769 mm); Ernakulam (3578 mm); Thrissur (3074 mm); Palakkad (2472 mm); Malappuram (2850 mm); Kozhikode (3671 mm); Wayanad (3409 mm); Kannur (3374 mm) and Kasargode (3613 mm).

The meteorological drought and flood year is defined as an year with total amount of annual rainfall over an area seems to be deficient or surplus respectively by more than 25% of its normal value. As per this criterion, in Thiruvananthapuram there were two drought years in 2012 and 2016. In Kollam, 1992 is identified as a flood year and 2012 as a drought year. For Pathanamthitta, there was only one drought year in 2012. In Alappuzha the years 1996, 2012 and 2016 were marked as drought years. In Kottayam, 2012 and 2016 were drought years. In Idukki, a surplus of 51.4% of the normal rainfall was received in 2005, but 2012 & 2016 were drought years. Five years, viz., 1990, 2000, 2003, 2012 and 2016 were noticed in Ernakulam as drought years. Thrissur district got 25% additional rainfall in 1992, 1994 & 2007 and deficit rainfall in 2000, 2003 & 2016. There were 6 drought years (1990, 2000, 2002, 2003, 2012 & 2016) in Palakkad and only one year with 25% more than the normal. In Malappuram, 1997 was a flood year and 2012 & 2016 were drought years. The drought years in Kasargode were 2000, 2002, 2003, 2005 and 2016 whereas in 2007 rainfall was surplus.

The highest number of drought years, under the study period was in Wayanad but not even a single flood year could be noticed, there. The drought years were 1993, a continuous drought period of 6 years from 1998 to 2003, alternate drought years in 2008, 2010 & 2012 and then in 2015 and 2016. For Kannur and Kasargode 1994 was a flood year and 2016 a drought year.

Table 3.4.3.1: District wise percentage variation of rainfall from normal in Kerala

Year	Tvm	Kllm	Ptmta	Alp	Ktym	Idk	Ekm	Tcr	Pkd	Mlp	Kzkd	Wyd	Knr	Ksgd
1990	-20.9	-19.1	-0.2	-10.2	-9.2	0.3	-31.1	-10.3	-28.4	-4.5	-18.1	-6.7	-4.7	12.9
1991	11.1	21.6	18.9	-10.6	-7.9	8.9	-7.0	10.3	-2.8	5.3	-11.1	-18.1	5.7	-5.0
1992	11.1	30.4	15.9	3.8	5.4	0.7	-1.3	25.8	-5.6	7.6	-1.6	-6.4	21.5	10.9
1993	9.0	16.2	5.4	0.1	-3.1	-18.0	-13.2	-0.6	-24.0	-15.6	-24.1	-27.5	-10.2	-2.1
1994	2.3	18.8	13.1	-11.9	2.8	4.6	7.3	25.7	10.1	22.8	16.6	2.7	26.2	27.5
1995	-19.6	19.0	6.6	-7.2	4.6	-5.7	0.4	6.1	-20.4	-1.3	-6.2	-20.7	-17.8	-2.0
1996	-18.0	-5.3	0.0	-25.0	-20.6	1.6	-10.3	-23.2	-23.5	-13.9	-18.5	-19.5	-1.7	-11.2
1997	-3.1	5.7	11.9	3.3	-1.9	3.1	-1.8	0.7	-2.3	42.4	-5.7	-16.7	17.9	3.1
1998	8.2	1.2	11.3	3.4	5.9	12.1	-7.6	9.3	-2.3	6.4	-7.9	-28.5	3.2	4.5
1999	0.1	15.6	9.4	12.7	-7.8	1.7	-14.7	-10.1	-14.2	-1.1	-22.3	-34.6	-10.0	-10.5
2000	-21.9	-5.7	-5.5	-12.0	-24.8	-14.4	-25.7	-32.6	-25.9	-23.1	-31.1	-31.2	-13.5	-12.8
2001	16.2	0.4	3.9	-5.7	-1.0	4.6	4.7	-9.8	-17.7	-6.3	-24.3	-39.1	-9.7	8.6
2002	-21.8	-9.1	-10.6	-14.5	-13.4	-16.2	-19.1	-17.7	-29.2	-20.0	-26.2	-43.9	-6.8	-10.8
2003	-18.5	-18.8	-9.3	-22.5	-13.3	-16.4	-27.5	-26.9	-30.1	-22.6	-38.1	-43.8	-15.1	-15.2
2004	-0.6	-1.9	3.2	-6.8	-9.2	1.7	-10.5	-4.8	-10.0	-7.9	-8.8	-22.8	1.4	-12.9
2005	10.9	-2.7	17.9	-13.3	5.5	51.4	-4.9	-7.1	7.1	-7.6	-36.1	-5.8	-21.7	-30.2
2006	20.7	14.6	7.2	0.7	17.1	6.5	7.8	16.4	7.6	19.6	-0.3	-24.1	1.6	-4.7
2007	6.7	10.3	14.5	3.6	8.1	18.2	13.1	28.6	32.3	24.3	28.1	-9.3	21.3	6.7
2008	0.4	-11.5	-6.4	-13.8	-21.0	-19.6	-19.7	-24.9	-23.8	-24.7	-9.3	-37.2	-16.3	-8.1
2009	-22.9	-14.7	-18.9	-16.6	-24.1	-12.0	-8.8	0.5	1.0	-11.9	9.7	-20.1	4.7	-13.1
2010	11.3	11.8	14.2	2.0	14.4	-5.3	13.8	1.3	-0.5	-8.4	5.5	-40.1	3.7	11.0
2011	-21.0	-8.1	-6.5	-13.2	2.5	-2.5	-2.1	2.2	5.6	3.2	8.2	-22.8	2.9	6.8
2012	-40.0	-33.6	-36.0	-38.5	-28.3	-31.0	-27.0	-23.2	-31.3	-30.3	-20.2	-46.0	-21.0	-15.7
2013	-4.1	7.8	0.3	-5.8	12.4	7.7	2.2	3.6	4.0	12.8	4.7	-7.0	19.2	-1.2
2014	-0.6	0.7	10.7	-17.7	4.4	-2.3	-4.0	-9.6	-7.8	9.9	-2.9	-4.4	4.7	-7.5
2015	17.1	-6.4	1.8	-21.8	-6.4	-23.9	-19.2	-15.6	-19.7	-12.7	-21.8	-33.0	-11.7	-24.0
2016	-37.7	-23.2	-24.4	-40.9	-35.0	-44.0	-35.0	-45.1	-45.4	-46.2	-38.4	-61.1	-34.3	-31.7

Variation of > 25% denote flood years (green shade) and < 25% denote drought (red shade)

The percentage of deficit and surplus rainfall in different years for all the districts in Kerala are given in Table (3.4.3.1). Idukki was marked as the district showing a surplus of 51.4% rainfall during the year 2005 followed by 42.4% in 1997 in Malappuram district.

In almost all the districts, drought occurred during the year 2016 with a maximum deficit of 61.1% in Wayanad followed by 46.2% in Malappuram district. Except in 3 districts there was drought incidence in 2012 also. The worst affected district due to drought, in the study period was Wayanad. Out of the 26 years of study 12 were drought years in Wayanad, 6 years in Palakkad and 5 years in Ernakulam and Kozhikode districts.

Plantation crops greatly affect Kerala’s economy and weather factors have indirect effects on it. In general there was an increase in annual mean temperature over decades and rising uncertainties in rainfall. Droughts in summer and floods in rainy season are not uncommon here (Gopakumar, 2012)

The continuous changes in the climate have put farmers of Wayanad in deep trouble. Crops have become more disease prone causing major losses. Growth of soil pathogens and pests would be favoured by erratic changes in soil temperature and moisture level which would lead to crop diseases and affect the yield. When compared to the mid and low land of Kerala a much higher increase in temperature is there in Wayanad due to deforestation.

A decline in the early phase of the South-West monsoon and a more number of heavy rainfall days were the major climate trends observed in Wayanad which has adversely affected a variety of crops like pepper, coffee etc. The rainfall during the South- West monsoon is observed to be declining.

World’s most widely used spice, black pepper, a major crop grown in Wayanad is now facing major survival challenges. The yield has significantly reduced due to pest attacks and diseases. The tropical climate and heavy monsoon of Kerala are ideal for the crop. It is the distribution pattern of monsoon rainfall and the timely occurrence of the “Thiruvathira Njattuvela’ which determines the yield.

The next important crop is coffee in Wayanad. It needs an annual rainfall of 1500 to 3000 mm and an average rainfall ranging from 15 to 24^0C for Arabia variety and 24 to 30^0C for Robusta variety. The Government has declared Wayanad as a climate vulnerable region since it has experienced the ill effects of irresponsible acts of humans such as mining of mountains, large scale deforestation, land use changes levelling of paddy land for construction, extensive use of chemical fertilisers and pesticides, etc. The current situation is to be studied in detail and take immediate steps to cope up with the climate change for the survival of the farming community.

Table 3.4.3.2
Districtwise variation of rainfall in January in Kerala,1990-2016

District	Mean	S.D	C.V (%)	Max	Min
Thiruvananthapuram	16.73	22.69	135.61	108.3	0.0
Kollam	20.47	28.89	141.15	97.0	0.0
Pathanamthitta	15.50	16.90	109.00	67.6	0.0
Alappuzha	16.98	18.31	107.84	55.0	0.0
Kottayam	12.71	14.92	117.34	56.1	0.0
Idukki	11.42	14.35	125.65	46.8	0.0
Ernakulam	11.51	20.76	180.26	98.3	0.0
Thrissur	3.40	8.84	259.89	42.2	0.0
Palakkad	2.06	3.90	189.22	13.7	0.0
Malapuram	1.99	4.60	231.77	17.6	0.0
Kozhikode	2.37	4.20	177.54	16.8	0.0
Wayanad	7.79	15.05	193.35	56.4	0.0
Kannur	2.80	8.06	287.96	37.5	0.0
Kasargode	1.63	6.04	370.39	30.9	0.0

Table 3.4.3.3
Districtwise variation of rainfall in February in Kerala,1990-2016

District	Mean	S.D	C.V (%)	Max	Min
Thiruvananthapuram	23.34	24.11	103.29	73.6	0.0
Kollam	33.61	33.05	98.34	140.9	0.0
Pathanamthitta	33.12	49.30	148.85	235.5	0.0
Alappuzha	32.98	41.22	125.00	187.0	0.0
Kottayam	23.20	26.55	114.46	94.6	0.0
Idukki	18.61	22.20	119.26	95.5	0.0
Ernakulam	21.87	30.62	139.99	98.2	0.0
Thrissur	11.47	26.39	230.11	131.0	0.0
Palakkad	11.70	18.56	158.59	64.0	0.0
Malapuram	5.44	10.20	187.30	34.2	0.0
Kozhikode	4.83	10.29	213.23	41.8	0.0
Wayanad	8.62	11.31	131.13	48.7	0.0
Kannur	2.17	6.95	320.55	35.5	0.0
Kasargode	3.49	15.96	457.97	83.2	0.0

Table 3.4.3.4
Districtwise variation of rainfall in March in Kerala,1990-2016

District	Mean	S.D	C.V (%)	Max	Min
Thiruvananthapuram	41.63	50.99	122.48	276.0	2.1
Kollam	63.50	48.87	76.95	224.9	2.0
Pathanamthitta	68.39	41.50	60.68	157.7	0.0
Alappuzha	48.81	37.54	76.91	175.5	0.0
Kottayam	69.48	56.63	81.51	253.7	0.0
Idukki	55.58	45.19	81.31	166.5	0.0
Ernakulam	37.66	60.31	160.17	319.6	0.0
Thrissur	20.12	42.30	210.20	218.1	0.0
Palakkad	25.18	36.32	144.25	153.9	0.0
Malapuram	21.83	42.08	192.79	207.2	0.0
Kozhikode	21.13	51.33	242.95	267.8	0.0
Wayanad	31.77	37.93	119.40	166.3	0.0
Kannur	14.37	47.91	333.32	250.2	0.0
Kasargode	16.80	57.13	339.96	295.0	0.0

Table3.4.3.5
Districtwise variation of rainfall in April in Kerala,1990-2016

District	Mean	S.D	C.V (%)	Max	Min
Thiruvananthapuram	133.58	74.10	55.47	354.9	5.0
Kollam	162.14	60.78	37.49	279.0	67.0
Pathanamthitta	204.53	100.46	49.12	477.0	40.0
Alappuzha	135.76	65.44	48.20	255.5	13.0
Kottayam	158.85	77.95	49.07	301.7	10.0
Idukki	166.91	78.76	47.19	400.3	39.1
Ernakulam	130.69	86.08	65.86	401.8	36.0
Thrissur	79.06	52.71	66.67	185.4	0.0
Palakkad	87.98	58.21	66.16	223.7	4.1
Malapuram	88.57	65.43	73.87	268.2	0.0
Kozhikode	84.88	61.07	71.94	237.4	0.0
Wayanad	109.12	55.41	50.78	209.9	0.0
Kannur	50.11	47.80	95.38	174.3	0.0
Kasargode	47.85	45.74	95.59	163.2	0.0

Table 3.4.3.6
Districtwise variation of rainfall in May
in Kerala,1990-2016

District	Mean	S.D	C.V (%)	Max	Min
Thiruvananthapuram	205.37	113.06	55.05	429.7	11.2
Kollam	244.49	132.72	54.28	613.8	73.5
Pathanamthitta	263.49	154.81	58.75	723.6	61.5
Alappuzha	279.96	149.23	53.30	685.1	82.0
Kottayam	278.33	172.39	61.94	720.5	50.4
Idukki	243.17	170.18	69.98	651.1	65.2
Ernakulam	284.46	183.92	64.66	711.6	52.7
Thrissur	241.54	179.08	74.14	659.0	38.0
Palakkad	141.06	98.49	69.82	391.7	41.2
Malapuram	191.22	154.05	80.56	552.1	31.0
Kozhikode	246.27	204.14	82.89	803.0	41.3
Wayanad	152.67	87.85	57.54	404.5	42.6
Kannur	209.23	195.75	93.56	772.3	20.4
Kasargode	221.11	205.26	92.83	734.0	16.5

Table 3.4.3.7
Districtwise variation of rainfall in June
in Kerala,1990-2016

District	Mean	S.D	C.V (%)	Max	Min
Thiruvananthapuram	315.11	186.38	59.15	869.0	99.1
Kollam	428.90	194.31	45.30	1158.0	167.5
Pathanamthitta	524.19	177.47	33.86	1165.0	179.5
Alappuzha	556.71	182.39	32.76	1087.0	215.7
Kottayam	635.91	212.62	33.44	1258.0	338.1
Idukki	732.90	242.86	33.14	1380.0	393.0
Ernakulam	719.04	229.78	31.96	1321.0	413.0
Thrissur	706.90	184.10	26.04	1087.0	437.0
Palakkad	476.67	131.06	27.49	729.2	282.0
Malapuram	687.73	193.76	28.17	1084.3	337.9
Kozhikode	855.21	223.04	26.08	1426.1	508.2
Wayanad	568.30	221.91	39.05	1065.0	278.4
Kannur	892.21	220.07	24.67	1503.7	614.3
Kasargode	984.93	231.86	23.54	1460.9	549.3

Table 3.4.3.8
Districtwise variation of rainfall in July
in Kerala,1990-2016

District	Mean	S.D	C.V (%)	Max	Min
Thiruvananthapuram	207.97	85.66	41.19	330.2	59.0
Kollam	371.54	119.87	32.26	587.3	131.5
Pathanamthitta	493.26	161.88	32.82	755.2	186.1
Alappuzha	483.15	154.26	31.93	780.2	219.5
Kottayam	565.90	155.96	27.56	921.1	264.7
Idukki	861.43	325.01	37.73	1986.0	407.1
Ernakulam	679.02	197.99	29.16	1132.8	365.3
Thrissur	676.65	241.22	35.65	1170.2	333.6
Palakkad	552.21	224.79	40.71	1032.6	281.8
Malapuram	674.71	297.46	44.09	1495.7	303.0
Kozhikode	842.87	332.21	39.41	1817.5	341.7
Wayanad	716.25	314.02	43.84	1256.6	279.0
Kannur	909.46	315.56	34.70	1571.1	325.2
Kasargode	945.39	314.76	33.29	1545.1	383.6

Table 3.4.3.9
Districtwise variation of rainfall in August
in Kerala,1990-2016

District	Mean	S.D	C.V (%)	Max	Min
Thiruvananthapuram	141.49	90.62	64.05	458.6	42.2
Kollam	261.02	112.59	43.13	591.5	104.3
Pathanamthitta	347.11	134.78	38.83	778.7	154.9
Alappuzha	316.73	129.84	40.99	615.3	114.2
Kottayam	381.19	147.19	38.61	805.1	174.1
Idukki	589.04	162.70	27.62	1011.1	271.3
Ernakulam	430.82	161.73	37.54	877.0	167.0
Thrissur	413.54	145.63	35.21	672.2	148.7
Palakkad	314.93	98.64	31.32	561.4	159.2
Malapuram	381.67	123.15	32.26	733.0	186.3
Kozhikode	442.84	173.73	39.23	879.0	225.0
Wayanad	429.77	143.72	33.44	801.0	185.4
Kannur	539.03	167.58	31.09	876.0	267.0
Kasargode	606.59	190.18	31.35	994.0	306.8

Table 3.4.3.10
Districtwise variation of rainfall in September
in Kerala,1990-2016

District	Mean	S.D	C.V (%)	Max	Min
Thiruvananthapuram	170.05	136.84	80.47	478.1	8.0
Kollam	227.34	114.70	50.45	434.1	16.0
Pathanamthitta	262.39	141.86	54.07	628.0	43.0
Alappuzha	257.17	132.53	51.53	596.3	28.0
Kottayam	290.19	154.37	53.20	694.6	57.0
Idukki	372.67	203.46	54.59	968.5	119.8
Ernakulam	330.84	194.11	58.67	712.0	28.0
Thrissur	285.78	178.69	62.53	662.3	47.5
Palakkad	197.45	123.18	62.38	507.3	33.3
Malapuram	236.80	153.93	65.01	617.0	32.0
Kozhikode	280.64	179.68	64.03	699.1	16.0
Wayanad	203.11	99.14	48.81	385.0	53.0
Kannur	252.18	154.22	61.16	595.6	51.0
Kasargode	263.30	155.53	59.07	631.4	74.2

Table 3.4.3.11
Districtwise variation of rainfall in October
in Kerala,1990-2016

District	Mean	S.D	C.V (%)	Max	Min
Thiruvananthapuram	295.26	123.45	41.81	521.4	43.4
Kollam	408.86	159.18	38.93	926.8	188.9
Pathanamthitta	395.54	144.94	36.64	664.7	158.9
Alappuzha	331.73	154.32	46.52	694.1	49.9
Kottayam	379.99	133.76	35.20	615.9	154.0
Idukki	380.70	153.62	40.35	818.7	117.1
Ernakulam	384.19	132.51	34.49	643.0	156.5
Thrissur	346.61	135.24	39.02	576.1	98.2
Palakkad	255.47	92.57	36.23	445.9	88.2
Malapuram	300.47	96.00	31.95	498.2	87.1
Kozhikode	327.57	125.76	38.39	614.0	42.5
Wayanad	222.83	93.12	41.79	450.7	58.6
Kannur	283.78	126.13	44.45	746.2	45.1
Kasargode	242.22	131.51	54.29	686.0	23.8

Table 3.4.3.12
Districtwise variation of rainfall in November
in Kerala,1990-2016

District	Mean	S.D	C.V (%)	Max	Min
Thiruvananthapuram	219.95	96.14	43.71	466.2	47.2
Kollam	236.23	98.89	41.86	507.0	89.0
Pathanamthitta	236.00	113.39	48.04	526.4	93.1
Alappuzha	185.51	82.12	44.27	372.6	63.4
Kottayam	196.41	94.24	47.98	456.0	60.0
Idukki	171.91	89.47	52.04	421.2	37.9
Ernakulam	185.37	116.07	62.62	517.5	37.4
Thrissur	121.33	91.53	75.44	387.0	8.3
Palakkad	118.28	82.04	69.36	282.5	8.6
Malapuram	131.37	75.99	57.84	259.0	14.8
Kozhikode	136.21	91.19	66.95	363.9	8.9
Wayanad	91.66	66.72	72.79	218.0	11.8
Kannur	120.09	99.90	83.19	396.0	3.0
Kasargode	96.47	108.22	112.18	522.0	13.0

Table 3.4.3.13
Districtwise variation of rainfall in December
in Kerala,1990-2016

District	Mean	S.D	C.V (%)	Max	Min
Thiruvananthapuram	63.14	59.99	95.01	188.3	1.4
Kollam	49.59	51.01	102.86	192.7	0.0
Pathanamthitta	47.20	51.05	108.15	176.0	0.0
Alappuzha	44.26	46.73	105.57	169.7	0.0
Kottayam	44.89	44.84	99.90	127.1	0.0
Idukki	41.56	47.73	114.87	142.9	0.0
Ernakulam	43.14	50.83	117.84	182.3	0.0
Thrissur	18.86	25.89	137.27	91.9	0.0
Palakkad	16.86	21.22	125.92	87.4	0.0
Malapuram	19.39	27.22	140.39	87.0	0.0
Kozhikode	18.15	25.65	141.28	100.3	0.0
Wayanad	24.07	33.96	141.10	120.3	0.0
Kannur	23.13	33.77	146.04	120.1	0.0
Kasargode	13.68	18.08	132.14	57.5	0.0

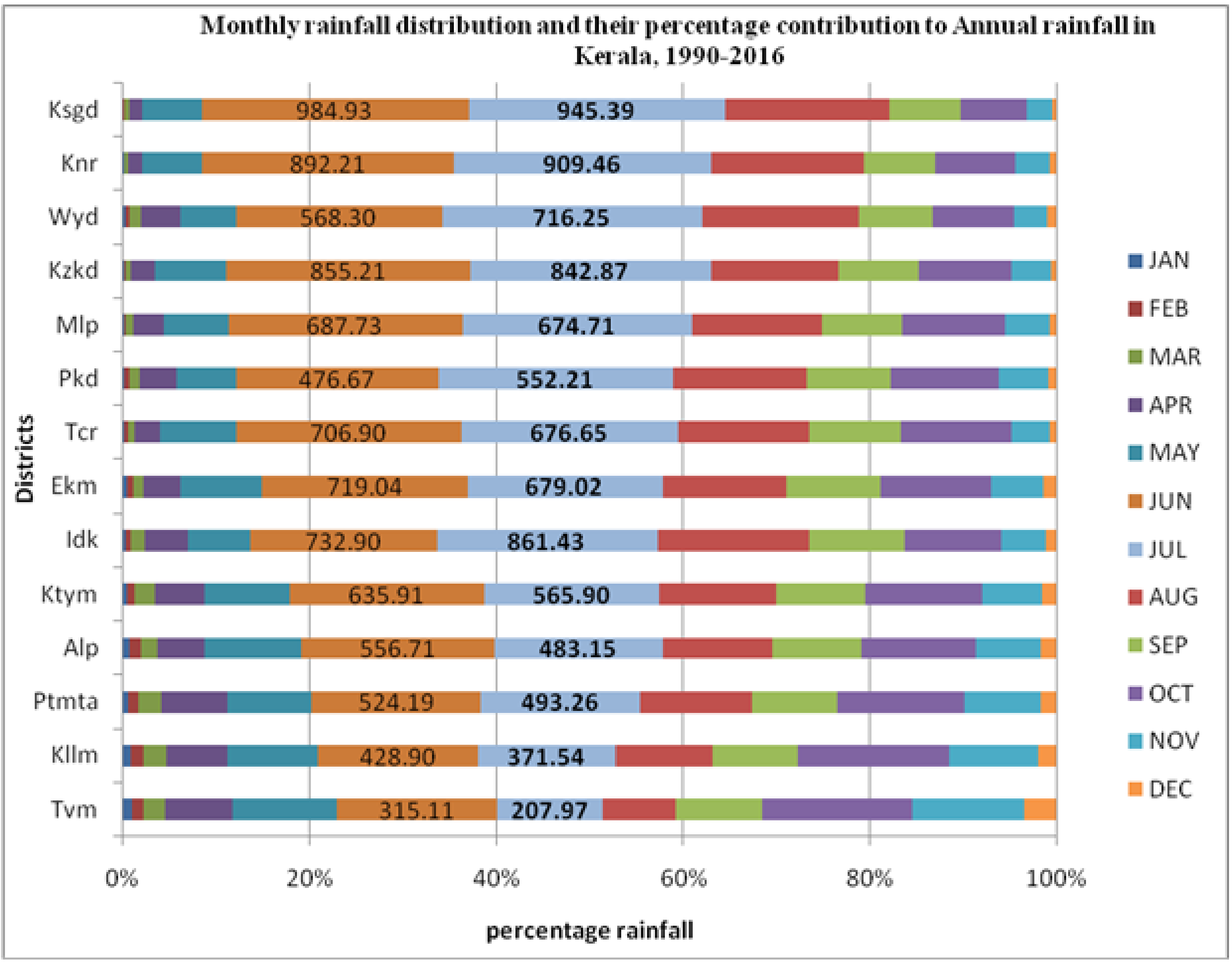


Fig. 3.4.3.2

The monthly and seasonal variations in rainfall with respect to different districts in Kerala were studied in detail. During January, the mean rainfall was maximum (20.47mm) in Kollam district and the least was in Kasargode (1.63mm). The coefficient of variation was very high for all the districts. In February also the maximum rainfall (33.61mm) was recorded in Kollam and the minimum (2.17 mm) in Kannur district. The maximum rainfall in the month of March was received in Kottayam district (69.48mm) and the minimum in Kannur district (14.37 mm). An amount of 204.53 mm was recorded as maximum rainfall in Pathanamthitta district and a minimum rainfall of 47.8 mm in Kasargode district in the month of April. In May, a maximum rainfall of 284.46 mm was recorded in Ernakulam district and a minimum of 141.06 mm in Palakkad. At the start of SW monsoon, in June, the maximum rainfall reached 984.93 mm in Kasargode district and the minimum 315.11 mm in Thiruvananthapuram. In July, the average maximum rainfall was 945.33 mm in Kasargode district and the minimum average rainfall was 207.97 mm in Thiruvananthapuram district. During the month of August the maximum average rainfall was 606.59 mm in Kasaragode district and the minimum 141.49 mm in Thiruvananthapuram district. At the end of the SW monsoon period, the average maximum rainfall was recorded as 372.67 mm in Idukki district and the minimum 170.05 mm in Thiruvananthapuram district. When the post monsoon season started, the average maximum rainfall was obtained as 408.86 mm in Kollam district and the minimum of 222.83 mm in Wayanad district, in the month of October. In the month of November also the average maximum rainfall of 236.23 mm was recorded in Kollam and the minimum 91.66 mm, in Wayanad district. Even though the quantity of rainfall in Thiruvananthapuram was the lowest when compared to all other districts in June, July, August and September (*i.e*. the whole SW monsoon period), this district recorded an average maximum rainfall of 63.14 mm in the month of December and the average minimum rainfall in December was 13.68mm in Kasargode district. The consistency of rainfall was very poor in the month of January, February and March, irrespective of the districts as obvious from the high values of coefficients of variation. The value of C.V (%) became smaller during the SW monsoon period and gradually it started increasing from the month of September and reached high values in the month of December showing the inconsistency in rainfall during the post monsoon period.

In short it could be observed that the Kasargode district has been subjected to extreme climatic variations as the rainfall received in June, July and August were maximum in this district and during the post monsoon seasons the district experienced worst dry conditions attaining a minimum average rainfall in December, January and April, when compared to other districts. Kollam district recorded average maximum rainfall during January, February, October and November. Even though Kasargode district was top in average maximum rainfall received during the SW monsoon period, at the end of the period, *i.e.* in September, Idukki recorded the average maximum rainfall. Idukki receives rainfall in a uniformly distributed pattern during the SW monsoon season, which would be more beneficial for the crops. During the summer season, March, April and May, the average maximum rainfall was recorded in Kottayam, Pathanamthitta and Ernakulam districts respectively. The average maximum rainfall in December was in Thiruvananthapuram district. But during SW monsoon period, the lowest average rainfall was recorded in June, July, August and September in this district. Kannur district recorded minimum average rainfall during February and March. Palakkad was worst hit in May with least rainfall and Wayanad was adversely affected with minimum average rainfall during the months of October and November.

Table 3.4.3.14: District wise variations of seasonal rainfall in Kerala, 1990 -2016

Districts	Winter (mm)	Summer (mm)	SW (mm)	NE (mm)	Annual (mm)
Thiruvananthapuram	40.07	380.58	834.62	578.35	1833.63
Kollam	54.07	470.13	1288.80	694.67	2507.67
Pathanamthitta	48.63	536.41	1626.95	678.74	2890.72
Alappuzha	49.96	464.53	1613.76	561.50	2689.74
Kottayam	35.91	506.66	1873.19	621.28	3037.04
Idukki	30.03	465.66	2556.05	594.17	3645.91
Ernakulam	33.39	452.81	2159.72	612.70	3258.61
Thrissur	14.87	340.73	2082.87	486.80	2925.27
Palakkad	13.76	254.21	1541.26	390.61	2199.85
Malappuram	7.43	300.80	1980.91	451.23	2740.37
Kozhikode	7.19	352.28	2421.57	481.93	3262.97
Wayanad	16.41	293.56	1917.43	338.57	2565.96
Kannur	4.97	273.72	2592.87	426.99	3298.56
Kasargode	5.11	285.76	2800.22	352.37	3443.47

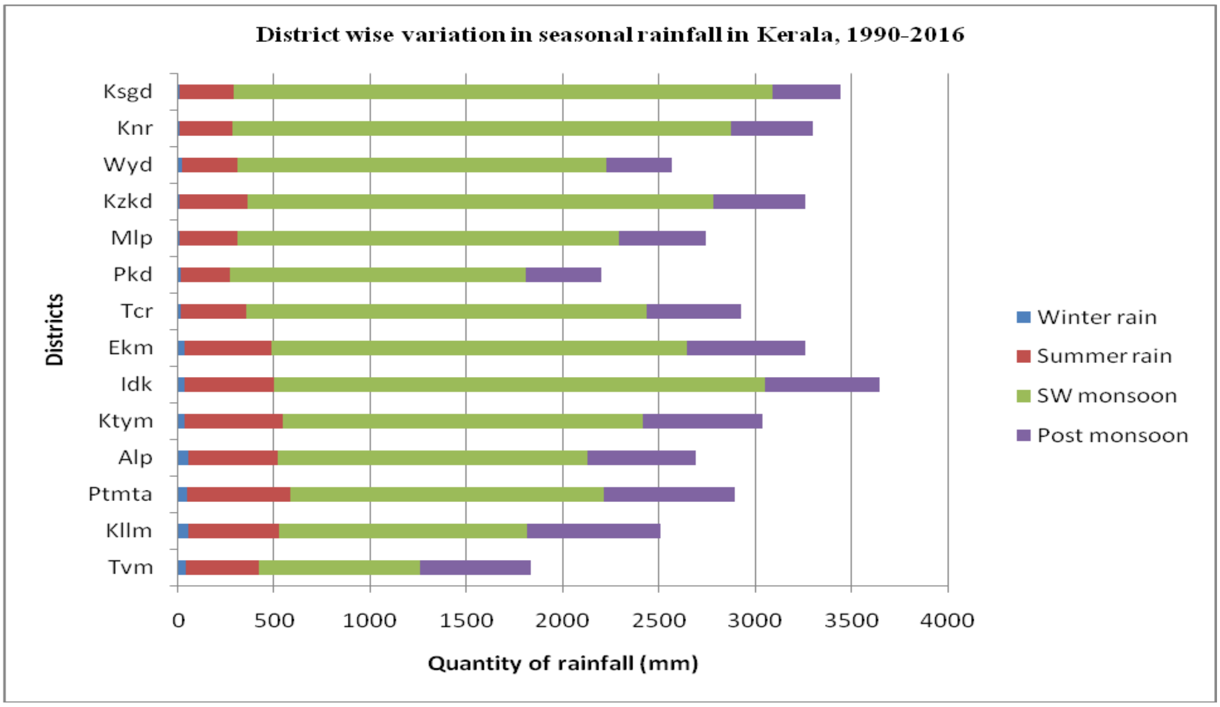


Fig. 3.4.3.3

When seasonal rainfall was considered, the winter rain (54.07 mm) and post monsoon rain (694.67 mm) was maximum in Kollam district as evidenced from the seasonal rainfall statistics. The SW monsoon was maximum in Kasargode district (2800.22 mm) and

Pathanamthitta recorded maximum summer rain (536.41 mm). The average minimum rainfall was recorded (4.97 mm) in Kannur district during the winter season, and in summer, Palakkad recorded the average minimum (254.21 mm) rainfall. South West monsoon was least in Thiruvananthapuram (834.62 mm) and Wayanad has recorded the least rainfall (338.57 mm) in the post monsoon period.

It is an exciting fact that the SW monsoon has its positive extreme towards the farthest North end *i.e.* in the Kasargode district and the negative extreme, towards the Southernmost district, Thiruvananthapuram. Whereas, rainfall during the other seasons were more in the Southern part of Kerala like Kollam and Pathanamthitta and drought has occurred towards the northern districts like Wayanad and Kannur. The summer drought was more prominent in Palakkad district.

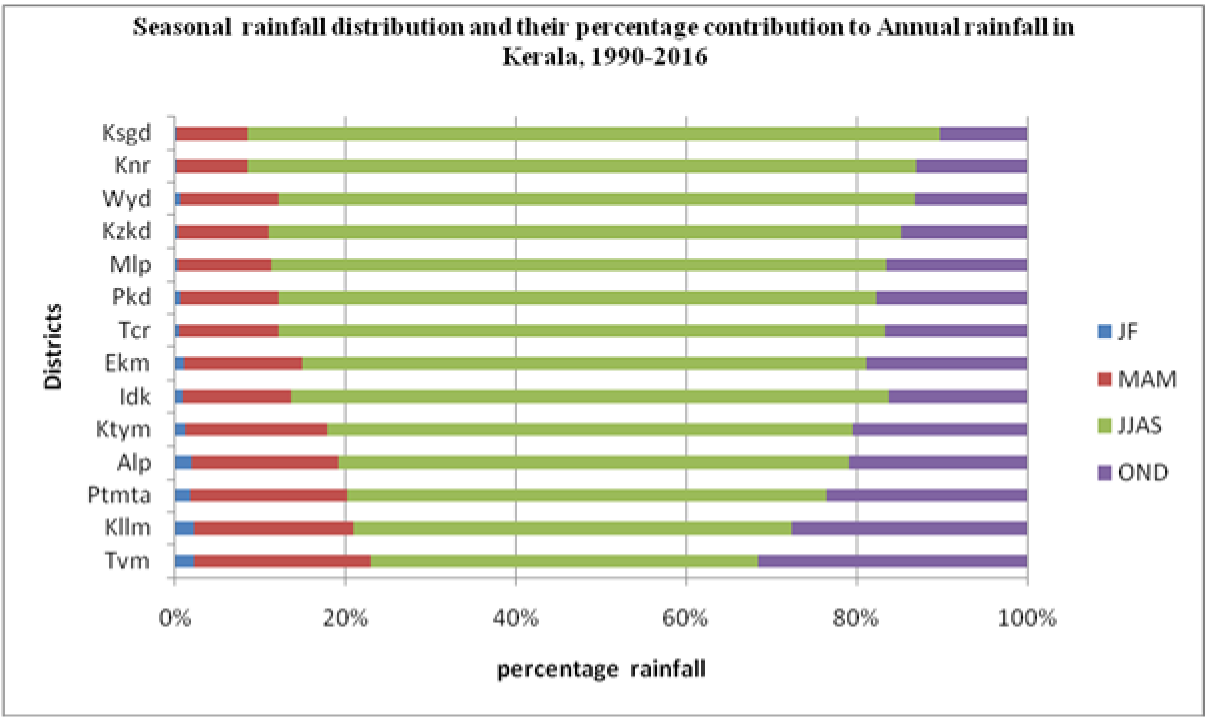


Fig. 3.4.3.4

The highest average annual rainfall was in Idukki, the second largest district in Kerala. It has some peculiarities when compared to the other districts of Kerala. Idukki, known for a variety of spices, is a high range district lies in the Western Ghats surrounded by mountains. More than half of the area of the district is covered by dense forests. Blessed with the beauty of nature, waterfalls, rivers & reservoirs, it is one of the most favourite attractions of the nature loving tourists. Major share of Kerala's power generation is coming from this district through large hydro-electric power stations like Idukki, Idamalayar, Pallivasal, etc.

Exploratory analysis of the distribution of monthly, seasonal and annual rainfall in Kerala, 1990-2016

A Box plot can be effectively used to depict numerical data using quartiles. The variability more than the upper and lower quartiles can be shown through lines extending vertically (whiskers) from the boxes. Hence they are named as box-and-whisker plot. Outliers are shown as individual points. As Box plots exhibit variation in samples of a statistical population without making any assumptions of the underlying statistical distribution they are non- parametric. The degree of dispersion and skewness in the data are indicated through the spacing between the different parts of the box.

In a box plot, the bottom and top of the box indicate the first and third quartiles and the band inside the box is the second quartile (the median). In some cases, the mean is displayed with a red +. The ends of the whiskers denote several possible alternatives such as the minimum and maximum of all the data, one S.D above and below the mean of the data, the 2nd percentile and the 98th percentile etc.. A mild outlier may be shown as dot or circle outside the whiskers and an extreme outlier may be denoted by a star.

Box-Whiskers plot

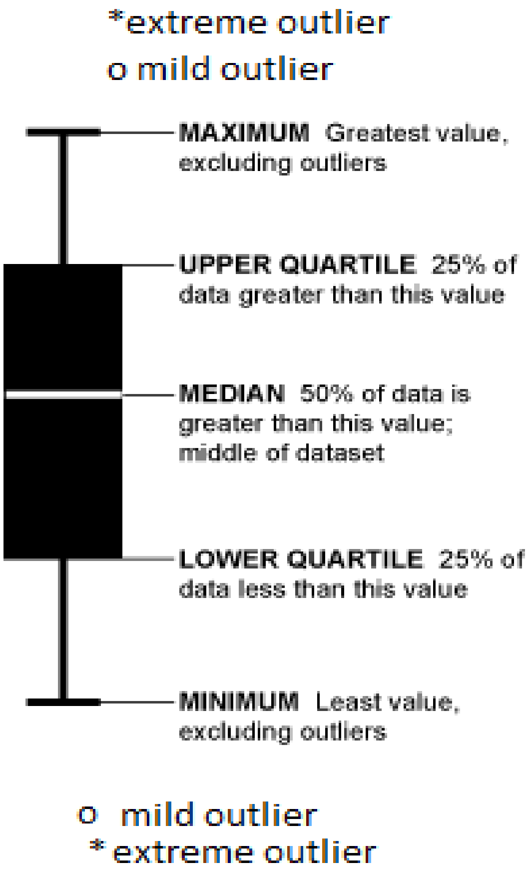


Fig. 3.4.3.5

In this study, the box plots were drawn using the s/w XLSTAT version 2017

The end of the whiskers are calculated as

Lower limit = Q_1 -1.5(Q_3-Q_1) and

Upper limit = Q_3 + 1.5(Q_3-Q_1)

Values that are outside the Q_1 – 3(Q_3-Q_1); Q_3+3(Q_3-Q_1)

are denoted by * symbol. Values that are in the

[Q_1-3(Q_3-Q_1); Q_1-1.5(Q_3-Q_1)] or

[Q_3+1.5(Q_3-Q_1); Q_3+ 3(Q_3-Q_1)] intervals are depicted using

The symbol “o”

A comparison of different districts in Kerala with respect to monthly, seasonal and annual rainfall variability are shown using Box plot.

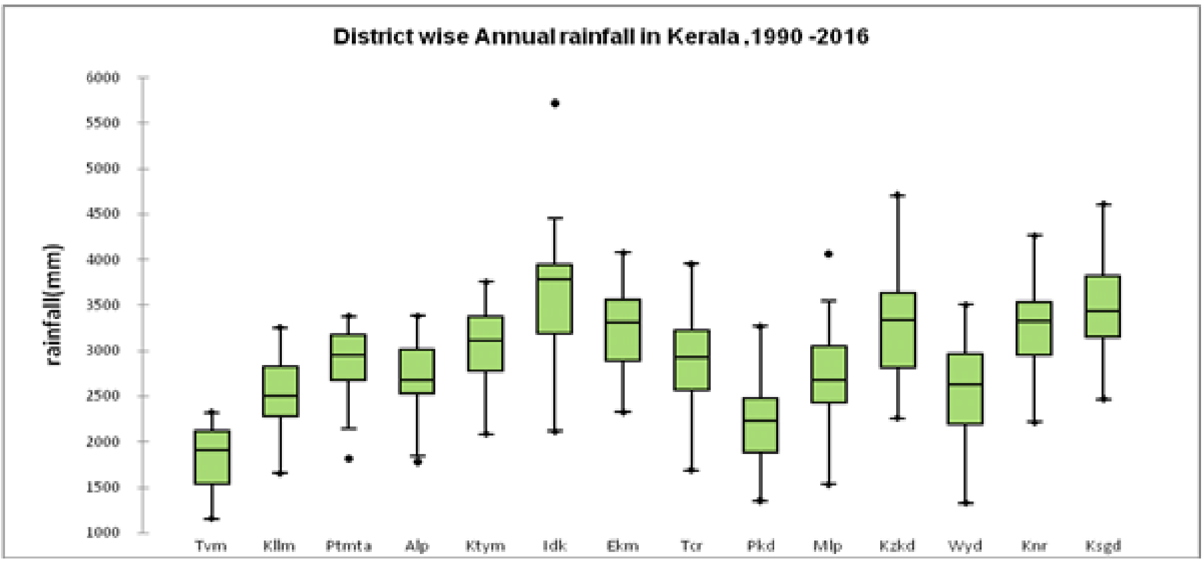


Fig. 3.4.3.6

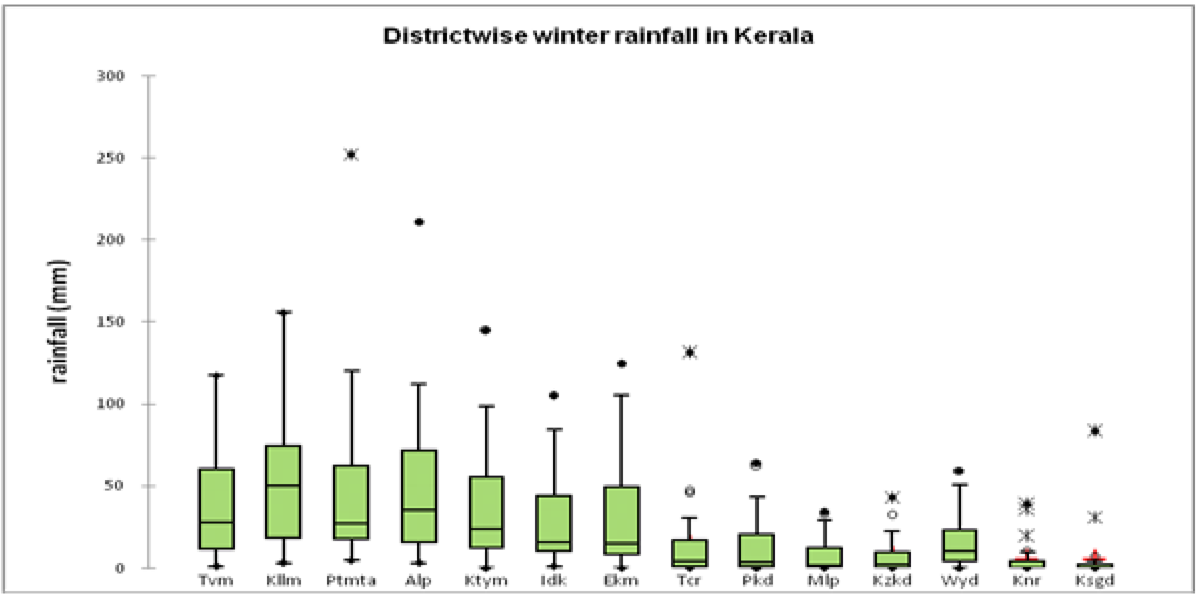


Fig. 3.4.3.7

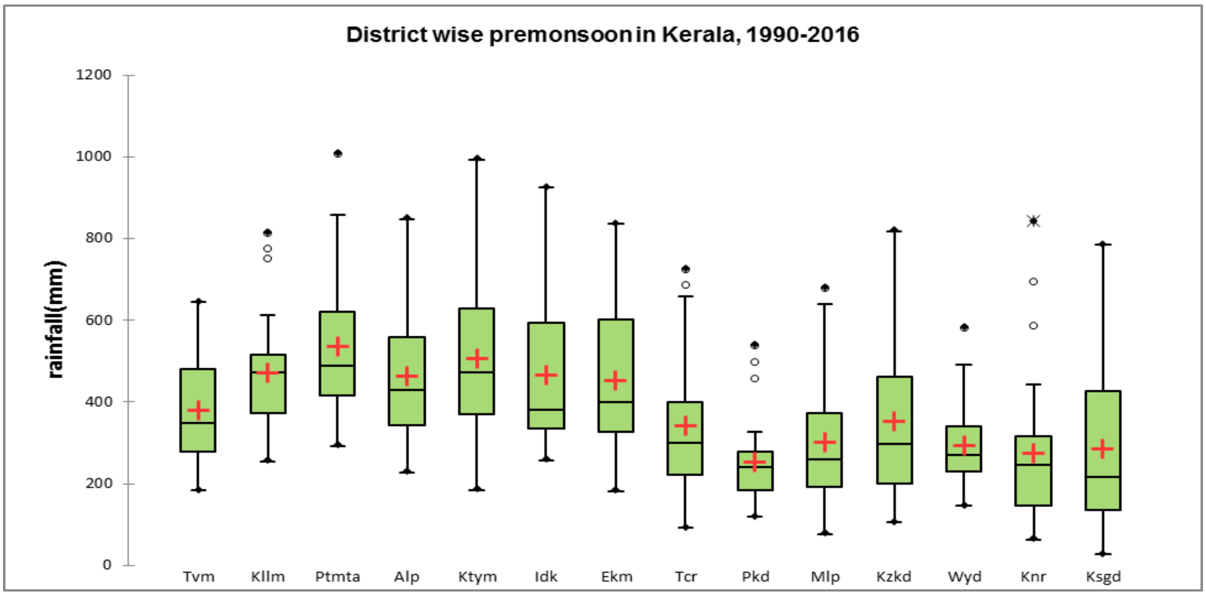


Fig. 3.4.3.8

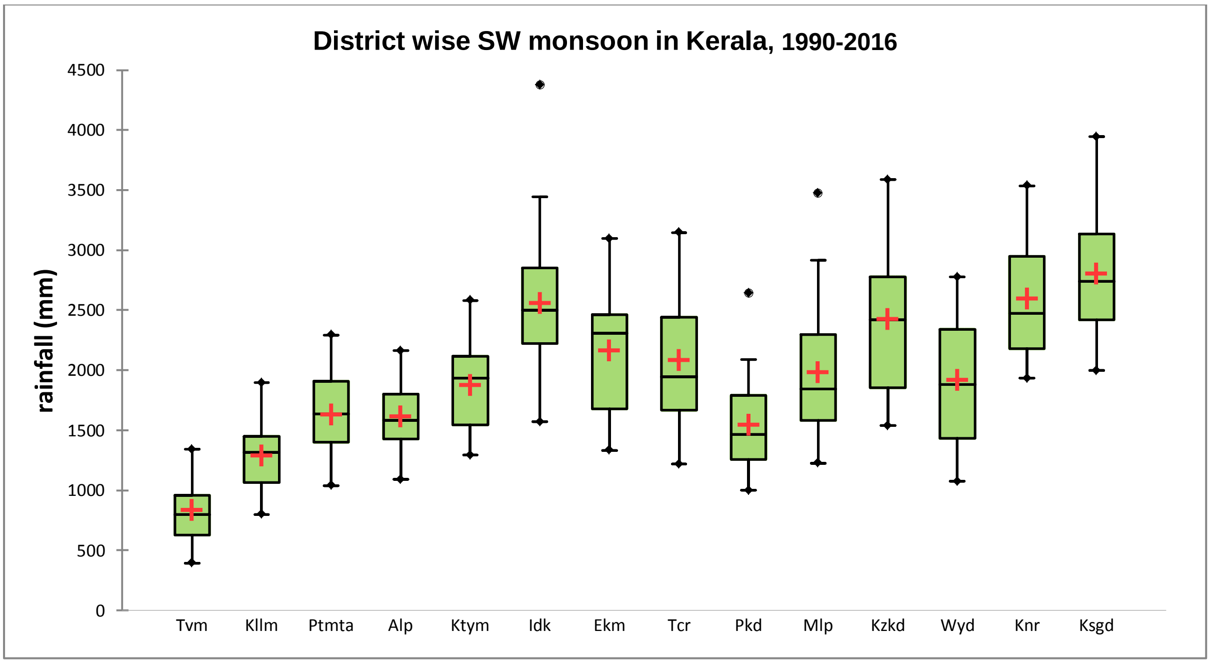
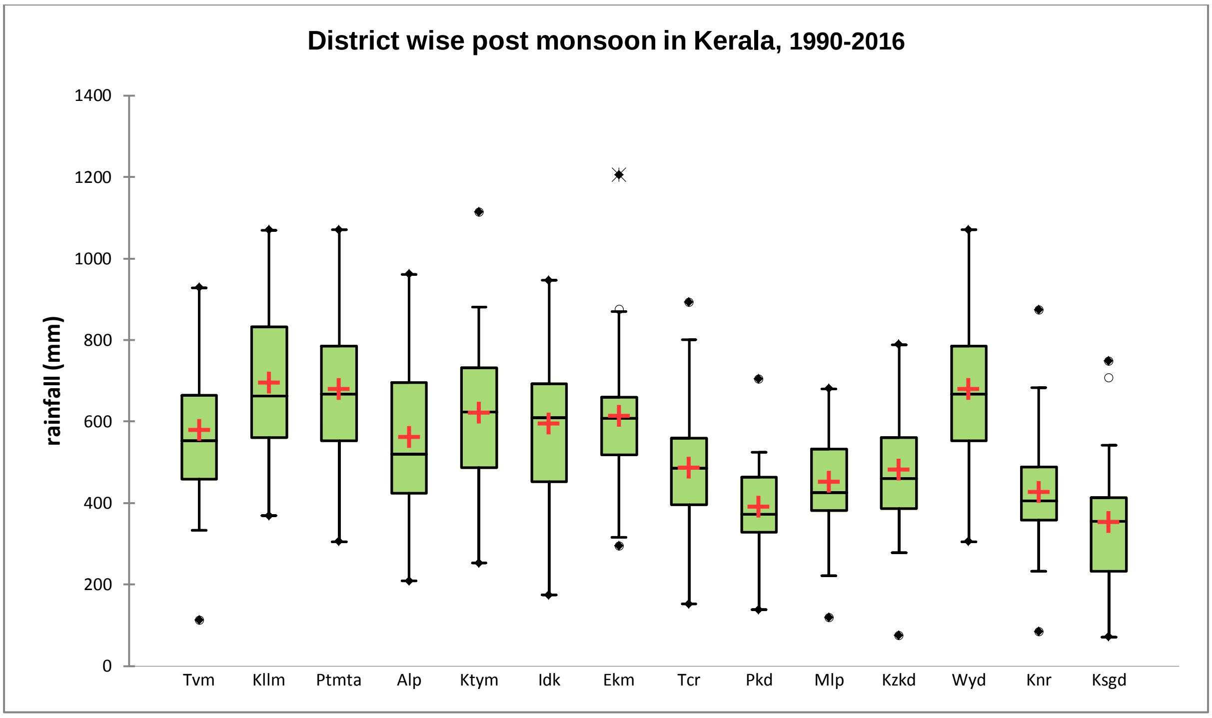


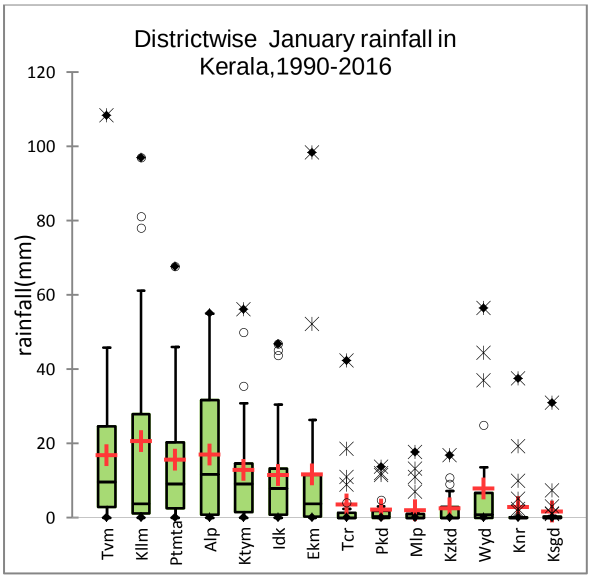
Fig. 3.4.3.9

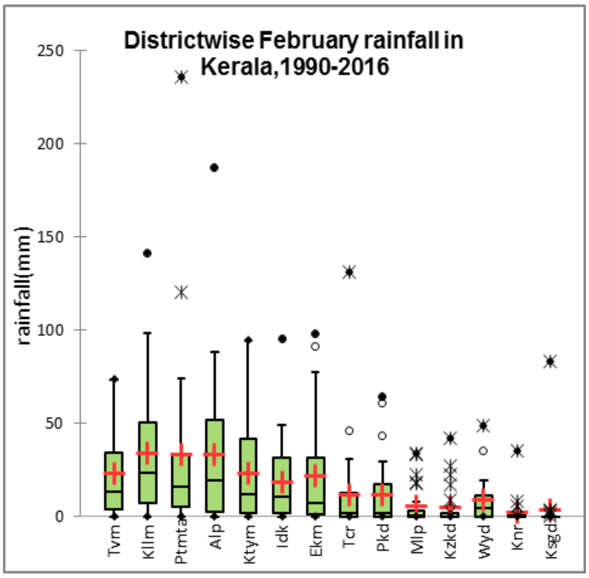


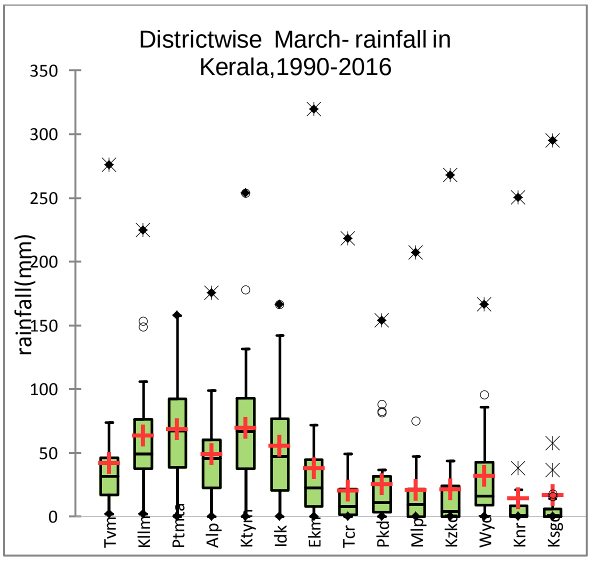
District wise post monsoon in Kerala, 1990-2016
rainfall (mm)
1400
1200
1000
800
600
400
200
0
Tvm
Kllm
Ptmta
Alp
Ktym
Idk
Ekm
Tcr
Pkd
Mlp
Kzkd
Wyd
Knr
Ksgd

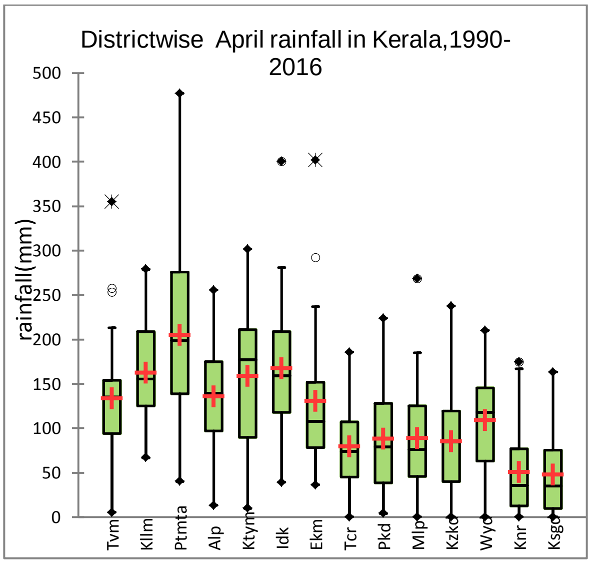
Fig. 3.4.3.10

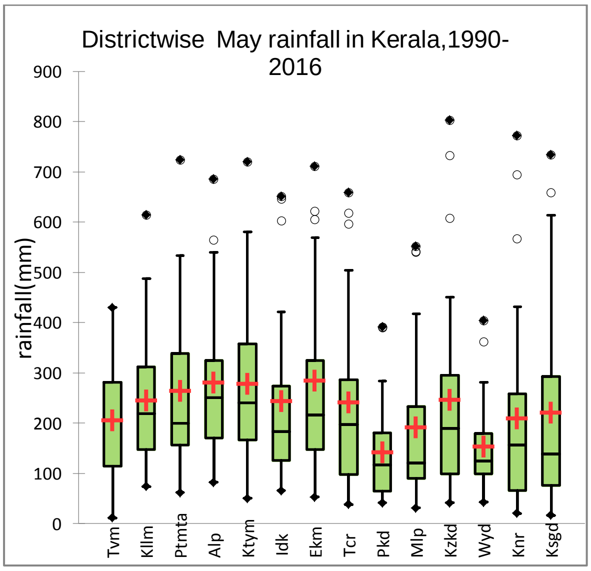
Box plot - District wise monthly rainfall in Kerala, 1990-2016

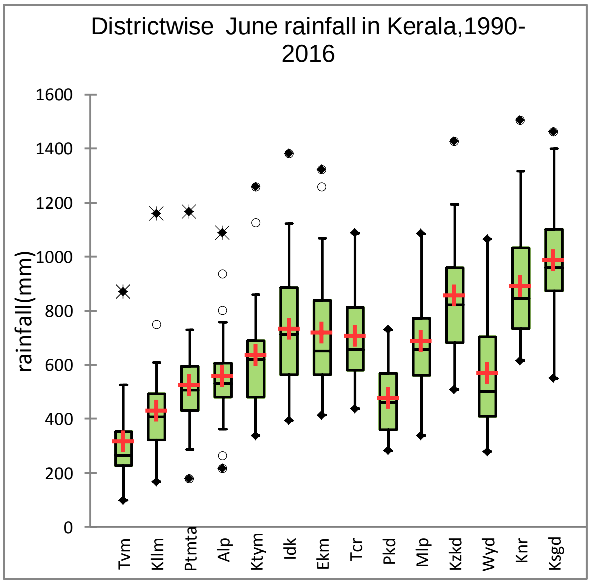












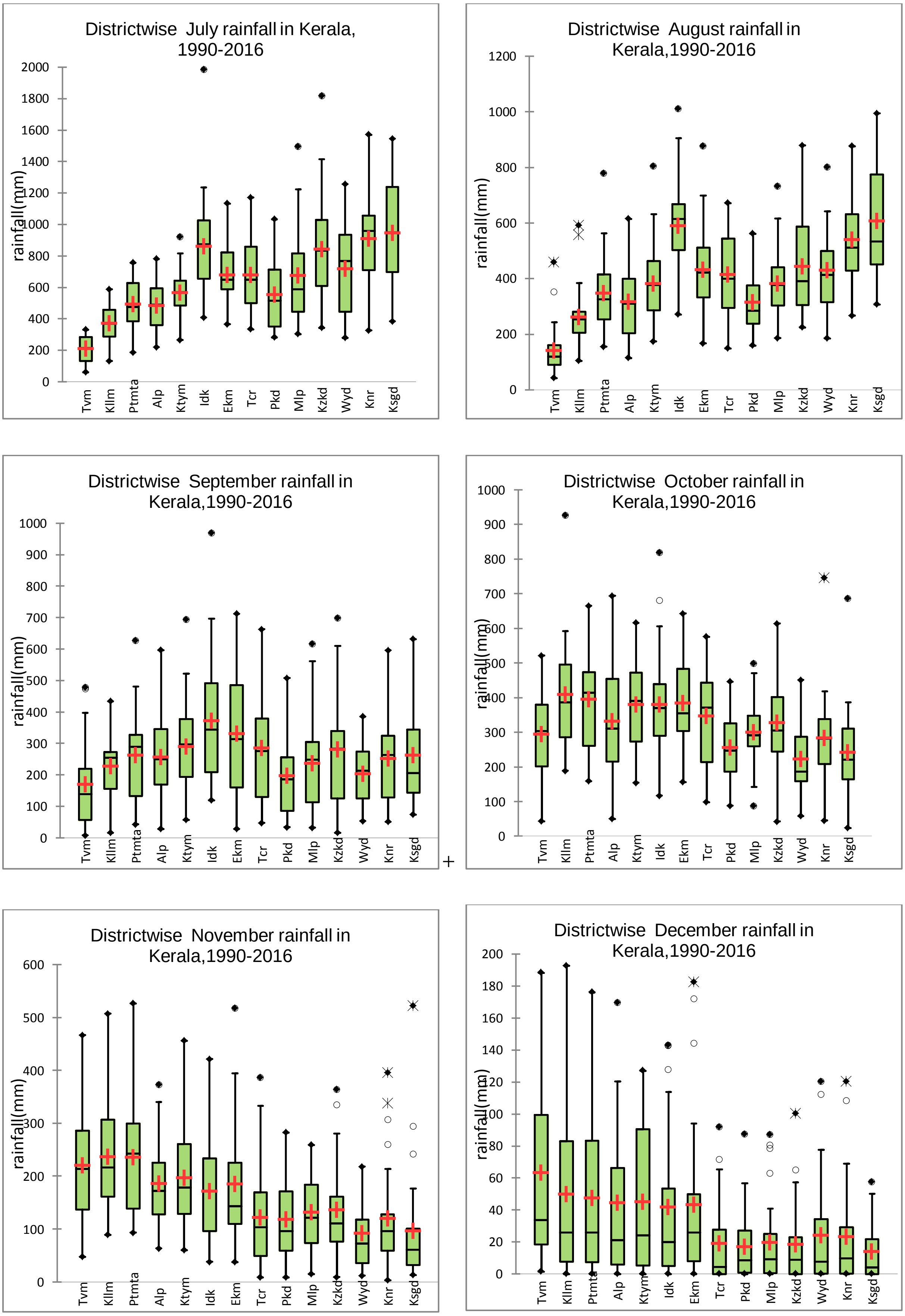

Districtwise July rainfall in Kerala, 1990-2016
rainfall(mm)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Tvm Kllm Ptmta Alp Ktym Idk Ekm Tcr Pkd Mlp Kzkd Wyd Knr Ksgd
Districtwise August rainfall in Kerala,1990-2016
rainfall(mm)
0
200
400
600
800
1000
1200
Tvm Kllm Ptmta Alp Ktym Idk Ekm Tcr Pkd Mlp Kzkd Wyd Knr Ksgd
Districtwise September rainfall in Kerala,1990-2016
rainfall(mm)
0
100
200
300
400
500
600
700
800
900
1000
Tvm Kllm Ptmta Alp Ktym Idk Ekm Tcr Pkd Mlp Kzkd Wyd Knr Ksgd
Districtwise October rainfall in Kerala,1990-2016
rainfall(mm)
0
100
200
300
400
500
600
700
800
900
1000
Tvm Kllm Ptmta Alp Ktym Idk Ekm Tcr Pkd Mlp Kzkd Wyd Knr Ksgd
Districtwise November rainfall in Kerala,1990-2016
rainfall(mm)
0
100
200
300
400
500
600
Tvm Kllm Ptmta Alp Ktym Idk Ekm Tcr Pkd Mlp Kzkd Wyd Knr Ksgd
Districtwise December rainfall in Kerala,1990-2016
rainfall(mm)
0
20
40
60
80
100
120
140
160
180
200
Tvm Kllm Ptmta Alp Ktym Idk Ekm Tcr Pkd Mlp Kzkd Wyd Knr Ksgd

Fig. 3.4.3.11

Table 3.4.3.15: Average annual rainfall for the period from 1989-‘90 to 2014-‘15 for selected stations of K.S.E.B

Station name	Average rainfall (mm)	C.V (%)
Achenkovil TB	3475.31	34.12
Kannankuzhi	3662.34	15.20
Manalaroo	2236.09	22.06
Mudies group	3593.33	20.69
Oriental Estate	3431.93	37.07
Pullala	2568.67	31.97
Puthuthottam	2665.38	21.59
Top Slip	1415.17	24.95
Thunakadavu	1699.85	25.96
Kuttiadi Power house Site	4305.57	16.91
Kannimalai	3117.41	28.40
Koompanpara (Adimali)	4268.89	28.07
Lockhart	2840.90	48.92
Meencut	2843.20	17.15
Munnar	4121.90	22.64
Nyamakad	3163.08	24.68
Panamkutty	3347.45	17.94
Sengulam dam site	2982.22	24.81
Upper Perinjankutty	3777.71	37.87

When the average annual rainfalls of selected K.S.E.B stations were considered it was observed that the rainfall for individual stations was either too high or too low from the district average or the state average. Also the coefficient of variation was too high and therefore the consistency of the rainfall amounts was poor.

4 PROBABILITY DISTRIBUTION FITTING

4.1 INTRODUCTION

The repeated measurements of a variable phenomenon can be best fitted through probability distributions. The basic purpose of distribution fitting is to predict the probability or to forecast the frequency of occurrence of the magnitude of the phenomenon in a certain interval. Depending on the characteristics of the phenomenon and of the distribution, some probability distribution can be fitted more closely to the observed frequency of the data. Good predictions can be realised through distributions giving close fit. So in distribution fitting, the most important part is to select a distribution that suits the data well.

Selection of distribution

The main criterion used to select the appropriate distribution is to check the presence or absence of symmetry of the data with respect to the mean value. All the data do not follow normal distribution. The practical implication of the non – normal distribution is a challenge for analysts. In many situations, the data would have a natural limit on one side of the distribution. Actually these natural limits produce skewed distributions.

The normal distribution, the logistic distribution or the student's t distribution can be selected if the data are symmetrically distributed around the mean. Here the frequency of occurrence of data farther away from the mean decreases. Normal distribution and logistic distribution are more or less similar. The student's t distribution with one degree of freedom has heavier tails revealing that relatively more number of observations occur farther away from the mean.

Skew distributions to the right

If positive skewness exists in the data, the larger values will fall farther away from the mean than the smaller values. The log normal distribution (*ie* the log values of the data are normally distributed), the log logistic distribution (*ie* the log values of the data follow a logistic distribution), the Gumbel distribution, the exponential distribution, the Pareto distribution, the Weibull distribution or the Frechet distribution can be used in such situations. The last three distributions are bound to the left.

Skew distributions to the left

When the smaller values tend to be farther away from the mean than the larger values, negative skewness occurs. The inverted Gumbel distribution or the Gompertz distribution which is bounded to the left can be made use of in such situations.

Techniques of fitting

There exists parametric methods by which the parameters of the distribution are calculated from the data. The parametric methods usually in practice are method of moments and maximum likelihood method.

Parameter Estimation

We have a sample of observed values and from this sample we want to estimate the parameters of a particular distribution. Typically a distribution will be having one or more than one parameters.

Let f(x) be the p.d.f and F(x) be the C.D.F . In general f(x) and F(x) are also functions of the parameters and therefore it can be written as

$f(x; \theta_1, \theta_2, \theta_3,..........\theta_m)$ or $F(x; \theta_1, \theta_2, \theta_3,..........\theta_m)$. Now the parameters $\theta_1, \theta_2, \theta_3,..........\theta_m$ are to be estimated from an available sample $x_1, x_2,........x_n$ (observed sample).

$\theta_1, \theta_2, \theta_3,..........\theta_m$ is in fact a function of the sample itself.

Let $\hat{\theta}_i$ is an estimate of θ_i. The estimates will always be a function of the sample values. Since the sample is random, $\theta_i^{\wedge}$ itself become a random sample. It will have it's own moments etc. Now, the best estimates from the available sample $x_1, x_2,........x_n$ which in some sense is best for the purpose for which the distribution f(x) is used, is to be found out.

There are two important properties for the estimators or estimates, namely unbiasedness and consistency. If the estimate is unbiased, then $E(\hat{\theta}_i) = \theta$. That is, the average of many independent estimates of θ will be equal to $\hat{\theta}_i$. An estimator $\hat{\theta}_i$ is said to be consistent if the probability that $\hat{\theta}_i$ differs from θ by more than an arbitrary constant ϵ approaches 0 as the sample size approaches ∞. That is, $P_{n\to\infty}$ [$|\hat{\theta}_i - \theta| \geq \epsilon$] $\to 0$.

Methods of estimating parameters from samples of data

The commonly used methods are: method of moments and method of maximum likelihood. In method of moments, as a first step, different moments are computed from the sample and these moments are equated to the moments of the population. This will result in m equations and can be solved for the estimators. If two parameters are to be estimated, the first two moments namely mean and variance are equated to the sample estimates of those corresponding moments which will result in two equations, solving these two equations the two parameters are estimated.

Method of maximum likelihood

Consider the sample of n random observations $x_1, x_2, ...x_n$. Let $\theta_1,\theta_2,\theta_3......\theta_m$ be the parameters to be estimated.

The joint p.d.f be $f(x_1, x_2,.....x_n; \theta_1,\theta_2,\theta_3......,\theta_m)$

For the function f(x), $x = x_1$, $x = x_2$,....... , the likelihood function can be defined as

$L = f(x_1; \theta_1;\theta_2;\theta_3......\theta_m)\, f(x_2; \theta_1;\theta_2;\theta_3......\theta_m) ....f(x_n; \theta_1;\theta_2;\theta_3......\theta_m)$

$= \prod_{i=1}^{n} f(xi; \theta 1, \theta 2, \theta 3 \dots \dots . \theta m)$

Actually the basis for this is, once the sample has occurred $x_1, x_2,.....x_n$ are independent. So we are looking for those set of parameters $\theta_1, \theta_2, \theta_3......\theta_m$ which will maximise the likelihood of the sample $x_1, x_2,.....x_n$ appearing from that particular p.d.f. So we write it as a joint distribution of $f(x_1)$, $f(x_2)$ etc. Since $x_1, x_2,.....$is the sample already occurred as independent we obtain the likelihood function as product of $f(x_1) \times f(x_2)$...... for those parameters $\theta_1, \theta_2, \theta_3......,\theta_m$. Now the likelihood function is defined as the product of

$f(x_1; \theta_1;\theta_2;\theta_3......\theta_m) \times f(x_2; \theta_1;\theta_2;\theta_3......\theta_m) \times ....f(x_n; \theta_1;\theta_2;\theta_3......\theta_m)$

$= \pi_{i=1}^{n} f(x_i ; \theta_1,\theta_2,\theta_3,......\theta_m)$.

Generating m number of equations and taking the first partial derivative to be equal to zero

$\partial L / \partial \theta_i = 0$ for all i and by solving such m equations, the parameters can be estimated.

Importance of Distribution fitting in climate research

In the field of climate research, one of the most challenging and important aspects of climate modelling is with respect to precipitation. Therefore fitting of rainfall probability distributions are of keen interest to fully describe the climate regime and to have a quantitative assessment of climate change for utilising it on other fields such as agriculture, hydrology etc. at a variety of scales.

In order to take protective measures and to deal with the consequences of rainfall anomalies, it is essential to provide a complete understanding about the range and likelihood of monthly or seasonal rainfall totals possibly receive. Modelling of rainfall data using different probability distributions are very much useful for gaining this kind of information. Once the accumulation parameters of the distribution are estimated, different rainfall patterns can be described using them. Distribution parameters can be used as a foundation for monitoring rainfall conditions. An assessment of monthly, seasonal or annual accumulation of rainfall can be made combining distributions with probabilistic forecasts.

The main objective of this study is to estimate and evaluate the parameters of the different probability distributions and comparison which can be applied in the study of modelling climatic as well as hydrologic data. Probability distributions would be fitted using historical monthly or seasonal data and the best fit model would be selected based on the goodness of fit of the parameters involved. Interpretation of these parameter estimates would give a description of general monthly or seasonal rainfall regimes for the state. Also it would give a way for the potential uses of the parameters in hydrologic resource modelling also. The accuracy of different probability distributions used to fit monthly, seasonal and annual rainfall and other hydrologic variables would be quantified.

There are many kind of probability distributions that can be used to fit rainfall distributions. An important point in this context is that they must be flexible enough to characterise a variety of rainfall regimes. By analysing the parameters of the distribution, the likelihood of a particular region to receive rainfall amounts that would cause flooding, wash out dams or provide sufficient water to support crops can be estimated. On the other hand it is also possible to quantify the range of possible drought scenarios that may happen in the region

The likelihood of receiving a specific amount of rainfall based on 146 monthly, seasonal and annual observations of rainfall in Kerala can be best represented by fitting probability distributions for different months, seasons and annual data separately.

4.2 REVIEW OF LITERATURE

Several works have been carried out related to fitting and evaluating the probability distributions suitable for rainfall data.

Jhon (1958), Wilks (1990) and Wilks (1995) were of the opinion that the method of moments, an alternate method to estimate the parameters of a distribution was a poor estimator due to its inefficiency for small scale parameters.

Ison *et al.* (1971) tried to generate precipitation pattern through simulation programs using probabilistic models for three rain stations in Kansas, USA. In this study a precipitation pattern was considered to be consisting of sequences of wet and dry days and sequences of consecutive wet days. In either case they are random variables and to describe the random behaviour, suitable probability models needed to be fitted. The study revealed that the precipitation amount over an i-day wet period could be best described by gamma distribution with a shape parameter that changes linearly with number of days in a wet period and a scale parameter independent of the length of a wet period.

Crutcher (1975) made use of the Kolmogorov Smirnov goodness of fit test to compare the estimated distributions with the empirical distribution.Wilks (1990) was of the opinion that Gamma distribution would provide a flexible representation of a variety of shapes for the distribution when two parameters were used. Various normalising transforms, Kappa and Weibull distributions were used by Woolhiser (1992).

The accuracy in matching of the estimated gamma distribution with the empirical distribution can be obtained by a comparison of their cumulative distribution functions (Wilks, 1995)

Ozturk (1981) made use of a mixture of Poisson and Gamma distributions to model precipitation totals. Likelihood equations were solved using a new approach. The occurrence of rainfall were considered as instantaneous showers according to a Poisson process with mean intensity $1/\mu$, then the number of showers in a prescribed time interval of length t would be Poisson distributed with mean t/μ. Single shower rainfall amounts are supposed to be independent of the process of their occurrence, mutually independent and exponentially distributed with mean 1/ p.

Ananthakrishnan and Soman (1989) studied the daily, monthly and annual rainfall series for 1901-1980 of 15 Indian stations and found an association between cumulated percentage rain amount (x) and cumulated percentage number of rainy days (y) of the rainfall series. The coefficient of variation was found to determine the normalized rainfall curve (NRC). The equation $x = ye^{-b(100-y)^c}$ where b and c are two empirical constants, gives a good representation of NRC's over a wide range of C.V values of the rainfall series.

Legates (1991) used about eight distributions in order to obtain monthly rainfall probabilities. Based on a study of cross- validation procedure for 253 stations with 100 years data it was found that a modified version of the Box-Cox transform normal distribution would describe the true rainfall distribution than any other methods.

Juras (1994) has discussed the feasibility of square root transformation to get a near normal distribution of precipitation data and its relationship with other commonly used two parameter distributions. Different distributions were compared using normal probability graph and the moment- ratio diagram.

Wilks (1995) has named the Kolmogorov- Smirnov test for the comparison of estimated and empirical distribution as the Lilliefors test since the values tested were the same values used for deriving the distribution parameters.

Ashkar and Mendi (2003) made an investigation on generalized probability weighted moments and maximum likelihood fitting methods in the two parameter log-logistic model. Log-logistic model has wider use in hydrological practice especially in fitting flood data.

Cho *et al*. (2004) made an investigation on the spatial characteristics of non-zero rain rates to develop a p.d.f model of precipitation using data from TRMM satellite. Using the minimum χ^2 method a comparison was made between Gamma and log normal distributions with respect to the estimation of rain rate. Both the models were found to match well with the p.d.f of the rainfall data. The parametric mean from the log normal distribution was found to overestimate the sample mean whereas, the Gamma distribution underestimates it. The reason may be due to the inflated tail in the log normal distribution and the small shape parameter in the Gamma distribution. The Gamma fits was better than log normal fits in wet region, but the reverse was realized in the dry regions.

Yue and Hashino (2007) used L moment ratio diagrams and the average weighted distance to fit annual, seasonal and monthly precipitation in Japan. The annual precipitation was best fitted using the log-Pearson type III distribution, the GEV. Overall the Pearson type III and log-Pearson type III were acceptable for representing precipitation in Japan.

Husak *et al.* (2007) was of the opinion that by using probability distributions it would be possible to estimate the likelihood of rainfall within a particular range. It was found that gamma distribution was very suitable for fitting cell by cell probability distribution to monthly data in Africa for 98% of locations over all months. The goodness of fit was tested by Kolmogorov Smrinov (KS) tests and results were compared with that of Weibull distribution. Since, the gamma distribution did not allow values less than or equal to zero, the zero values for rainfall were discarded initially to estimate the shape and scale parameters using maximum likelihood method. Then an additional parameter was added to account for the probability of receiving no rainfall.

Shukla *et al*. (2010) applied extreme value distribution to capture uncertainty of extreme rainfall in Ranchi, Jharkhand, India and found that GEV model was the best fitted model.

Liu *et al.* (2011) modelled daily precipitation using first order Markov chain dependent exponential, gamma, mixed exponential and log normal distribution using the data collected from ten stations in the watershed of Yisha River. Parameters were estimated using maximum likelihood method. Bayesian information criterion, simulated monthly mean, maximum daily value etc., were tested and compared. The results showed that even though the BIC’s for Gamma and exponential distribution were larger the simulation for monthly mean precipitation was very well done than using log normal and mixed exponential distributions.

Alam *et al.* (2018) developed suitable models to anticipate extreme events like flood by using probability distributions to fit maximum monthly rainfall for 30 years (1984 – 2013) from 35 locations in Bangladesh. Estimation of parameters was done using method of moments and L – moments estimations. Kolmogorov-Smrinov goodness of fit test was used. Generalised extreme value, Pearson type III and log-Pearson type III distributions were showing maximum number of best fit results.

4.3 DATA AND METHODOLOGY

The ability of different probability distributions and parameter estimates to adequately fit the empirical distribution of rainfall series in the history was tried using an add in software XLSTAT 2017 of Ms Excel package. The software would identify the best possible distribution out of the several distributions available by default viz., Arc sine, Bernoulli, Beta, Beta4, Binomial, Negative Binomial type I, Negative Binomial type II, Chi square, Erlang, Exponential, Fisher, Fisher Tippett, Gamma, GEV, Gumbel, Logistic, Lognormal, Lognormal 2, Normal, Standard Normal, Pareto, Poisson, Student, Trapezoidal, Triangular, Uniform and Weibull.

The parameters of the distribution are estimated by maximising the likelihood of the sample. This method enables approximate standard deviations for parameter estimators. Once the parameters of the chosen distribution have been estimated, Kolmogorov – Smirnov test is used to test the goodness of fit when the data is continuous and Chi square test when the data is discrete. These tests show the perfect distribution and the estimated parameters that could not be rejected as a suitable distribution for the data at a 0.05 confidence level. The distributions fitted for the monthly, seasonal and annual rainfall in Kerala for a period from 1871-2016 and the necessary statistics associated with the test are provided in tables and figures. The best distribution corresponding to each period was selected based on the goodness of fit test, the highest p value and minimum error.

Kolmogorov – Smirnov (K – S) test

The K-S statistic is based on the maximum vertical difference between the theoretical and empirical distributions (Canover, 1999). The test is used to compare the empirical cumulative frequency $S_n(x)$ with the c.d.f of an assumed theoretical distribution $F_n(x)$. The maximum difference between $S_n(x)$ and $F_n(x)$ is the K-S test statistic. The data is rearranged in increasing order $X_1 < X_2$ ……. X_n and the K-S statistic is assessed for each ordered value.

$$
\begin{aligned}
S_n(x) &= 0; \text{ if } X < X_1 \\
&= k/n; \text{ if } X_k \leq X < X_{k+1} \\
&= 1; \text{ if } X > X_n
\end{aligned}
$$

$D_n = \max [F_x(x) - S_n(x)]$, P ($D_n \leq D_n^{\alpha}$) = 1- α, where D_n^{α} is the critical value, α is the significance level, k is the rank order of the data set.

Table 4.3.1 : Probability density function of distributions identified in the study of rainfall

Sl no	Name of distribution	PDF	specifications
1	Fisher Tippett (2)	$\frac{1}{\beta} exp\left(-\frac{x-\mu}{\beta} - exp\left(-\frac{x-\mu}{\beta}\right)\right)$	with β>0 E(X) = $\mu+\beta\gamma$ and V(X) = $(\pi\beta)^2/6$ where γ is the Euler-Mascheroni constant
2	Log Normal	$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}}$	μ ϵ (-∞, + ∞); σ > 0; x ϵ (0 +∞)
3	Logistic	$f(x) = \frac{e^{-\frac{x-\mu}{s}}}{s(1+e^{-\frac{x-\mu}{s}})^2}$	μ location (real) s >0, scale (real)
4	GEV	$f(x) = \frac{1}{\sigma} t(x)^{\xi+1} e^{-t(x)}$	$t(x) = \begin{cases} \left(1+\xi\left(\frac{x-\mu}{\sigma}\right)\right)^{-1/\xi} & if\ \xi \neq 0 \\ e^{-(x-\mu)/\sigma} & if\ \xi = 0 \end{cases}$ μ ϵ R is the location parameter σ > 0 is the scale, ξ ϵ R shape x ϵ [μ - σ / ξ , +∞) when ξ > 0, x ϵ (-∞, + ∞) when ξ = 0, x ϵ (-∞, μ- σ / ξ] when ξ < 0
5	Beta 4	$f(x) = \frac{1}{B(\alpha,\beta)} \frac{(x-c)^{\alpha-1}(d-x)^{\beta-1}}{(d-c)^{\alpha+\beta-1}}$	Where $B(\alpha,\beta)$ is a Beta function α> 0,β > 0
6	Gamma distribution	$\frac{1}{\Gamma(k)\theta^k} x^{k-1} e^{-\frac{x}{\theta}}$	k > 0 shape; θ > 0 shape α > 0 shape; β > 0 rate x ϵ (0, ∞)
7	Normal distribution	$\frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$	μ ϵ R, σ^2>0 x ϵ R
8	Exponential	$\lambda e^{-\lambda x}$	λ >0 rate x ϵ [0,∞)

4.4 RESULTS AND DISCUSSION

The impact of climate extremes is very complex and depends on several factors and not yet fully explored. So a detailed knowledge of the extreme climate events and their spatio – temporal pattern is needed to estimate the potential ill effects of them to our eco- system. Recently there is a growing trend for the extreme events of rainfall and temperature. So a thorough study of the extreme weather events and their impact on the environment are needed for their forecasting and mitigation of their effects (Ryazanova et al, 2014). The probability distributions suitable for fitting extreme events can be utilised in these situations.

According to the particular situation that prevails, different type of distributions can be fitted to the data. Usually when the annual rainfall series are considered it can be well fitted by a normal distribution. Skewed distributions are particularly common when mean values are low, variance large and values cannot be negative. Log normal distribution is very much useful in describing such natural phenomena. For instance, the rainfall during May and pre monsoon seasons are small events when they are taken individually but the accumulation of such small percentages makes them additive on a log scale. Even if the effect of any single change is negligible, the central limit theorem confirms that the distribution of their sum is normal.

Logistic distribution which is a continuous probability distribution resembles the normal distribution in shape but has heavier tails indicating higher kurtosis. It can be effectively used in fitting long duration river discharge and rainfall of monthly durations. The time between events in a Poisson point process *i.e.*, when the events occur continuously and independently at a constant average rate, the exponential distribution can be used which is a special case of Gamma distribution. Monthly rainfall and daily maximum rainfall can be analysed through this distribution.

The continuous Gamma distribution which is the maximum entropy probability distribution can be used to model the amount of rainfall accumulated in a reservoir and to fit monthly rainfall data. Beta which is a continuous probability distribution can be applied to model the status of random variables limited to intervals of finite length. The probability of rare occurrence (tail distribution) can be made through extreme value theory (Rahayu, 2013). Generalised extreme value (GEV) distribution would be a best fit in such situation.

The best distribution fitted for onset dates of SW monsoon in Kerala was Logistic distribution. The details of the best fitted distributions for rainfall in different periods are presented in table 4.4.1 and the fit summary statistics, estimated parameters, observed and theoretical frequencies are shown. The best probability distribution for monthly peak rainfall series also has been identified.

Table 4.4.1: Distributions identified for different months, seasons and annual rainfall in Kerala

Period	Name of distribution	Period	Name of distribution
April	Fisher Tippett (2)	November	Gamma (2)
May	Log Normal	December	Exponential
June	Logistic	Winter	Exponential
July	Logistic	Pre monsoon	Log Normal
August	GEV	SW monsoon	Beta 4
September	GEV	Post monsoon	Beta 4
October	Beta 4	Annual	Normal

Table 4.4.2: The detailed statistics of distribution fitting of rainfall in Kerala for different periods

Variable	Observation	Minimum	Maximum	Mean	Std. deviation
January	146	0.000	96.900	10.770	16.357
February	146	0.000	87.600	16.354	18.652
March	146	0.000	242.800	36.973	31.988
April	146	18.300	310.100	111.659	52.090
May	146	41.200	837.400	243.319	156.136
June	146	222.500	1123.700	679.614	192.950
July	146	152.500	1281.100	633.452	205.574
August	146	107.000	1023.500	375.807	156.156
September	146	36.000	586.100	229.914	122.139
October	146	54.600	593.200	287.166	108.685
November	146	19.000	379.800	154.458	83.921
December	146	0.000	221.100	37.185	37.651
Jan - Feb	146	0.000	113.400	27.122	25.656
M A M	146	100.200	1036.800	391.946	158.632
J J A S	146	1150.200	3115.300	1918.777	374.090
OND	146	93.200	857.500	478.798	148.645
Annual	146	1837.400	3944.900	2816.651	415.056

Table 4.4.3: Fit Summary for onset of SW monsoon

Distribution	p-value	Distribution	p-value
Beta4	0.323	Gumbel	0.000
Negative binomial (1)	0.000	Log-normal	0.100
Chi-square	0.000	**Logistic**	**0.412**
Erlang	0.099	Normal	0.118
Exponential	0.000	Normal (Standard)	0.000
Fisher-Tippett (1)	0.000	Poisson	0.000
Fisher-Tippett (2)	0.002	Student	0.000
Gamma (2)	0.105	Weibull (1)	0.000
GEV	0.000	Weibull (2)	0.158
The distribution that fits best the data for the goodness of fit test is the Logistic distribution.			

Table 4.4.4: Estimated parameters (Logistic)

Parameter	Value	Standard error
s	518.517	0.448
	3.959	0.448

Table 4.4.5: Log-likelihood statistics

Log-likelihood(LL)	-495.758
BIC(LL)	1001.497
AIC(LL)	995.516

Table 4.4.6: Statistics estimated on the input data and computed using the estimated parameters of the Logistic distribution:

Statistic	Data	Parameters
Mean	518.238	518.517
Variance	50.114	51.561
Skewness (Pearson)	-0.405	0.000
Kurtosis (Pearson)	0.142	1.200

Table 4.4.7: Chi-square test:

Chi-square (Observed value)	5.986
Chi-square (Critical value)	14.067
DF	7
p-value (Two-tailed)	0.541
alpha	0.05

Table 4.4.8: Fit Summary for onset, Comparison between the observed and theoretical frequencies:

Class	Lower bound	Upper bound	Frequency (Data)	Frequency (Distribution)	Chi-square
1	490.000	494.600	0	0.239	0.239
2	494.600	499.200	1	0.760	0.076
3	499.200	503.800	5	2.378	2.892
4	503.800	508.400	7	7.105	0.002
5	508.400	513.000	15	18.636	0.709
6	513.000	517.600	36	35.796	0.001
7	517.600	522.200	43	40.394	0.168
8	522.200	526.800	24	25.433	0.081
9	526.800	531.400	14	10.684	1.029
10	531.400	536.000	2	3.710	0.788

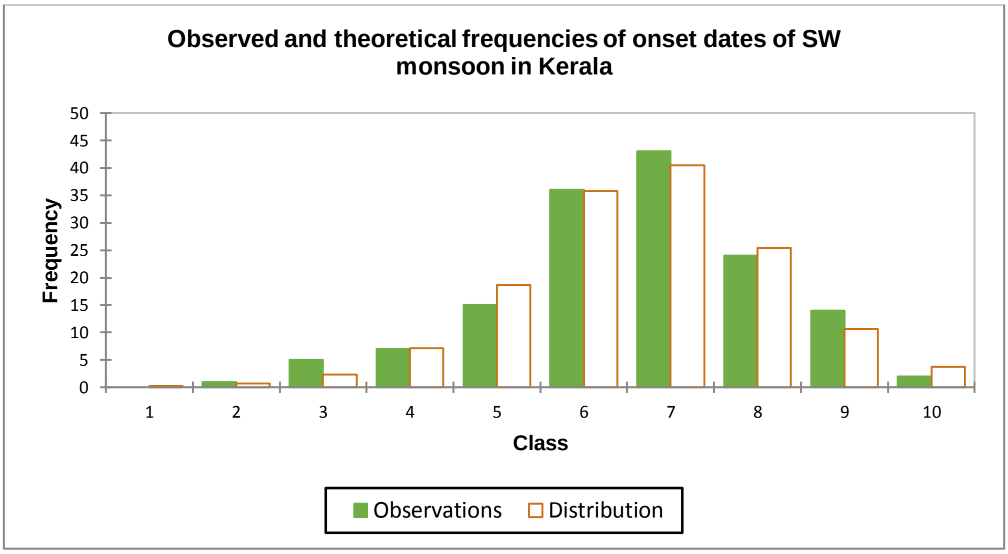


Fig. 4.4.1

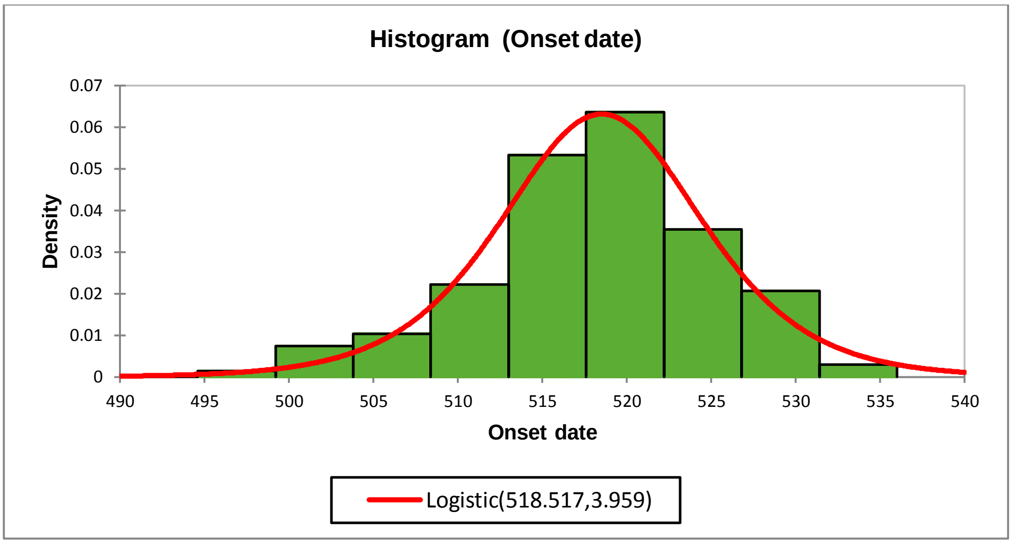


Fig. 4.4.2

Table 4.4.9: Descriptive statistics for the intervals (Onset date):					
Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
490	494.6	0	0.000	0.000	0.002
494.6	499.2	1	0.007	0.001	0.005
499.2	503.8	5	0.034	0.007	0.016
503.8	508.4	7	0.048	0.010	0.048
508.4	513	15	0.102	0.022	0.127
513	517.6	36	0.245	0.053	0.244
517.6	522.2	43	0.293	0.064	0.275
522.2	526.8	24	0.163	0.035	0.173
526.8	531.4	14	0.095	0.021	0.073
531.4	536	2	0.014	0.003	0.025

Table 4.4.10: Fit Summary of rainfall in April in Kerala

Distribution	p-value	Distribution	p-value
Beta4	0.974	GEV	0.901
Chi-square	0.000	Gumbel	0.000
Erlang	0.002	Log-normal	0.432
Exponential	0.000	Logistic	0.712
Fisher-Tippett (1)	0.000	Normal	0.363
Fisher-Tippett (2)	**0.977**	Normal (Standard)	0.000
Gamma (1)	0.000	Student	0.000
Gamma (2)	0.964	Weibull (2)	0.937

The distribution that fits best the data for the goodness of fit test is the Fisher-Tippett (2) distribution.

Table 4.4.11: Estimated parameters (April) (Fisher-Tippett (2)

Parameter	Value	Standard error
beta	42.660	3.725
μ	87.397	2.752

Table 4.4.12: Log-likelihood statistics (April)

Log-likelihood(LL)	-776.999
BIC(LL)	1563.965
AIC(LL)	1557.998

Table 4.4.13: Statistics estimated on the input data and computed using the estimated parameters of the Fisher-Tippett (2)

Statistic	Data	Parameters
Mean	111.659	112.021
Variance	2713.399	2993.556
Skewness	0.703	1.140
Kurtosis	0.504	2.400

Table 4.4.14: Kolmogorov-Smirnov test (April)

D	0.038
p-value (Two-tailed)	0.977
alpha	0.05

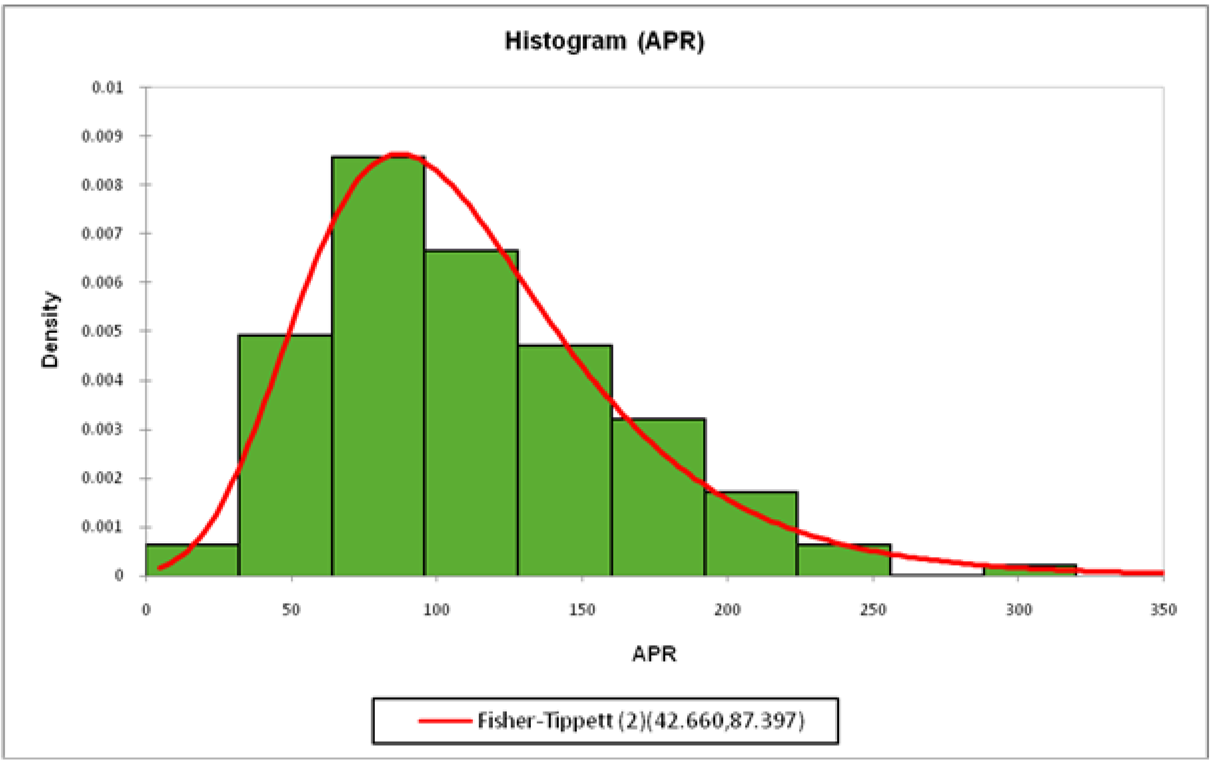


Fig. 4.4.3

Table 4.4.15: Descriptive statistics of rainfall in Kerala for the intervals (April)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
0	32	3	0.021	0.001	0.025
32	64	23	0.158	0.005	0.152
64	96	40	0.274	0.009	0.264
96	128	31	0.212	0.007	0.238
128	160	22	0.151	0.005	0.154
160	192	15	0.103	0.003	0.084
192	224	8	0.055	0.002	0.043
224	256	3	0.021	0.001	0.021
256	288	0	0.000	0.000	0.010
288	320	1	0.007	0.000	0.005

Table 4.4.16: Fit Summary of rainfall in May in Kerala

Distribution	p-value	Distribution	p-value
Chi-square	0.000	Gumbel	0.000
Erlang	0.003	**Log-normal**	**0.876**
Exponential	0.000	Logistic	0.032
Fisher-Tippett (1)	0.000	Normal	0.006
Fisher-Tippett (2)	0.256	Normal (Standard)	0.000
Gamma (1)	0.000	Student	0.000
Gamma (2)	0.374	Weibull (1)	0.000
GEV	0.001	Weibull (2)	0.335

The distribution that fits best the data for the goodness of fit test is the Log-normal distribution.

Table 4.4.17: Estimated parameters (May) (Log-normal)

Parameter	Value	Standard error
μ	5.306	0.051
sigma	0.617	0.036

Table 4.4.18: Log-likelihood statistics (May)

Log-likelihood(LL)	-911.460
BIC(LL)	1832.887
AIC(LL)	1826.920

Table 4.4.19: Statistics estimated on the input data and computed
using the estimated parameters of the Log-normal distribution (May)

Statistic	Data	Parameters
Mean	243.319	243.921
Variance	24378.46	27597.284
Skewness (Pearson)	1.314	2.359
Kurtosis (Pearson)	1.482	11.294

Table 4.4.20: Kolmogorov-Smirnov test (May)

D	0.048
p-value (Two-tailed)	0.876
alpha	0.05

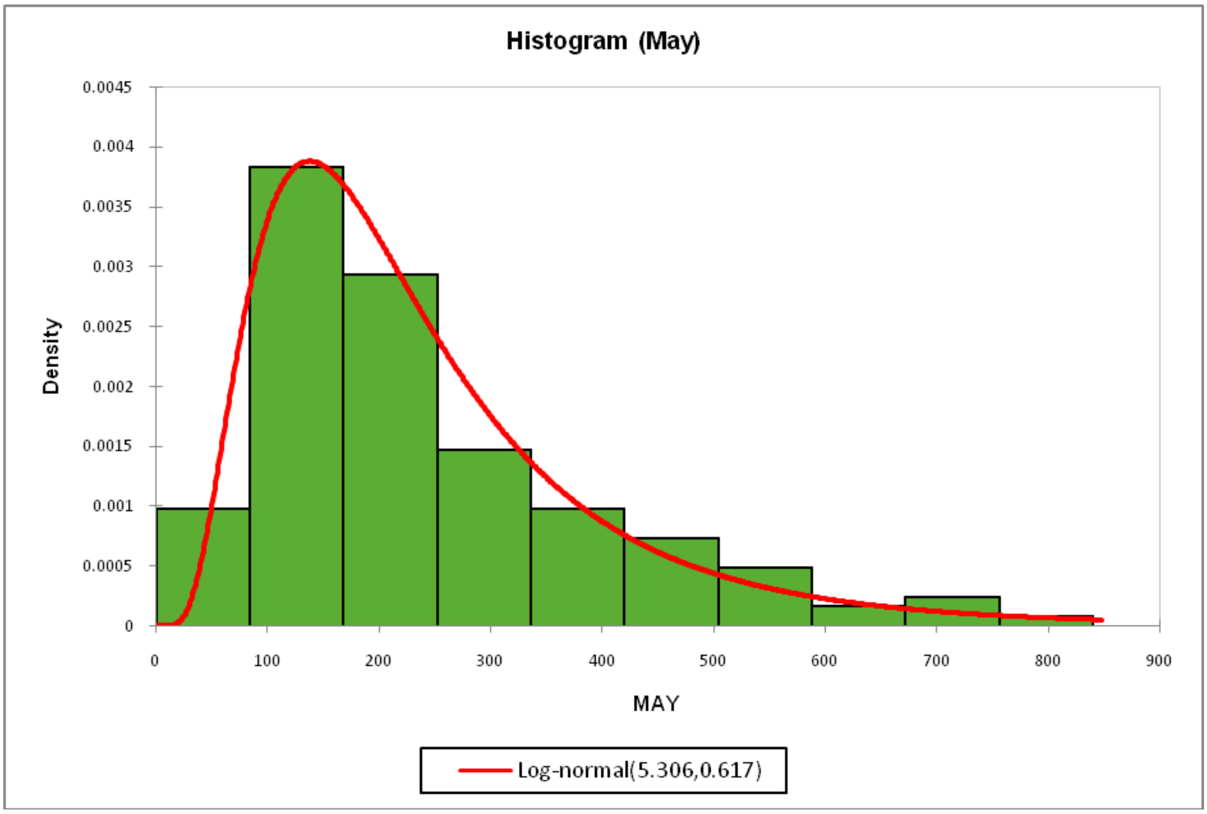


Fig. 4.4.4

Table 4.4.21: Descriptive statistics of rainfall in Kerala for the intervals (May)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
0	84	12	0.082	0.001	0.078
84	168	47	0.322	0.004	0.306
168	252	36	0.247	0.003	0.257
252	336	18	0.123	0.001	0.155
336	420	12	0.082	0.001	0.087
420	504	9	0.062	0.001	0.048
504	588	6	0.041	0.000	0.027
588	672	2	0.014	0.000	0.016
672	756	3	0.021	0.000	0.009
756	840	1	0.007	0.000	0.006

Table 4.4.22: Fit Summary of rainfall in June in Kerala

Distribution	p-value	Distribution	p-value
Beta4	0.598	Gumbel	0.000
Chi-square	0.000	Log-normal	0.101
Erlang	0.039	**Logistic**	**0.616**
Exponential	0.000	Normal	0.589
Fisher-Tippett (1)	0.000	Normal (Standard)	0.000
Fisher-Tippett (2)	0.085	Student	0.000
Gamma (1)	0.000	Weibull (1)	0.000
Gamma (2)	0.284	Weibull (2)	0.537
GEV	0.017		

The distribution that fits best the data for the goodness of fit test is the Logistic distribution.

Table 4.4.23: Estimated parameters (June) (Logistic)

Parameter	Value	Standard error
s	675.733	0.297
	110.249	

Table 4.4.24: Log-likelihood statistics (June)

Log-likelihood(LL)	-976.892
BIC(LL)	1963.751
AIC(LL)	1957.784

Table 4.4.25: Statistics estimated on the input data and computed using the estimated parameters of the Logistic distribution (June)

Statistic	Data	Parameters
Mean	679.614	675.733
Variance	37229.713	39987.513
Skewness	0.112	0.000
Kurtosis	-0.337	1.200

Table 4.4.26: Kolmogorov-Smirnov test (June)

D	0.062
p-value (Two-tailed)	0.616
alpha	0.05

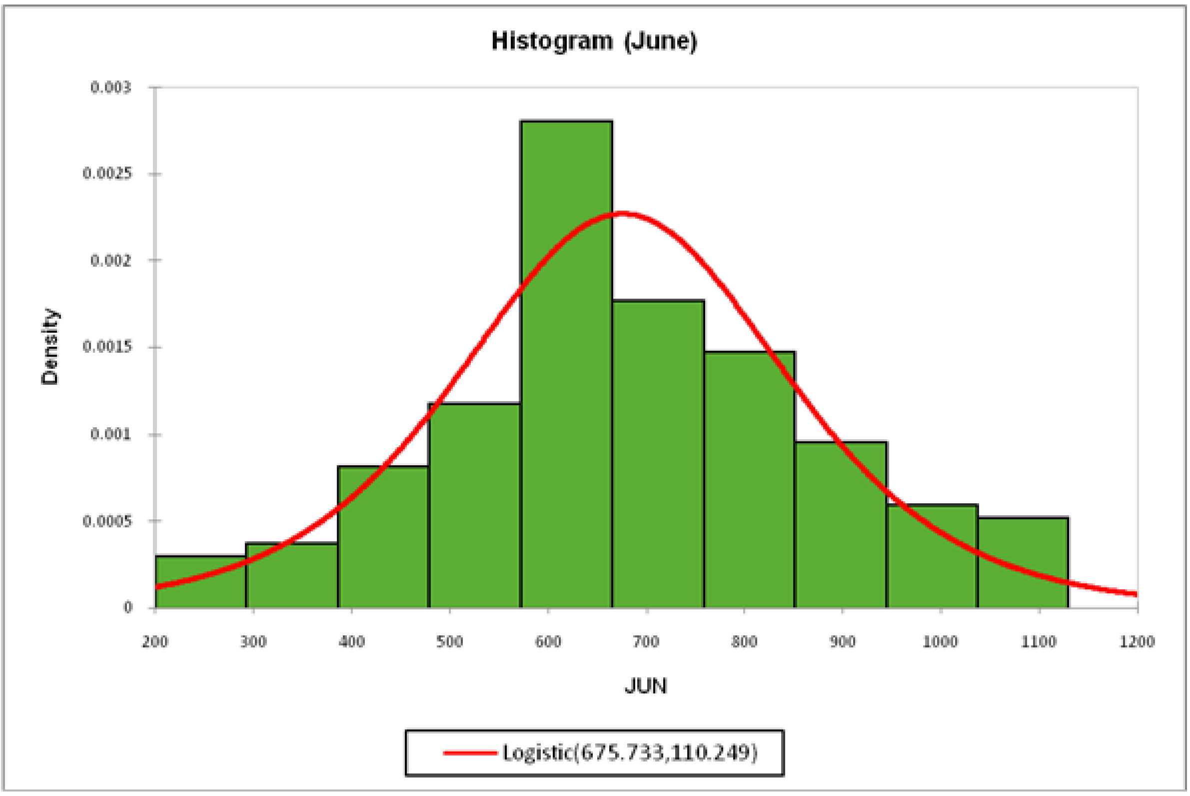


Fig. 4.4.5

Table 4.4.27: Descriptive statistics of rainfall in Kerala for the intervals (June)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
200	293	4	0.027	0.000	0.017
293	386	5	0.034	0.000	0.037
386	479	11	0.075	0.001	0.076
479	572	16	0.110	0.001	0.137
572	665	38	0.260	0.003	0.195
665	758	24	0.164	0.002	0.203
758	851	20	0.137	0.001	0.152
851	944	13	0.089	0.001	0.089
944	1037	8	0.055	0.001	0.044
1037	1130	7	0.048	0.001	0.020

Table 4.4.28: Fit Summary of rainfall in July in Kerala

Distribution	p-value	Distribution	p-value
Beta4	0.918	Gumbel	0.000
Chi-square	0.000	Log-normal	0.223
Erlang	0.024	**Logistic**	**0.973**
Exponential	0.000	Normal	0.898
Fisher-Tippett (1)	0.000	Normal (Standard)	0.000
Fisher-Tippett (2)	0.303	Student	0.000
Gamma (1)	0.000	Weibull (1)	0.000
Gamma (2)	0.588	Weibull (2)	0.843
GEV	0.129		

The distribution that fits best the data for the goodness of fit test is the Logistic distribution.

Table 4.4.29: Estimated parameters (July) (Logistic)

Parameter	Value	Standard error
s	626.952	1.186
	115.224	

Table 4.4.30: Log-likelihood statistics (July)

Log-likelihood(LL)	-984.194
BIC(LL)	1978.355
AIC(LL)	1972.388

Table 4.4.31: Statistics estimated on the input data and computed using the estimated parameters of the Logistic distribution (July)

Statistic	Data	Parameters
Mean	633.452	626.952
Variance	42260.492	43678.076
Skewness (Pearson)	0.401	0.000
Kurtosis (Pearson)	0.298	1.200

Table 4.4.32: Kolmogorov-Smirnov test (July)

D	0.039
p-value (Two-tailed)	0.973
alpha	0.05

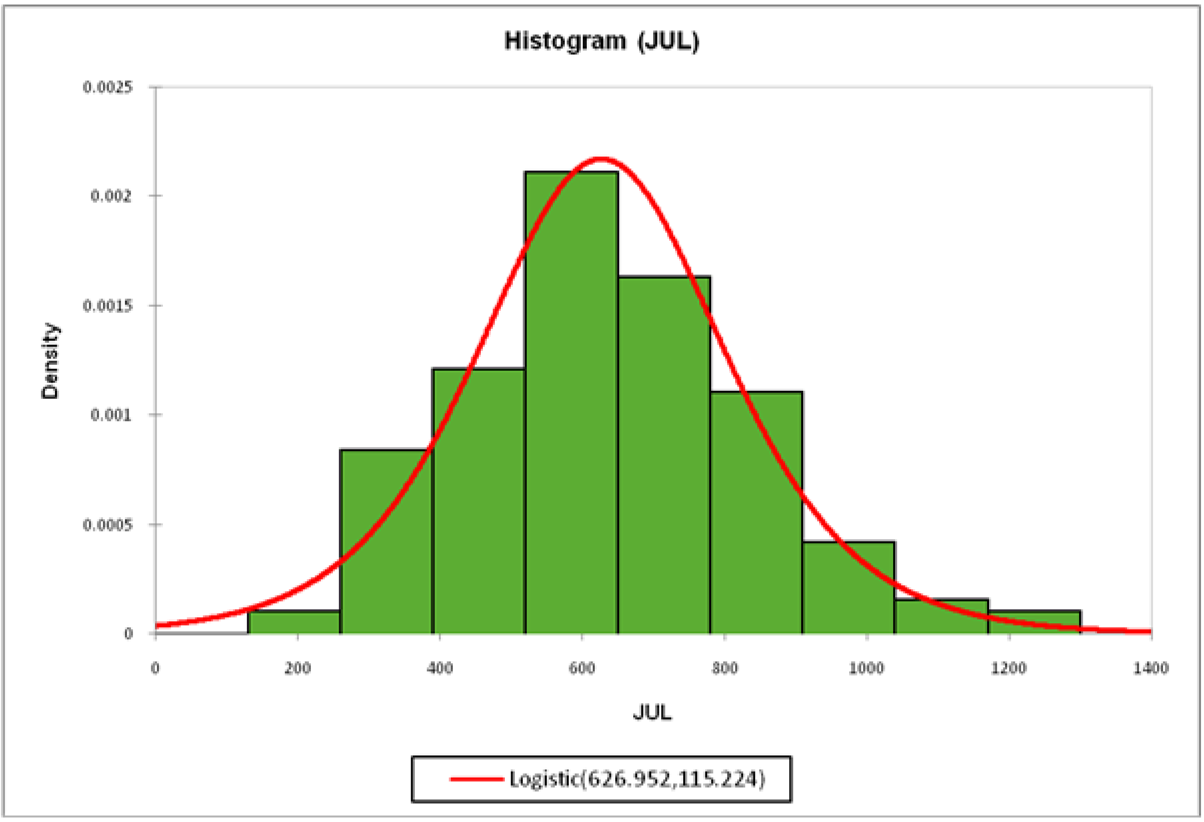


Fig. 4.4.6

Table 4.4.33: Descriptive statistics of rainfall in Kerala for the intervals (July)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
0	130	0	0.000	0.000	0.009
130	260	2	0.014	0.000	0.027
260	390	16	0.110	0.001	0.074
390	520	23	0.158	0.001	0.170
520	650	40	0.274	0.002	0.267
650	780	31	0.212	0.002	0.241
780	910	21	0.144	0.001	0.130
910	1040	8	0.055	0.000	0.052
1040	1170	3	0.021	0.000	0.018
1170	1300	2	0.014	0.000	0.006

Table 4.4.34: Fit Summary of rainfall in August in Kerala

Distribution	p-value	Distribution	p-value
Beta4	0.822	Gumbel	0.000
Chi-square	0.000	Log-normal	0.998
Erlang	0.001	Logistic	0.774
Exponential	0.000	Normal	0.205
Fisher-Tippett (1)	0.000	Normal (Standard)	0.000
Fisher-Tippett (2)	0.998	Student	0.000
Gamma (1)	0.000	Weibull (1)	0.000
Gamma (2)	0.988	Weibull (2)	0.457
GEV	**1.000**		

The distribution that fits best the data for the goodness of fit test is the GEV distribution.

Table 4.4.35: Estimated parameters (August)(GEV)

Parameter	Value	Standard error
k	0.010	0.070
beta	121.753	0.106
µ	305.528	0.094

Table 4.4.36: Log-likelihood statistics (August)

Log-likelihood(LL)	-929.500
BIC(LL)	1873.950
AIC(LL)	1864.999

Table 4.4.37: Statistics estimated on the input data and computed using the estimated parameters of the GEV distribution (August)

Statistic	Data	Parameters
Mean	375.807	377.002
Variance	24384.731	25029.394
Skewness (Pearson)	1.166	0.001
Kurtosis (Pearson)	2.063	229255884.370

Table 4.4.38: Kolmogorov-Smirnov test (August)

D	0.028
p-value (Two-tailed)	1.000
alpha	0.05

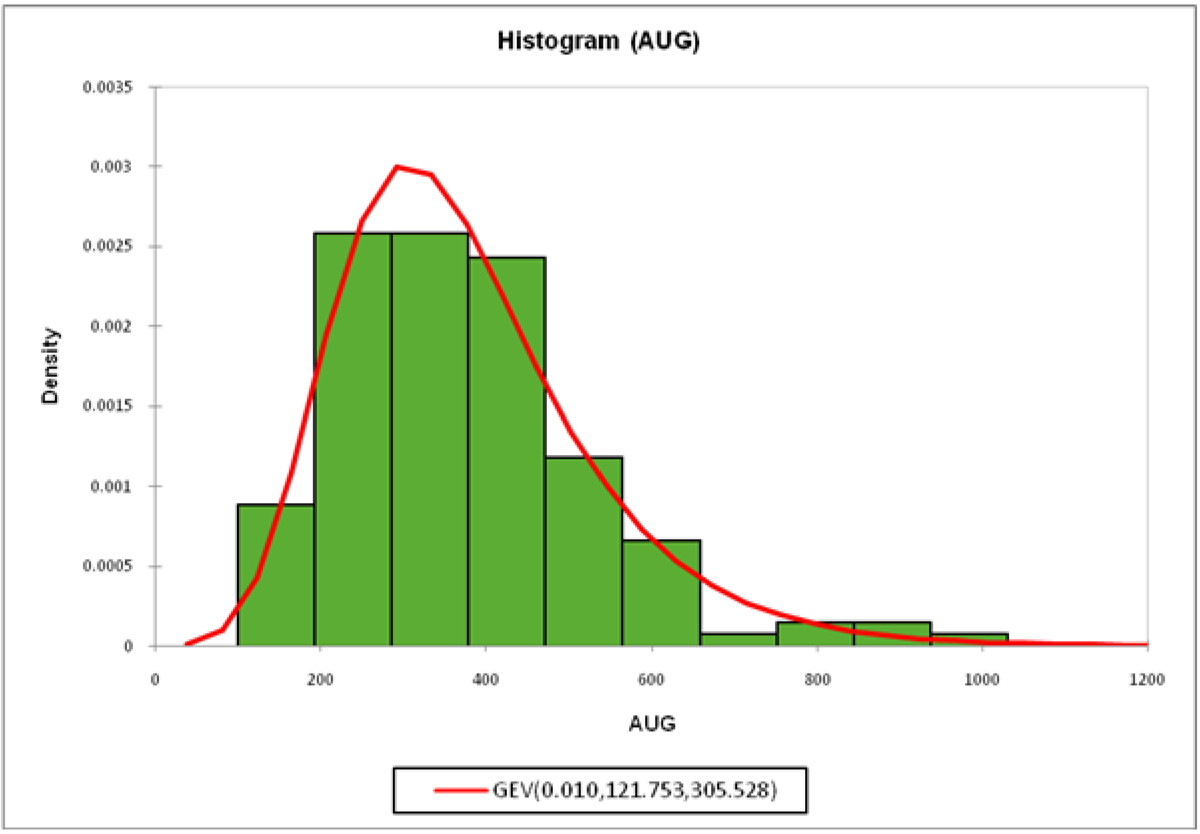


Fig. 4.4.7

Table 4.4.39

Descriptive statistics of rainfall in Kerala for the intervals (August)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
100	193	12	0.082	0.001	0.076
193	286	35	0.240	0.003	0.228
286	379	35	0.240	0.003	0.270
379	472	33	0.226	0.002	0.198
472	565	16	0.110	0.001	0.114
565	658	9	0.062	0.001	0.058
658	751	1	0.007	0.000	0.028
751	844	2	0.014	0.000	0.013
844	937	2	0.014	0.000	0.006
937	1030	1	0.007	0.000	0.003

Table 4.4.40: Fit Summary of rainfall in September in Kerala

Distribution	p-value	Distribution	p-value
Chi-square	0.000	Gumbel	0.000
Erlang	0.002	Log-normal	0.437
Exponential	0.000	Logistic	0.488
Fisher-Tippett (1)	0.000	Normal	0.165
Fisher-Tippett (2)	0.785	Normal (Standard)	0.000
Gamma (1)	0.000	Student	0.000
Gamma (2)	0.663	Weibull (1)	0.000
GEV	**0.894**	Weibull (2)	0.878

The distribution that fits best the data for the goodness of fit test is the GEV distribution.

Table 4.4.41: Estimated parameters (September) (GEV)

Parameter	Value	Standard error
k	-0.027	0.079
beta	99.242	0.062
µ	173.505	0.282

Table 4.4.42: Log-likelihood statistics (September)

Log-likelihood(LL)	-900.719
BIC(LL)	1816.389
AIC(LL)	1807.438

Table 4.4.43: Statistics estimated on the input data and computed using the estimated parameters of the GEV distribution (September)

Statistic	Data	Parameters
Mean	229.914	228.237
Variance	14917.869	15149.366
Skewness (Pearson)	0.590	0.003
Kurtosis (Pearson)	-0.368	4751584.865

Table 4.4.44: Kolmogorov-Smirnov test (September)

D	0.047
p-value (Two-tailed)	0.894
alpha	0.05

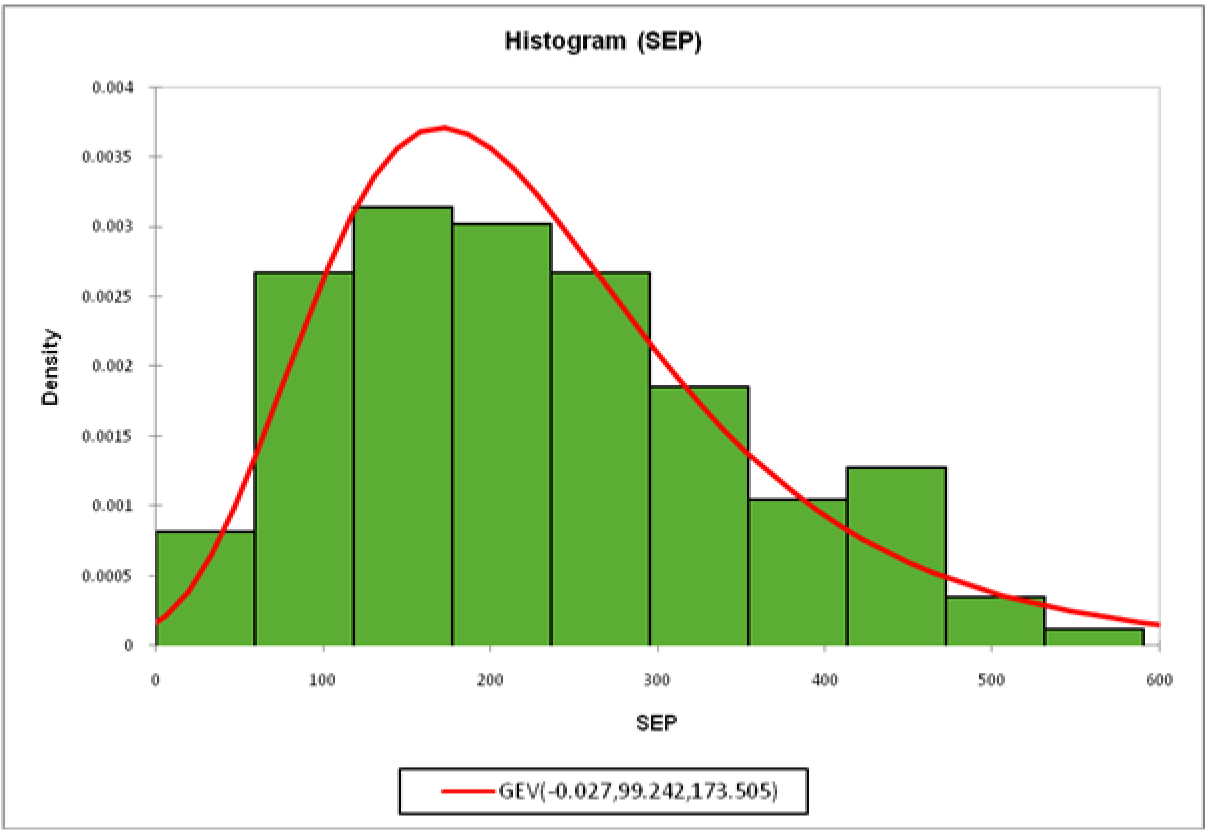


Fig. 4.4.8

Table 4.4.45: Descriptive statistics of rainfall in Kerala for the intervals (September)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
0	59	7	0.048	0.001	0.037
59	118	23	0.158	0.003	0.133
118	177	27	0.185	0.003	0.208
177	236	26	0.178	0.003	0.205
236	295	23	0.158	0.003	0.156
295	354	16	0.110	0.002	0.103
354	413	9	0.062	0.001	0.064
413	472	11	0.075	0.001	0.038
472	531	3	0.021	0.000	0.022
531	590	1	0.007	0.000	0.013

Table 4.4.46: Fit Summary of rainfall in October in Kerala

Distribution	p-value	Distribution	p-value
Beta4	**0.973**	Gumbel	0.000
Chi-square	0.000	Log-normal	0.208
Erlang	0.000	Logistic	0.825
Exponential	0.000	Normal	0.622
Fisher-Tippett (1)	0.000	Normal (Standard)	0.000
Fisher-Tippett (2)	0.445	Student	0.000
Gamma (1)	0.000	Weibull (1)	0.000
Gamma (2)	0.632	Weibull (2)	0.801
GEV	0.183		

The distribution that fits best the data for the goodness of fit test is the Beta4 distribution.

Table 4.4.47 Estimated parameters (October) (Beta4)

Parameter	Value	Standard error
alpha	4.052	0.124
beta	8.631	0.034
c	12.901	7.035
d	871.651	13.487

Table 4.4.48: Log-likelihood statistics (October)

Log-likelihood(LL)	-887.820
BIC(LL)	1795.575
AIC(LL)	1783.641

Table 4.4.49: Statistics estimated on the input data and computed using the estimated parameters of the Beta4 distribution (October)

Statistic	Data	Parameters
Mean	287.166	287.243
Variance	11812.507	11717.509
Skewness (Pearson)	0.416	0.390
Kurtosis (Pearson)	-0.135	-0.169

Table 4.4.50: Kolmogorov-Smirnov test (October)

D	0.039
p-value (Two-tailed)	0.973
alpha	0.05

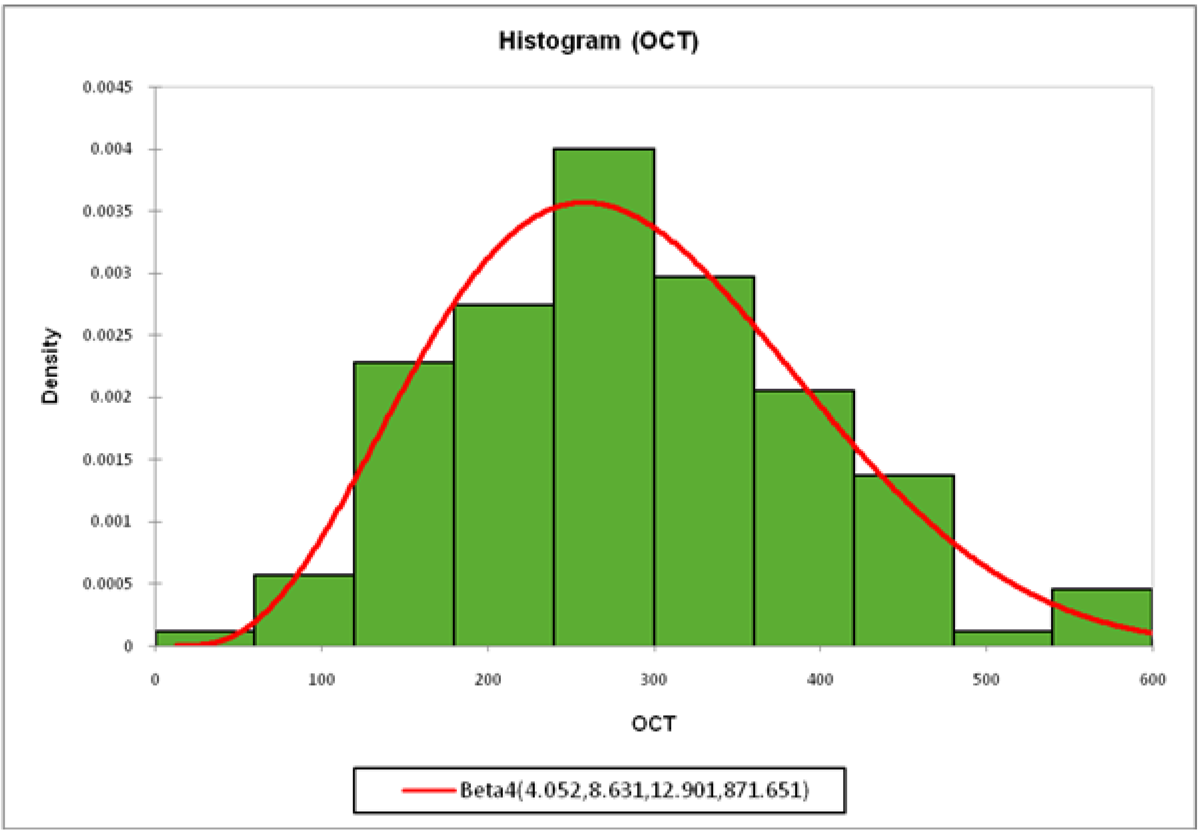


Fig. 4.4.9

Table 4.4.51: Descriptive statistics of rainfall in Kerala for the intervals (October)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
0	60	1	0.007	0.000	0.002
60	120	5	0.034	0.001	0.042
120	180	20	0.137	0.002	0.124
180	240	24	0.164	0.003	0.193
240	300	35	0.240	0.004	0.211
300	360	26	0.178	0.003	0.180
360	420	18	0.123	0.002	0.126
420	480	12	0.082	0.001	0.072
480	540	1	0.007	0.000	0.033
540	600	4	0.027	0.000	0.012

Table 4.4.52 Fit Summary of rainfall in November in Kerala

Distribution	p-value	Distribution	p-value
Beta4	0.806	Gumbel	0.000
Chi-square	0.000	Log-normal	0.837
Erlang	0.109	Logistic	0.416
Exponential	0.000	Normal	0.079
Fisher-Tippett (1)	0.000	Normal (Standard)	0.000
Fisher-Tippett (2)	0.943	Student	0.000
Gamma (1)	0.000	Weibull (1)	0.000
Gamma (2)	**0.995**	Weibull (2)	0.709
GEV	0.946		

The distribution that fits best the data for the goodness of fit test is the Gamma (2) distribution.

Table 4.4.53: Estimated parameters (November)(Gamma2)

Parameter	Value	Standard error
k	3.363	0.364
beta	45.596	5.276

Table 4.4.54: Log-likelihood statistics (November)

Log-likelihood(LL)	-841.375
BIC(LL)	1692.717
AIC(LL)	1686.750

Table 4.4.55: Statistics estimated on the input data and computed using the estimated parameters of the Gamma2 distribution (November)

Statistic	Data	Parameters
Mean	154.458	153.346
Variance	7042.705	6991.986
Skewness (Pearson)	0.754	1.091
Kurtosis (Pearson)	-0.084	1.784

Table 4.4.56: Kolmogorov-Smirnov test (November)

D	0.033
p-value (Two-tailed)	0.995
alpha	0.05

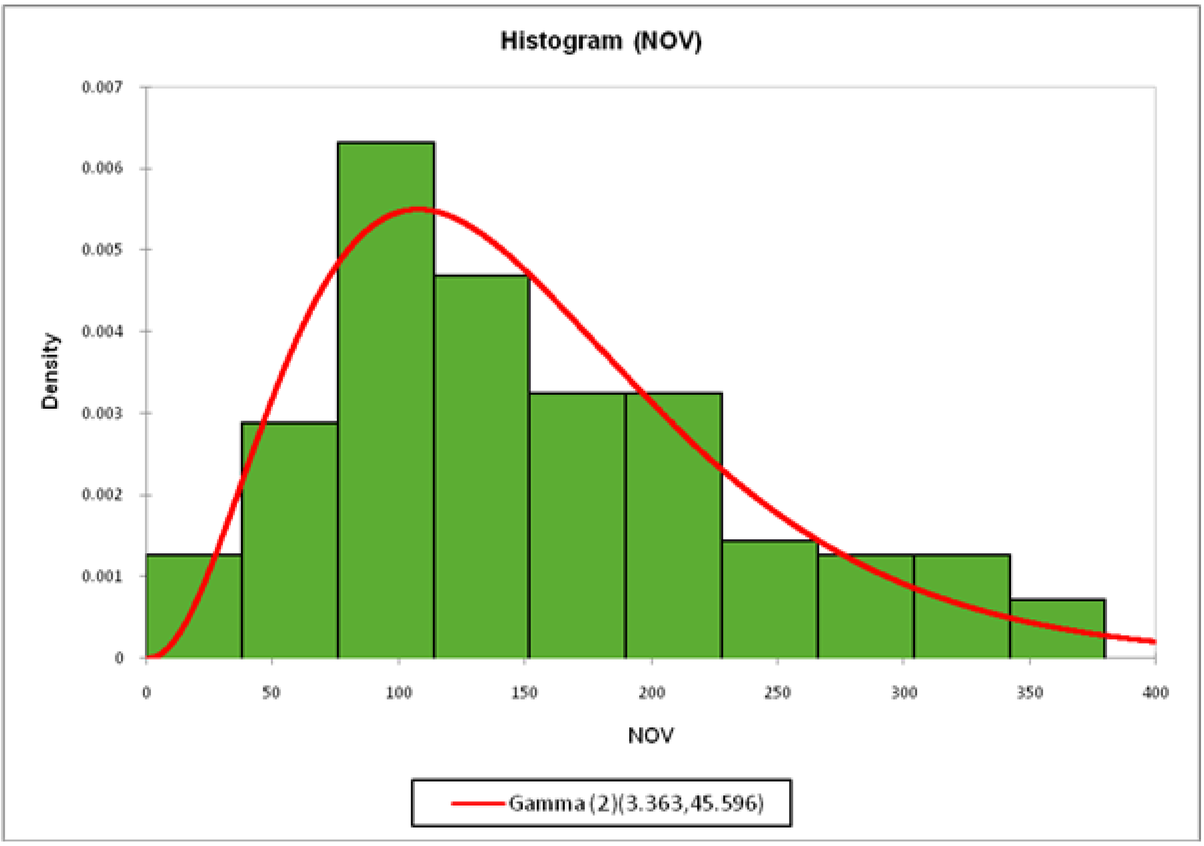


Fig. 4.4.10

Table 4.4.57: Descriptive statistics of rainfall in Kerala for the intervals (November)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
0	38	7	0.048	0.001	0.030
38	76	16	0.110	0.003	0.138
76	114	35	0.240	0.006	0.202
114	152	26	0.178	0.005	0.196
152	190	18	0.123	0.003	0.155
190	228	18	0.123	0.003	0.109
228	266	8	0.055	0.001	0.070
266	304	7	0.048	0.001	0.043
304	342	7	0.048	0.001	0.025
342	380	4	0.027	0.001	0.014

Table 4.4.58: Fit Summary of rainfall in December in Kerala

Distribution	p-value
Exponential	**0.810**
Fisher-Tippett (1)	0.000
Fisher-Tippett (2)	0.014
GEV	0.000
Gumbel	0.000
Logistic	0.001
Normal	0.001
Normal (Standard)	0.000
Student	0.000

The distribution that fits best the data for the goodness of fit test is the Exponential distribution.

Table 4.4.59: Estimated parameters (DEC)(Exponential)

Parameter	Value	Standard error
lambda	0.027	0.002

Table 4.4.60: Log-likelihood statistics (December)

Log-likelihood(LL)	-673.922
BIC(LL)	1352.827
AIC(LL)	1349.844

Table 4.4.61: Statistics estimated on the input data and computed using the estimated parameters of the Exponential distribution (December)

Statistic	Data	Parameters
Mean	37.185	37.185
Variance	1417.584	0.001
Skewness (Pearson)	1.823	2.000
Kurtosis (Pearson)	4.203	6.000

Table 4.4.62: Kolmogorov-Smirnov test (December)

D	0.052
p-value (Two-tailed)	0.810
alpha	0.05

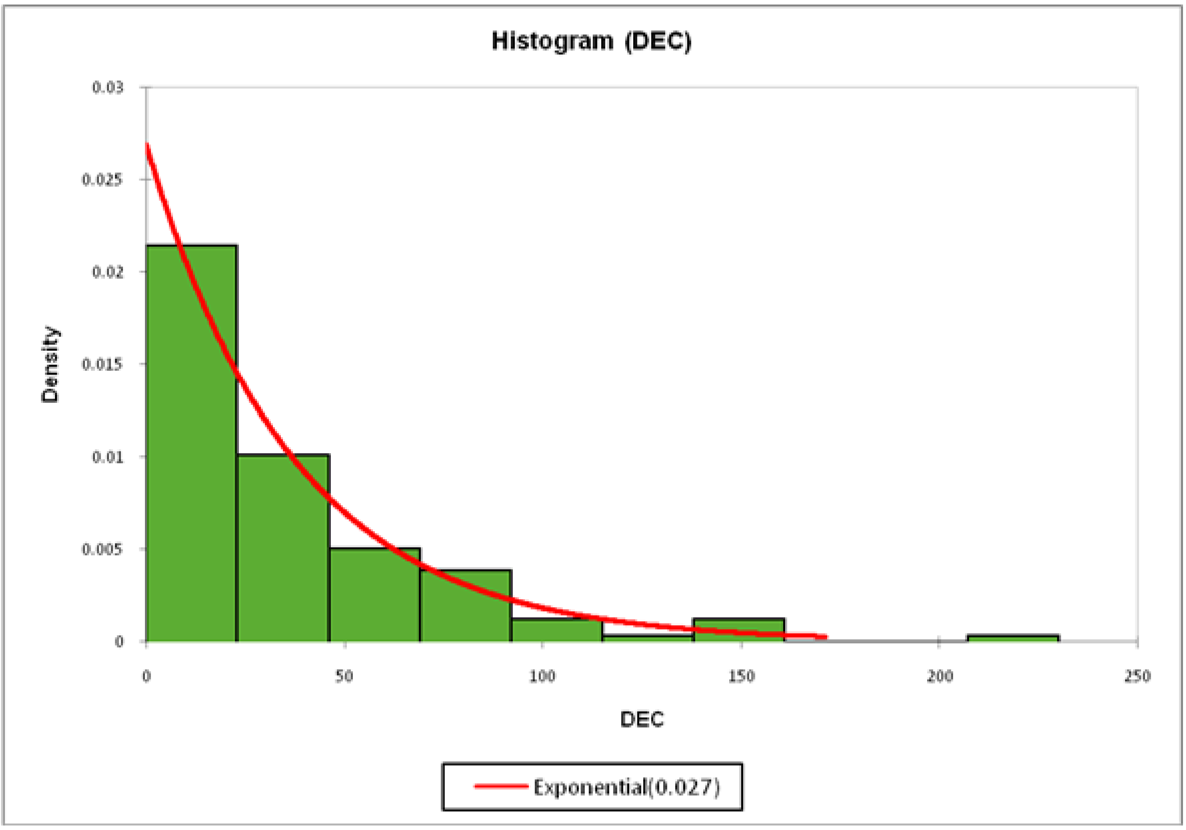


Fig. 4.4.11

Table 4.4.63
Descriptive statistics of rainfall in Kerala for the intervals (December)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
0	23	72	0.493	0.021	0.461
23	46	34	0.233	0.010	0.248
46	69	17	0.116	0.005	0.134
69	92	13	0.089	0.004	0.072
92	115	4	0.027	0.001	0.039
115	138	1	0.007	0.000	0.021
138	161	4	0.027	0.001	0.011
161	184	0	0.000	0.000	0.006
184	207	0	0.000	0.000	0.003
207	230	1	0.007	0.000	0.002

Table 4.4.64: Fit Summary of rainfall in winter Season (JF) in Kerala

Distribution	p-value
Chi-square	0.000
Exponential	**0.898**
Fisher-Tippett (1)	0.000
Fisher-Tippett (2)	0.030
GEV	0.000
Gumbel	0.000
Logistic	0.001
Normal	0.003
Normal (Standard)	0.000
Student	0.000

The distribution that fits best the data for the goodness of fit test is the Exponential distribution.

Table 4.4.65: Estimated parameters (JF) (Exponential)

Parameter	Value	Standard error
lambda	0.037	0.003

Table 4.4.66: Log-likelihood statistics (JF)

Log-likelihood(LL)	-627.850
BIC(LL)	1260.684
AIC(LL)	1257.700

Table 4.4.67: Statistics estimated on the input data and computed using the estimated parameters of the Exponential distribution (JF)

Statistic	Data	Parameters
Mean	27.122	27.122
Variance	658.205	0.001
Skewness (Pearson)	1.177	2.000
Kurtosis (Pearson)	0.691	6.000

Table 4.4.68: Kolmogorov-Smirnov test (JF)

D	0.046
p-value (Two-tailed)	0.898
alpha	0.05

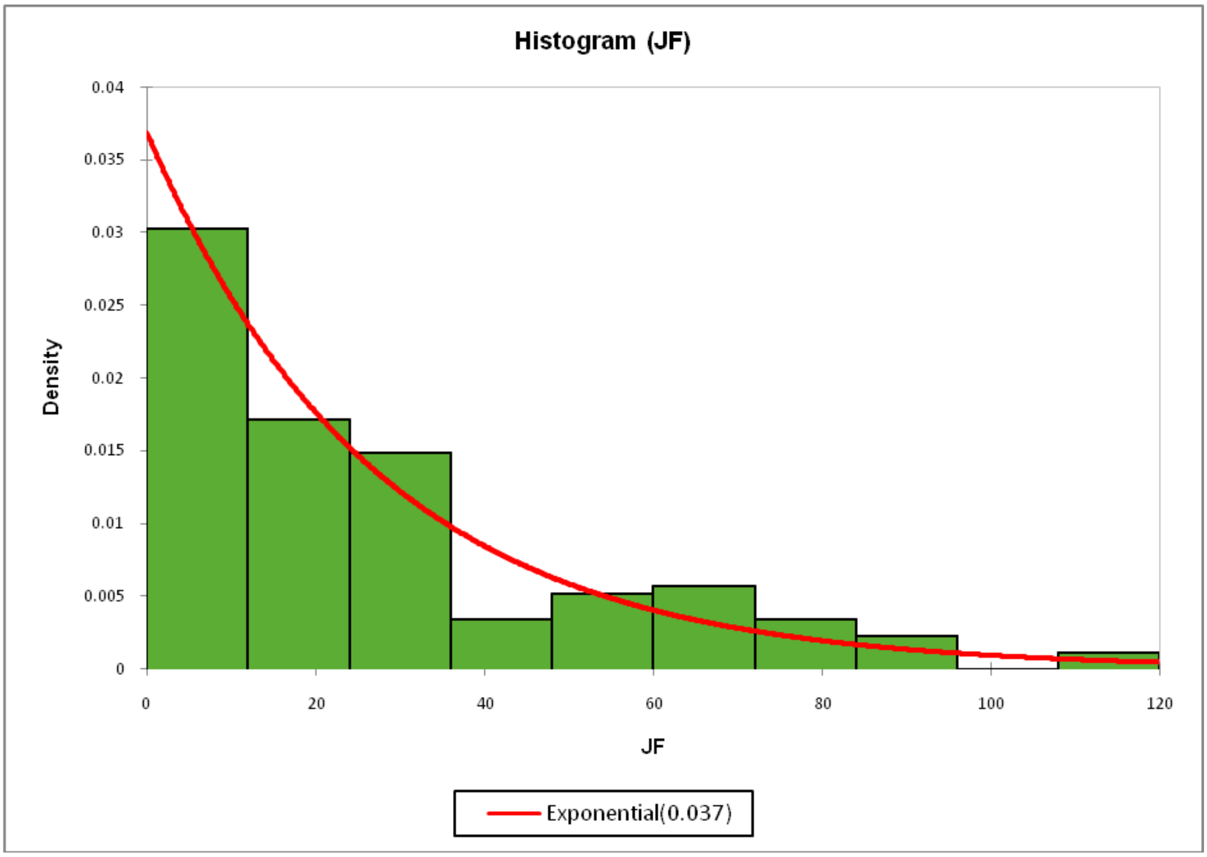


Fig. 4.4.12

Table 4.4.69: Descriptive statistics of rainfall in Kerala for the intervals (JF)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
0	12	53	0.363	0.030	0.358
12	24	30	0.205	0.017	0.230
24	36	26	0.178	0.015	0.148
36	48	6	0.041	0.003	0.095
48	60	9	0.062	0.005	0.061
60	72	10	0.068	0.006	0.039
72	84	6	0.041	0.003	0.025
84	96	4	0.027	0.002	0.016
96	108	0	0.000	0.000	0.010
108	120	2	0.014	0.001	0.007

Table 4.4.70: Fit Summary of rainfall in Pre monsoon Season (MAM) in Kerala

Distribution	p-value	Distribution	p-value
Beta4	0.671	Gumbel	0.000
Chi-square	0.000	**Log-normal**	**0.977**
Erlang	0.523	Logistic	0.265
Exponential	0.000	Normal	0.037
Fisher-Tippett (1)	0.000	Normal (Standard)	0.000
Fisher-Tippett (2)	0.948	Student	0.000
Gamma (1)	0.000	Weibull (1)	0.000
Gamma (2)	0.560	Weibull (2)	0.148
GEV	0.797		

The distribution that fits best the data for the goodness of fit test is the Log-normal distribution.

Table 4.4.71: Estimated parameters (MAM) (Log-normal)

Parameter	Value	Standard error
µ	5.895	0.032
sigma	0.392	0.023

Table 4.4.72 Log-likelihood statistics (MAM)

Log-likelihood(LL)	-931.211
BIC(LL)	1872.389
AIC(LL)	1866.422

Table 4.4.73: Statistics estimated on the input data and computed using the estimated parameters of the Log-normal distribution (MAM)

Statistic	Data	Parameters
Mean	391.946	392.144
Variance	25163.979	25600.424
Skewness (Pearson)	1.104	1.292
Kurtosis (Pearson)	1.499	3.108

Table 4.4.74: Kolmogorov-Smirnov test (MAM)

D	0.038
p-value (Two-tailed)	0.977
alpha	0.05

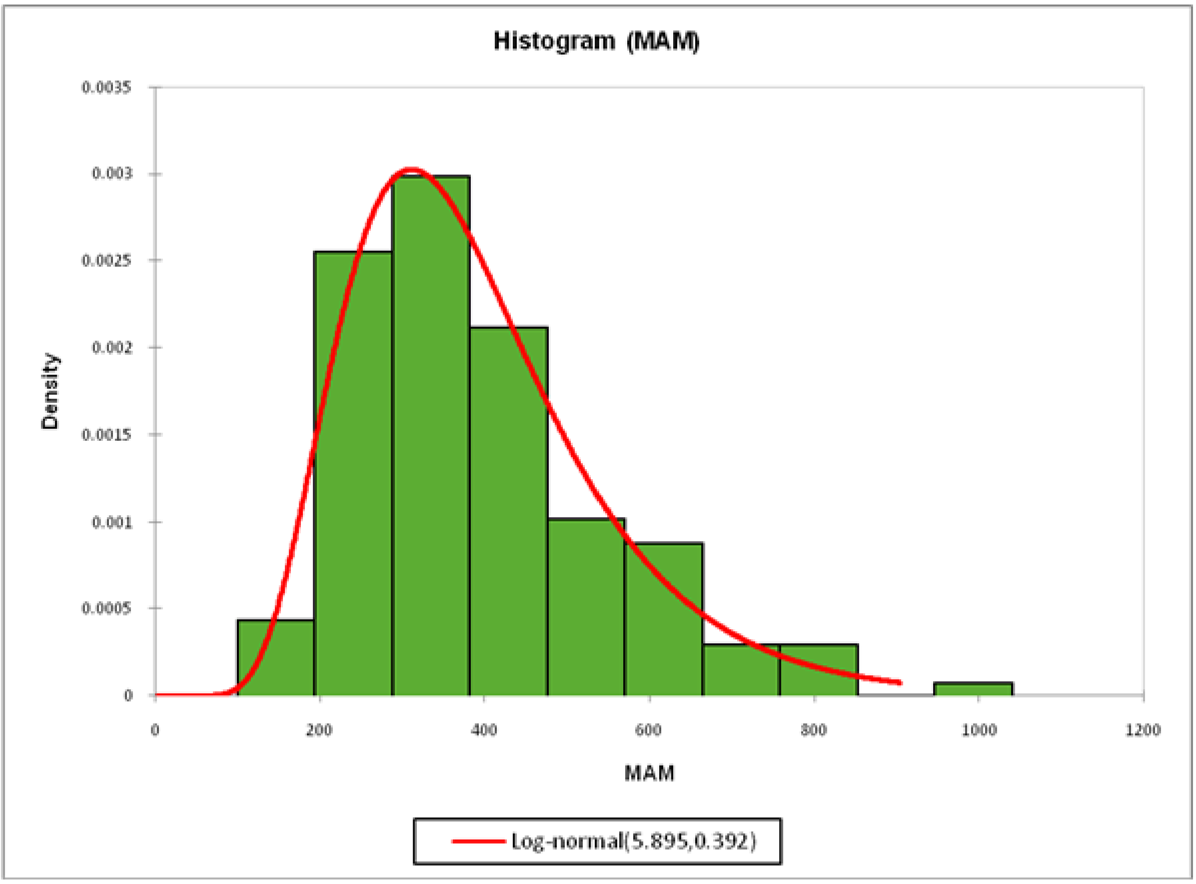


Fig. 4.4.13

Table 4.4.75: Descriptive statistics of rainfall in Kerala for the intervals (MAM)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
100	194	6	0.041	0.000	0.055
194	288	35	0.240	0.003	0.222
288	382	41	0.281	0.003	0.274
382	476	29	0.199	0.002	0.203
476	570	14	0.096	0.001	0.120
570	664	12	0.082	0.001	0.063
664	758	4	0.027	0.000	0.032
758	852	4	0.027	0.000	0.015
852	946	0	0.000	0.000	0.008
946	1040	1	0.007	0.000	0.004

Table 4.4.76: Fit Summary of SW monsoon Season (JJAS) in Kerala

Distribution	**p-value**	**Distribution**	**p-value**
Beta4	**0.988**	Gumbel	0.000
Chi-square	0.000	Log-normal	0.888
Erlang	0.834	Logistic	0.728
Exponential	0.000	Normal	0.673
Fisher-Tippett (1)	0.000	Normal (Standard)	0.000
Fisher-Tippett (2)	0.780	Student	0.000
Gamma (1)	0.000	Weibull (1)	0.000
Gamma (2)	0.878	Weibull (2)	0.322
GEV	0.447		

The distribution that fits best the data for the goodness of fit test is the Beta4 distribution.

Table 4.4.77: Estimated parameters (JJAS) (Beta4)

Parameter	Value	Standard error
alpha	4.045	0.141
beta	10.008	0.039
c	1001.347	23.081
d	4188.320	6.519

Table 4.4.78: Log-likelihood statistics (JJAS)

Log-	-1067.516
BIC(LL)	2154.967
AIC(LL)	2143.033

Table 4.4.79
Statistics estimated on the input data and computed using the estimated parameters of the Beta4 distribution (JJAS)

Statistic	Data	Parameters
Mean	1918.777	1918.733
Variance	139943.206	138310.023
Skewness (Pearson)	0.494	0.453
Kurtosis (Pearson)	0.031	-0.062

Table 4.4.80
Kolmogorov-Smirnov test (JJAS)

D	0.036
p-value (Two-tailed)	0.988
alpha	0.05

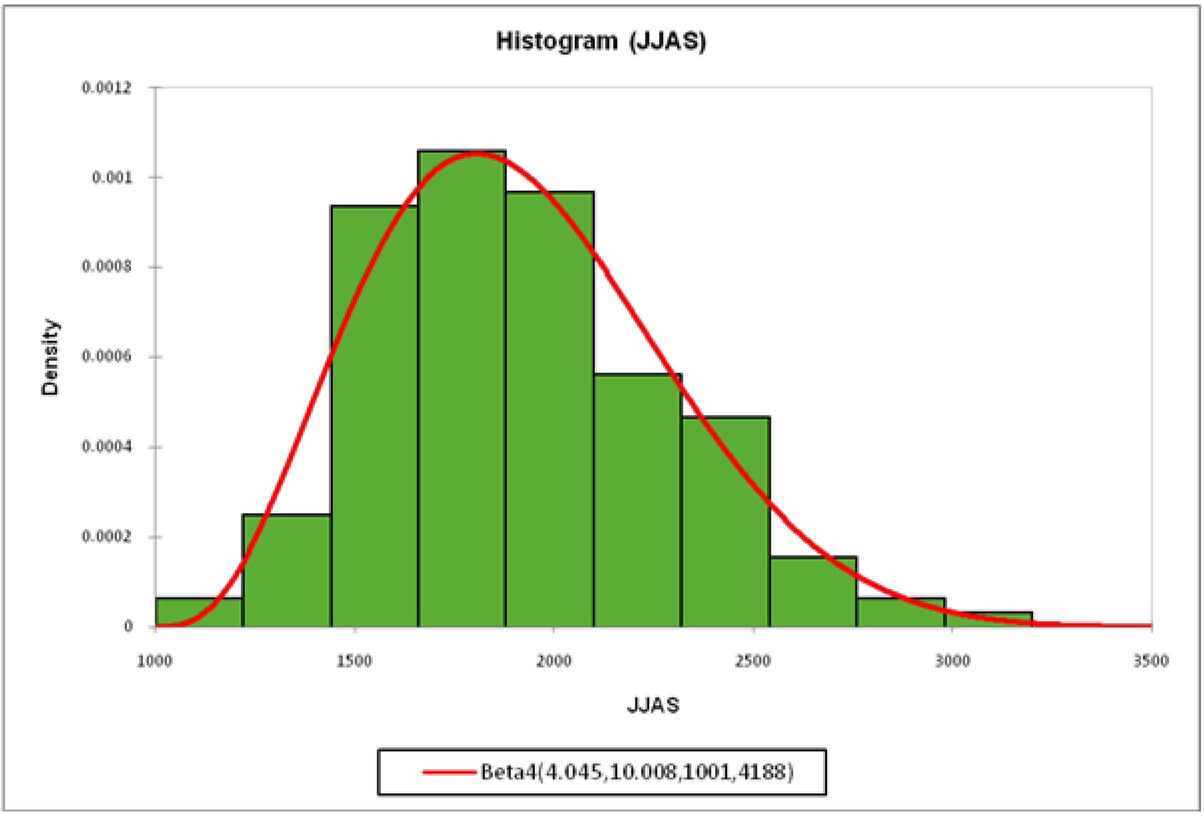


Fig. 4.4.14

Table 4.4.81: Descriptive statistics of rainfall in Kerala for the intervals (JJAS)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
1000	1220	2	0.014	0.000	0.009
1220	1440	8	0.055	0.000	0.079
1440	1660	30	0.205	0.001	0.178
1660	1880	34	0.233	0.001	0.227
1880	2100	31	0.212	0.001	0.208
2100	2320	18	0.123	0.001	0.150
2320	2540	15	0.103	0.000	0.087
2540	2760	5	0.034	0.000	0.041
2760	2980	2	0.014	0.000	0.015
2980	3200	1	0.007	0.000	0.004

Table 4.4.82: Fit Summary of rainfall in post monsoon Season (OND) in Kerala

Distribution	p-value	Distribution	p-value
Beta4	**0.914**	Gumbel	0.000
Chi-square	0.000	Log-normal	0.674
Erlang	0.168	Logistic	0.766
Exponential	0.000	Normal	0.772
Fisher-Tippett (1)	0.000	Normal (Standard)	0.000
Fisher-Tippett (2)	0.500	Student	0.000
Gamma (1)	0.000	Weibull (1)	0.000
Gamma (2)	0.886	Weibull (2)	0.865
GEV	0.008		

The distribution that fits best the data for the goodness of fit test is Beta4

Table 4.4.83: Estimated parameters (OND)(Beta4)

Parameter	Value	Standard error
alpha	9.036	0.267
beta	11.056	0.033
c	-134.867	12.746
d	1230.198	6.887

Table 4.4.84: Log-likelihood statistics (OND)

Log-	-936.235
BIC(LL)	1892.404
AIC(LL)	1880.469

Table 4.4.85: Statistics estimated on the input data and computed using the estimated parameters of the Beta4 distribution (OND)

Statistic	Data	Parameters
Mean	478.798	479.063
Variance	22095.367	21863.091
Skewness (Pearson)	0.178	0.084
Kurtosis (Pearson)	-0.306	-0.250

Table 4.4.86: Kolmogorov-Smirnov test (OND)

D	0.045
p-value (Two-tailed)	0.914
alpha	0.05

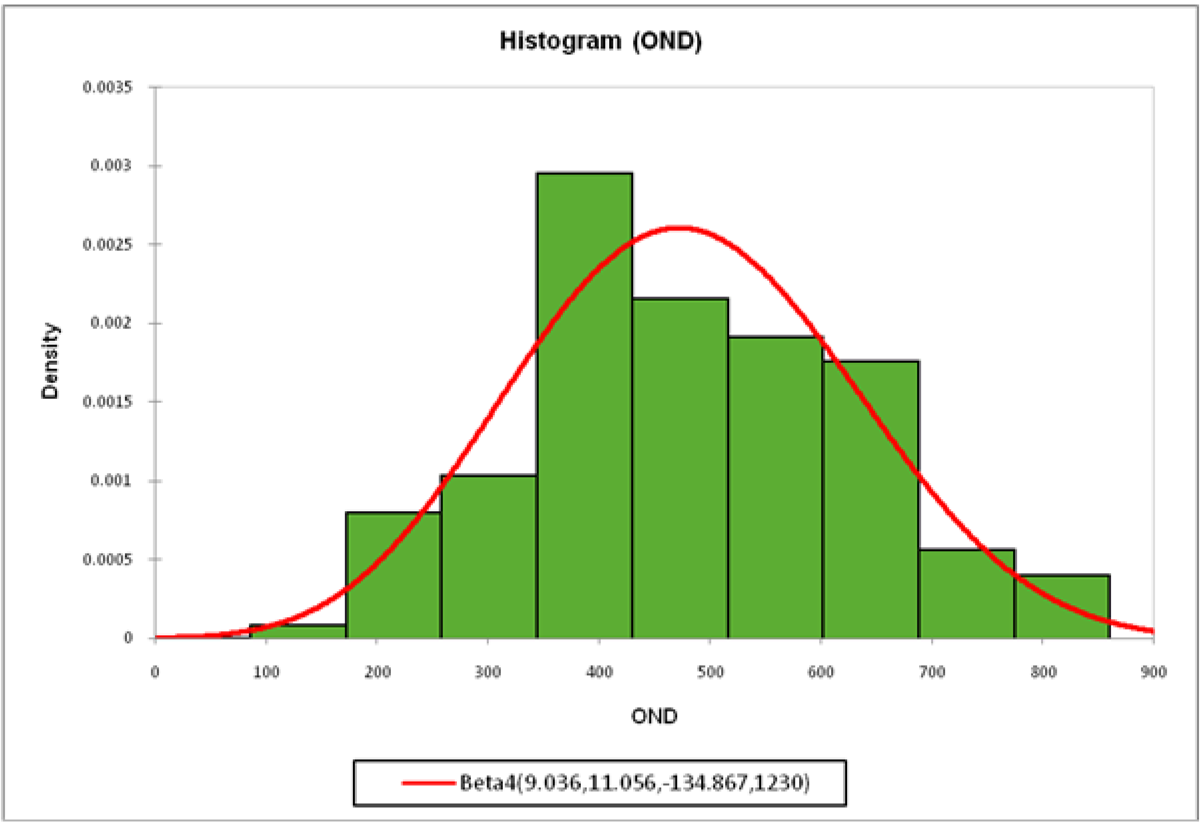


Fig. 4.4.15

Table 4.4.87: Descriptive statistics of rainfall in Kerala for the intervals (OND)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
0	86	0	0.000	0.000	0.001
86	172	1	0.007	0.000	0.013
172	258	10	0.068	0.001	0.052
258	344	13	0.089	0.001	0.121
344	430	37	0.253	0.003	0.192
430	516	27	0.185	0.002	0.221
516	602	24	0.164	0.002	0.191
602	688	22	0.151	0.002	0.124
688	774	7	0.048	0.001	0.059
774	860	5	0.034	0.000	0.020

Table 4.4.88: Fit Summary of annual rainfall in Kerala

Distribution	p-value	Distribution	p-value
Beta4	0.886	Gumbel	0.000
Chi-square	0.000	Log-normal	0.564
Erlang	0.669	Logistic	0.771
Exponential	0.000	**Normal**	**0.938**
Fisher-Tippett (1)	0.000	Normal (Standard)	0.000
Fisher-Tippett (2)	0.350	Student	0.000
Gamma (1)	0.000	Weibull (1)	0.000
Gamma (2)	0.729	Weibull (2)	0.503
GEV	0.016		

The distribution that fits best the data for the goodness of fit test is the Normal distribution.

Table 4.4.89: Estimated parameters (ANN) (Normal)

Parameter	Value	Standard error
μ	2816.651	
sigma	415.054	

Table 4.4.90: Log-likelihood statistics (ANN)

Log-likelihood(LL)	-1086.813
BIC(LL)	2183.594
AIC(LL)	2177.627

Table 4.4.91: Statistics estimated on the input data and computed using the estimated parameters of the Normal distribution (ANN)

Statistic	Data	Parameters
Mean	2816.651	2816.651
Variance	172271.594	172269.595
Skewness (Pearson)	0.206	0.000
Kurtosis (Pearson)	-0.181	0.000

Table 4.4.92: Kolmogorov-Smirnov test (ANN)

D	0.043
p-value (Two-tailed)	0.938
alpha	0.05

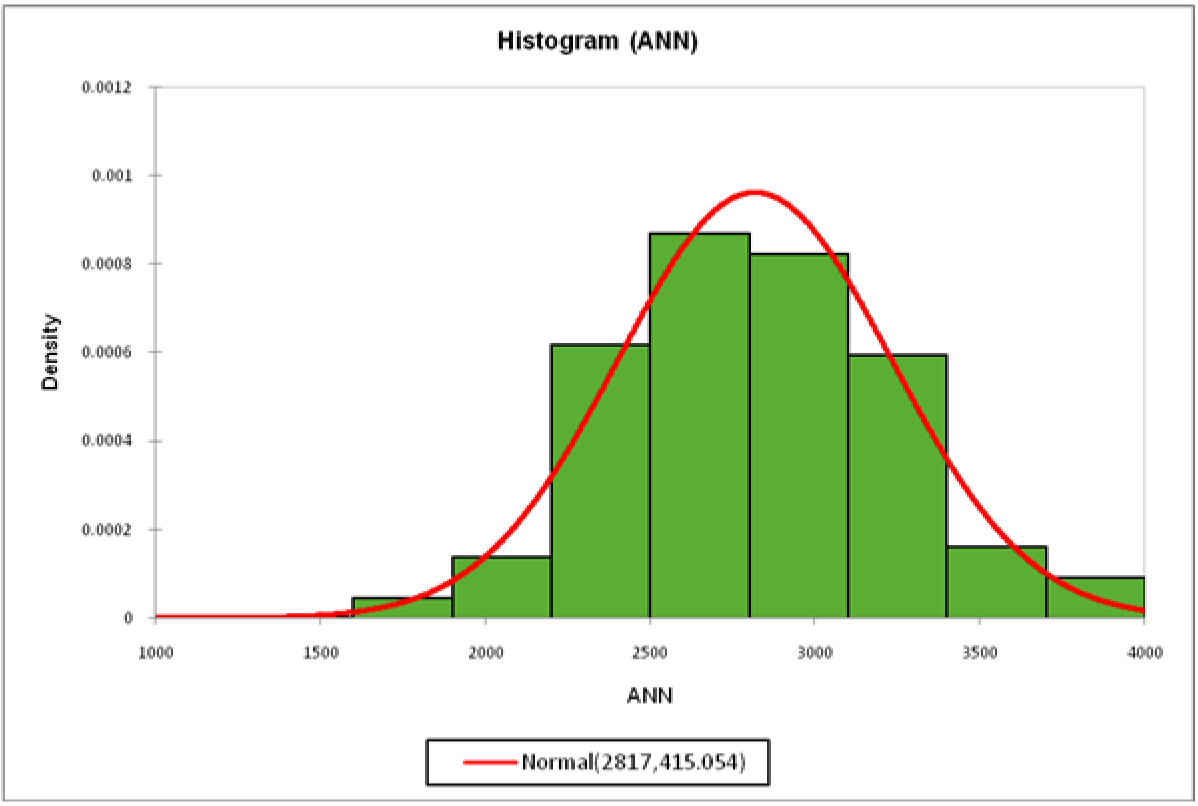


Fig. 4.4.16

Table 4.4.93: Descriptive statistics of rainfall in Kerala for the intervals (ANN)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
1000	1300	0	0.000	0.000	0.000
1300	1600	0	0.000	0.000	0.002
1600	1900	2	0.014	0.000	0.012
1900	2200	6	0.041	0.000	0.055
2200	2500	27	0.185	0.001	0.154
2500	2800	38	0.260	0.001	0.261
2800	3100	36	0.247	0.001	0.269
3100	3400	26	0.178	0.001	0.167
3400	3700	7	0.048	0.000	0.063
3700	4000	4	0.027	0.000	0.014

Table 4.4.94: Fit summary for peak monthly rainfall in Kerala

Distribution	p-value	Distribution	p-value
Beta4	**0.994**	Gumbel	0
Chi-square	0	Log-normal	0.969
Erlang	0.747	Logistic	0.767
Exponential	0	Normal	0.463
Fisher-Tippett (1)	0	Normal (Standard)	0
Fisher-Tippett (2)	0.969	Student	0
Gamma (1)	0	Weibull (1)	0
Gamma (2)	0.952	Weibull (2)	0.218
GEV	0.561		

The distribution that fits best the data for the goodness of fit test is the Beta4 distribution.

Table 4.4.95: Estimated parameters(Beta4)

Parameter	Value	Standard error
alpha	3.677	0.132
beta	9.634	0.039
c	398.332	9.658
d	1777.142	4.488

Table 4.4.96: Log-likelihood statistics

Log-likelihood(LL)	-946.053
BIC(LL)	1912.040
AIC(LL)	1900.105

Table 4.4.97: Statistics estimated on the input data and computed using the estimated parameters of the Beta4 distribution

Statistic	Data	Parameters
Mean	779.027	779.186
Variance	26919.672	26559.375
Skewness (Pearson)	0.529	0.495
Kurtosis (Pearson)	-0.099	-0.023

Table 4.4.98: Kolmogorov-Smirnov test

D	0.034
p-value (Two-tailed)	0.994
alpha	0.05

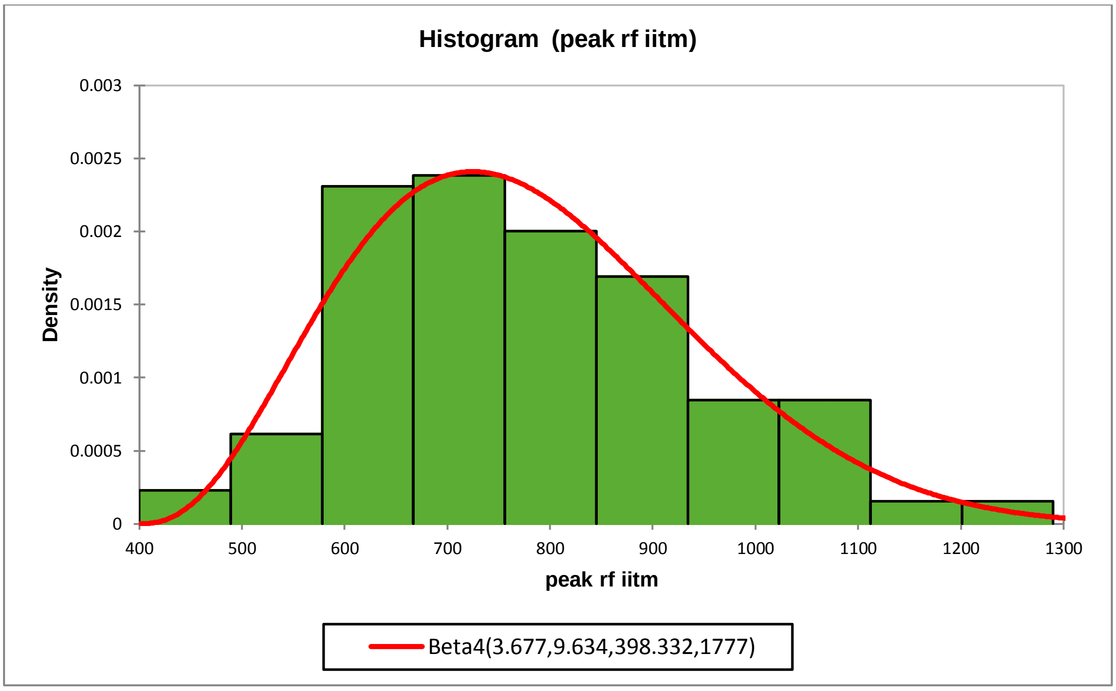


Fig. 4.4.17

Table 4.4.99: Descriptive statistics of rainfall in Kerala for the intervals (peak rf IITM)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
400	489	3	0.021	0.000	0.013
489	578	8	0.055	0.001	0.086
578	667	30	0.205	0.002	0.172
667	756	31	0.212	0.002	0.211
756	845	26	0.178	0.002	0.195
845	934	22	0.151	0.002	0.147
934	1023	11	0.075	0.001	0.093
1023	1112	11	0.075	0.001	0.049
1112	1201	2	0.014	0.000	0.022
1201	1290	2	0.014	0.000	0.008

5 PENTAD ANALYSIS OF CLIMATIC VARIABLES

5.1 INTRODUCTION

The spatial and temporal variability in rainfall was examined in detail using monthly as well as seasonal rainfall data for different districts as well as for the State as a whole. Even though the annual variability of rainfall in Kerala is small, there exists significant spatial variability. Evidence of the dominant pattern of inter-seasonal rainfall variability has been proved by Todd & Washington (1999) and Tennant & Hewitson (2002) by examining the inter-seasonal variability using daily rainfall data. The intra seasonal variability of the climatic variables are also very crucial especially with respect to agriculture and related fields.

In agriculture and water management studies, more detailed information than just departures from a mean state is required. It is well known that a well distributed rainfall is always better than heavy rainfall for few days over an agriculture region. The consistency of the minimum required rainfall is more important than the total received over time for crop cultivation. Crops perform well with a uniformly spread light rain than with a few heavy rains interrupted by dry periods. This timing of dry spells relative to cropping calendar is fundamental to crop variability rather than total seasonal or annual rainfall. (Usman & Reason, 2004).

The pentad rainfall reveals finer details of rainfall variations in space and time of individual stations, which may be regarded as spectra of rainfall under high dispersion compared to low dispersion spectra of monthly rainfall (Ananthakrishnan *et al.* 1971). The consistency of the advance and ending of the rainy pentads can be found out. The analysis of daily rainfall by 5-day totals is a satisfactory technique to identify the beginning, end and duration of the rainy pentad groups. The two peaked nature of the rainy season and the deviation of the period of diminished rains between the two peak periods can also be found out.

The Pentad timeframe is appropriate to cover the Tropical Temperature Trough (TTT) rain producing systems that are responsible for most of the regional rainfall (Sivakumar, 1992)

Previous investigations have provided information on variability of rainfall in a general sense pertaining to monthly and seasonal periods. None of these studies presents a comprehensive picture of a particular area from the stand point of daily rainfall data. These type of studies are kept within the particular offices and are not available as publications. Hence the possibility of extracting minute details of variability of weather elements has been tried using the daily data on rainfall, maximum temperature, minimum temperature, relative humidity, sunshine hours and wind velocity pertaining to Vellanikkara (bounded by 10^0 31'; $76^0$13'), Thrissur district of Kerala for a period from 1983 to 2016.

Since rainfall is the most important meteorological element of a region, investigators have devoted much attention to rainfall studies of a particular area. So the main purpose of this study is to identify the rainy pentads or beginning and end of the heavier rains, using 25 mm of rainfall in 5 days as the identifier. A Navigation through the different pentads of other climatic variables also has been attempted.

5.2 REVIEW OF LITERATURE

Sivakumar (1992) showed that the dry spell frequency ranging between 2 and 3 pentads in West Africa was independent of long term seasonal means with a direct consequence for agriculture. Dry spells relate directly to agricultural impacts since their frequency and duration indicates the degree of stress, plants were exposed to. A time series of occurrence of dry spell was generated and then subjected to further analysis to identify spatio - temporal patterns.

Spatial and temporal patterns of rainfall during mid - summer and their relationships to inter annual drought occurrences in Southern Africa have been studied using dry spell frequencies. Pentads with mean daily rainfall less than 1 mm were defined as dry spells (Usman and Reason, 2004)

The wet and dry spells for 19 sub regions across India have been studied by Sing and Ranade (2009) using gridded daily rainfall available on 1^o latitude x 1^o longitude spatial resolution for the period 1951 – 2007. A continuous period with daily rainfall equal to or greater than (less than) daily mean rainfall of monsoon period over the area of interest was taken as the intra-annual variation. The rainfall due to wet spells contributes 68% and dry spells 17% to the respective annual total. In a majority of regions the actual and extreme wet spells were slightly shorter and thus rainfall intensity was higher in recent years/decades. But the actual and extreme dry spells are slightly longer with weaker rainfall intensity. A tendency for the first wet spell to start 6 days earlier and to end two days earlier was observed leading to larger duration of rainfall activities. In any of the 40 wet spell/dry spell parameters studied, a spatially coherent, robust long term trend was not found.

Owiti and Zhu (2012) have studied the geographical variation of seasonality of rainfall over East Africa using pentad rainfall data at 36 stations during 1962 – 2006. The seasonal cycles of rainfall have been modelled using harmonic analysis. The degree of uni - model or bi - model behaviour of rainfall at a given station was assessed through indexing the ratio of the modelled semi - annual range (R_2) to annual range (R_1). Based on the amplitude of the annual and semi-annual nodes, stations were further classified. A check was made to see whether the maximum rainfall of the smoothened annual cycle appears during March – April - May and October – November - December seasons or in a different season of the year.

5.3 DATA AND METHODOLOGY

Each year was divided into 73 pentads starting from January 1st to December 31st. The last pentad, 73, includes 6 days in leap years. The daily meteorological data of the Vellanikkara station for the period from 1983- 2016 were grouped into 5 day totals for all the years under study. Then for each pentad the total rainfall as well as average rainfall, average maximum and minimum temperatures, average relative humidity (I & II), average sunshine hours and average wind velocity were computed for each year.

Rainy pentads were identified based on the criterion of incidence of 25 mm rainfall and 50 mm rainfall in each pentad. In the 25 mm criterion, pentads with mean rainfall ≥ 25 mm were noted. Those pentads with 50% or more occurrence of 25 mm rainfall *ie* the pentads with frequency of occurrence of 25 mm rainfall or more per day were identified. This particular approach is named as 50% criterion. The 25 mm was chosen because this amount represents the rain from one mesoscale rainstorm which is meteorologically significant (Gramsow and Henry, 1972).

For climatic variables other than rainfall, the average for 1983-2016 for 73 pentads have been worked out and plotted. The significance of the trend in pentad distribution of climatic variables in Vellanikkara has been checked using the non-parametric Mann - Kendall test.

5.4 RESULTS AND DISCUSSION

The distribution of pentad total rainfall averaged over 34 years is shown in Fig. (5.4.1). Pentads from 1 to 12 denote the winter season (January to February), pentads from 13 to 30 cover the months March, April and May (pre monsoon season) and the South-West Monsoon from pentad 31 to 55. The Post monsoon season starts from pentad 56 and ends on pentad 73. The peak value of rainfall was recorded in two pentads viz., pentad 33 (10 June – 14 June) and in pentad 37 (30^{th} June – 4^{th} July) in the study area. The first pentad for which the rainfall was 25 mm was identified as the beginning of the rainy pentad and the last pentad with a mean of 25 mm was denoted as the end of rainy pentad. The 50% criterion was used in the same manner. The rainfall mean for each pentad and the frequency of occurrence of 25 mm and greater and 50 mm and greater were computed and plotted.

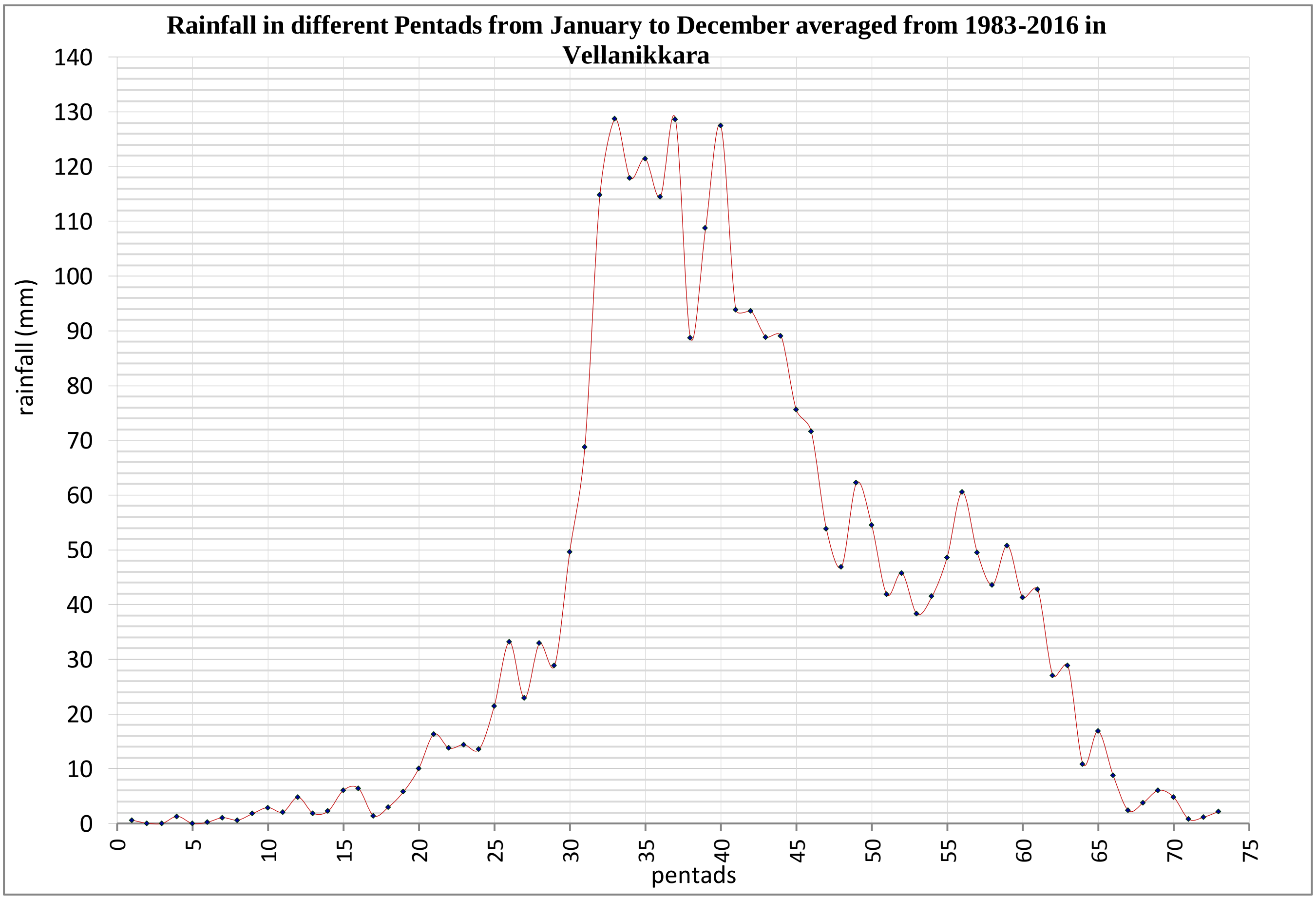


Fig. 5.4.1

Temporal variations of pentad climatic variables in Vellanikkara

Usually the rainfall Atlas incorporates statistics related to the spatial and temporal variations of monthly, seasonal and annual variations of rainfall over different regions. These will depict the major rainfall characteristics whereas to get the finer features of the rainfall variation, such as the dates of onset and withdrawal of the monsoon rain etc. the long term rainfall data are averaged over time periods less than a month. The five-day period (pentad) forms a convenient time unit for this purpose. (Ananthakrishnam & Pathan 1971). The features like the existence of any mid - month minimum or maximum during different monsoon periods can be easily studied. These features are not brought out by monthly or seasonal data in which they are not usually noticed.

Pentad total rainfall, average rainfall, average maximum temperature, average relative humidity, average sunshine hours and average wind velocity for 73 pentads of a year were computed for a period from 1983 to 2016. The sequential changes in the temporal distribution of rainfall and other weather variables through the 73 pentads per year have been brought out and the salient features are thoroughly examined.

Pentad Analysis of Rainfall

Pentad P-1 to P-12 (January – February, Winter season)

The study region was driest during the winter months with pentad rainfall amount of 1.29 mm on the average. The pentad rainfall ranges from 0 mm to 4.8 mm during this season. The different pentad rainfall averaged over 34 years from 1983 to 2016 is shown in table 5.4.1. The maximum value of pentad rainfall was 132.6 mm in the pentad 12 in 2003.

Table 5.4.1a: Average pentad (P1-P12) rainfall(mm) over 34 years from 1983 to 2016 in Vellanikkara

p-1	p-2	p-3	p-4	p-5	p-6	p-7	p-8	p-9	p-10	p-11	p-12
0.6	0.1	0.0	1.3	0.0	0.2	1.1	0.6	1.8	2.9	2.1	4.8

Pentad P-13 to P-30 (March, April, May - Summer season)

Pentad rainfall amounts averaged for 34 years ranges from 1.42 mm in pentad 17 (22 March-26 March) to 49.65 mm in pentad 30 (26 May - 30 May). In general there was a progressive increase in the amount of rainfall as the pentads advance. The maximum pentad rainfall was 449.5 mm in pentad 30 during 2006.

Table 5.4.1b Average pentad (P13-P30) rainfall(mm) over 34 years from 1983 to 2016 in Vellanikkara

p-13	p-14	p-15	p-16	p-17	p-18	p-19	p-20	p-21	p-22	p-23	p-24
1.9	2.3	6.0	6.4	1.4	3.0	5.8	10.0	16.3	13.8	14.4	13.6
p-25	p-26	p-27	p-28	p-29	p-30						
21.5	33.2	22.9	32.9	28.9	49.7						

Pentad P-31 to P-55 (June- July-August-September, SW monsoon)

In the South-West monsoon season the pentad average for 34 years recorded a maximum value of 128.7 mm in pentad 33 as well as in pentad 37. In this season after pentad 40 there was a steady decrease in the amount of rainfall and came to a minimum of 38.3 mm in pentad 53. When the rainfall in the individual pentads were considered, the minimum value 0 mm occurred in pentads starting from P- 46 to P-55 in different years and the maximum pentad value was 390.1 mm in P-32 during 2004.

Table 5.4.1c: Average pentad (P31-P55) rainfall(mm) over 34 years from 1983 to 2016 in Vellanikkara

p-31	p-32	p-33	p-34	p-35	p-36	p-37	p-38	p-39	p-40	p-41	p-42	
68.8	114.8	128.7	118.0	121.5	114.6	128.7	88.7	108.8	127.5	93.9	93.7	
p-43	p-44	p-45	p-46	p-47	p-48	p-49	p-50	p-51	p-52	p-53	p-54	p-55
88.9	89.0	75.6	71.6	53.8	46.9	62.2	54.5	41.9	45.8	38.3	41.5	48.6

During these pentads the region receives on an average 2066 mm rainfall out of 2767 mm of the annual rainfall (*ie* about 75%). The normal date of onset of monsoon rains in Kerala is 1st June. A substantial increase in the pentad rainfall occurs from P-30 to P-31 onwards *ie* in pentads ending on May 30 (p30) and starting from May 31st (p 31). The progressive enhancement in the quantity of rainfall through the advance of each successive pentad from the month of May to the end of October for each year is presented in Table (5.4.2).

Table 5.4.2: Progress of average rainfall from pentads P-25 to P- 61(May 1- Nov.1) in Vellanikkara, 1983-2016

Pentad	Increase in rainfall (mm) from the previous pentad	Pentad	Increase in rainfall(mm) from the previous pentad	Pentad	Increase in rainfall(mm) from the previous pentad
p-26	33.16	p-38	88.69	p-50	54.54
p-27	22.88	p-39	108.76	p-51	41.87
p-28	32.92	p-40	127.5	p-52	45.79
p-29	28.85	p-41	93.85	p-53	38.27
p-30	49.65	p-42	93.68	p-54	41.50
p-31	68.82	p-43	88.87	p-55	48.64
p-32	114.83	p-44	89.04	p-56	60.56
p-33	128.7	p-45	75.63	p-57	49.46
p-34	117.96	p-46	71.59	p-58	43.6
p-35	121.46	p-47	53.82	p-59	50.79
p-36	114.55	p-48	46.87	p-60	41.3
p-37	128.68	p-49	62.24	p-61	42.74

Pentad P-56 to P-73, October- November- December

Pentad rain averaged for 34 years in this season fall from 60.6 mm in p -56 to 0.8 mm in p -71. The peak rainfall in this period was 359.7 mm in p -56, during 2004 and the least value 0.0 mm occur in several pentads.

Table 5.4.1d: Average pentad (P56-P73) rainfall(mm) over 34 years from 1983 to 2016 in Vellanikkara

p-56	p-57	p-58	p-59	p-60	p-61	p-62	p-63	p-64
60.6	49.5	43.6	50.8	41.3	42.7	27.0	28.8	10.9
p-65	p-66	p-67	p-68	p-69	p-70	p-71	p-72	p-73
16.9	8.8	2.4	3.8	6.1	4.8	0.8	1.2	2.2

Rainy pentads in Vellanikkara

A detailed study of the rainy pentads in Vellanikkara region showed that, on an average the number of rainy pentads in a year is 7 and the average number of days with more than 25 mm rainfall per day is 20. The details of rainy pentads and the number of days with more than 25 mm rainfall and the percentage contribution of rainy pentads towards the annual rainfall and peak rainfall pentad are given in table (5.4.4). The pentads in which the rainfall peaks occur is given in Table (5.4.3). It could be seen that on an average, the peak rainfall event occurs in the

30^{th} pentad starting from 5^{th} July to 9^{th} July in the SW monsoon period. The enormous contribution of rainy pentads to annual rainfall shows the importance of the study on rainy pentads in a particular location.

Table 5.4.3: Rainy pentads and the number of days with more than 25 mm rainfall in Vellanikkara

Year	No. of rainy pentads	No. of days with more than 25 mm RF	Peak RF pentad	Peak pentad rainfall (mm)	Year	No. of rainy pentads	No of days with more than 25 mm RF	Peak RF pentad	Peak pentad rainfall (mm)
1983	6	16	45	282.8	2000	6	15	48	213.0
1984	9	25	34	305.0	2001	4	14	33	269.2
1985	6	19	36	360.6	2002	4	9	46	321.8
1986	8	21	36	281.1	2003	6	14	35	285.4
1987	6	12	35	226.2	2004	5	13	32	390.1
1988	9	21	31	286.6	2005	7	26	43	266.0
1989	6	16	35	254.8	2006	9	28	30	449.5
1990	8	22	26	193.9	2007	13	42	37	370.8
1991	8	21	42	323.5	2008	6	18	60	216.8
1992	11	29	32	250.1	2009	6	18	40	333.1
1993	8	21	37	221.2	2010	9	28	33	306.4
1994	11	38	43	282.4	2011	12	31	49	259.1
1995	7	18	33	240.1	2012	4	10	34	190.0
1996	3	10	34	239.4	2013	12	35	35	261.6
1997	6	20	37	348.0	2014	6	18	43	230.2
1998	12	31	37	327.1	2015	4	10	36	203.6
1999	8	18	40	235.8	2016	4	9	39	175.5

Table 5.4.4: Contribution of rainy pentads towards annual rainfall in Vellanikkara, 1983-2016

Year	Rainfall through rainy pentads	Annual rainfall	Contribution of rainy pentads to annual rainfall (%)	Year	Rainfall through rainy pentads	Annual rainfall	Contribution of rainy pentads to annual rainfall (%)
1983	1069.7	2418.2	44.24	2000	1052	2179.3	48.27
1984	1625.2	2544.7	63.87	2001	780.5	2400.1	32.52
1985	1162.6	2617	44.2	2002	836.5	2303.6	36.31
1986	1428.6	2467.9	57.89	2003	1093	2223.0	49.17
1987	1007.4	2414.3	41.73	2004	1322	2962.8	44.62
1988	1538.8	2961.1	51.97	2005	1352.4	2662.9	50.79
1989	1107.3	2538.9	43.61	2006	1966.1	3460.3	56.82
1990	1251.6	2696	46.42	2007	2648.3	3992.4	66.33
1991	1758	3182.3	55.24	2008	1034.2	2406.3	42.98
1992	1999.8	3626.5	55.14	2009	1243.2	2883.3	43.12
1993	1404	2515.9	55.81	2010	1575.2	3018.4	52.19
1994	2138.9	3521.9	60.73	2011	2068.5	3465.3	59.69
1995	1320	2807.6	47.02	2012	632.3	2170.6	29.13
1996	623	2241.4	27.8	2013	2085	3264.5	63.87
1997	1430.7	3044.4	46.99	2014	1108.7	2631.1	42.14
1998	2127.3	3437.7	61.88	2015	678.1	2634.3	25.74
1999	1235.2	2619.6	47.15	2016	600.4	1777.2	33.78

The progressive enhancement of rainfall through different pentads in the active rainy seasons from the month of May 1st to November 1st was computed for each year. The average was found out for the period from 1983 to 2016. The Fig (5.4.2) shows the progressive raise in rainfall through the pentads. In the month of May there was an average increase of 33.49 mm of rainfall as the pentads advanced. But, in June there was a tremendous increase of 111 mm per pentad where as in July it has come down to 106.86 mm per pentad. Again in August, the increase rate through a pentad was 70.97 mm and towards the end of SW monsoon the increase rate of rainfall was 47.37 mm. In the beginning of NE monsoon, it has slightly increased to 48.16 mm per pentad during the month of October.

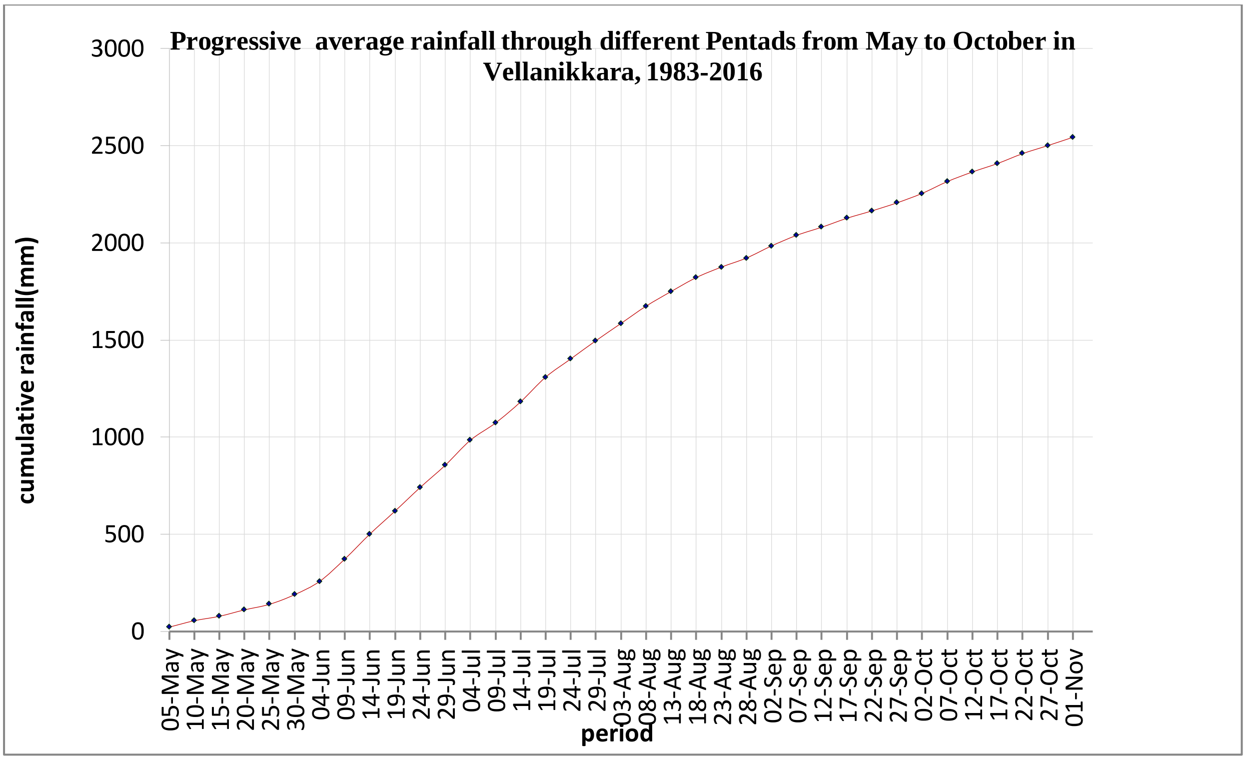


Fig. 5.4.2

Table 5.4.5: Frequency of rainy pentads in different seasons in Vellanikkara region for the period from 1983 to 2016

Season	Frequency of occurrence of rainy pentads in 34 years
P1 – P12 (Winter)	1
P13 – P30 (Summer)	12
P31 – P 55 (SW Monsoon)	213
P56 – P73 (NE Monsoon)	22
Total	248

Table 5.4.5 shows that the occurrence of rainy pentads were highest (213) in the SW Monsoon period. In post monsoon period it was very low (22), but higher than the summer season. In winter there was only one rainy pentad during the period 1983-2016.

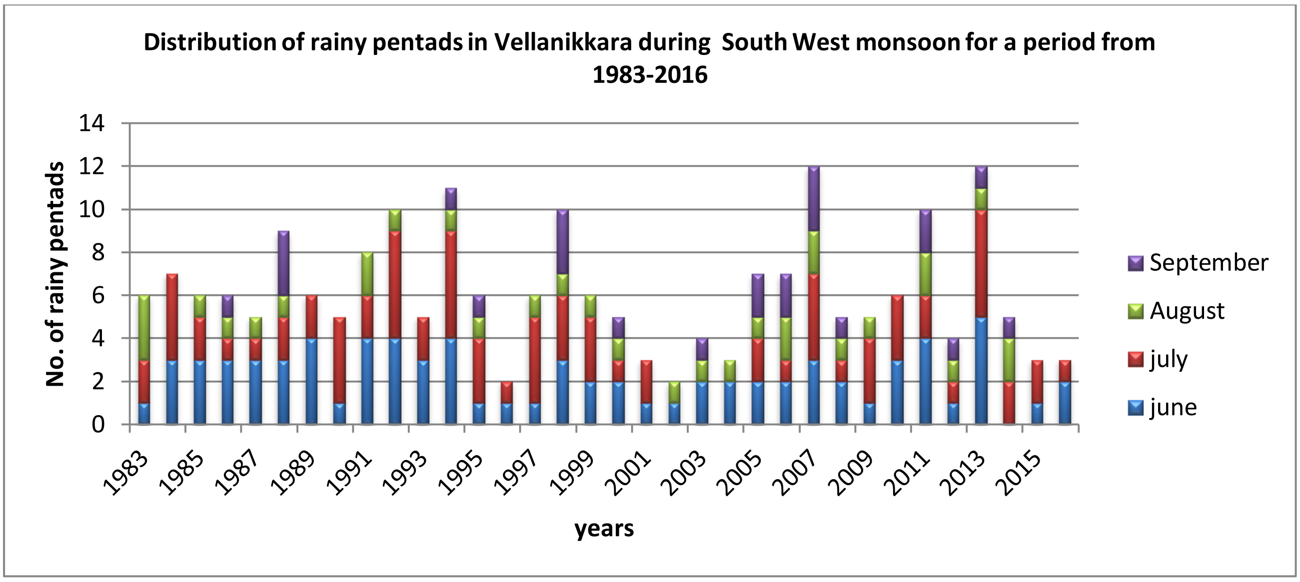


Fig. 5.4.3

Table 5.4.6: Frequency of rainy pentads in different months in Vellanikkara region for the period from 1983 to 2016

Month	Pentads	Frequency of rainy pentads in 34 years
January	P1 – P6	0
February	P7 – P12	1
March	P13 – P18	0
April	P19 – P24	2
May	P25 – P30	10
June	P31 – P36	78
July	P37 – P42	76
August	P43 – P48	32
September	P49 – P55	27
October	P56 – P60	14
November	P61 – P67	8
December	P68 – P73	0

From a detailed study of rainy pentads distributed over different months it was found that the highest number of rainy pentads were recorded in the month of June (78) followed by July (76). August was ranked 3rd (32) and in September there were 27 rainy pentads followed by October with 14. Then came the summer rainy pentads in May (10) and then the post monsoon rainy pentads in November (8). During the month of December, January and March there was no rainy pentad in any of the years under the study period from 1983 to 2016. And it was negligibly small in February (1) and April (2).

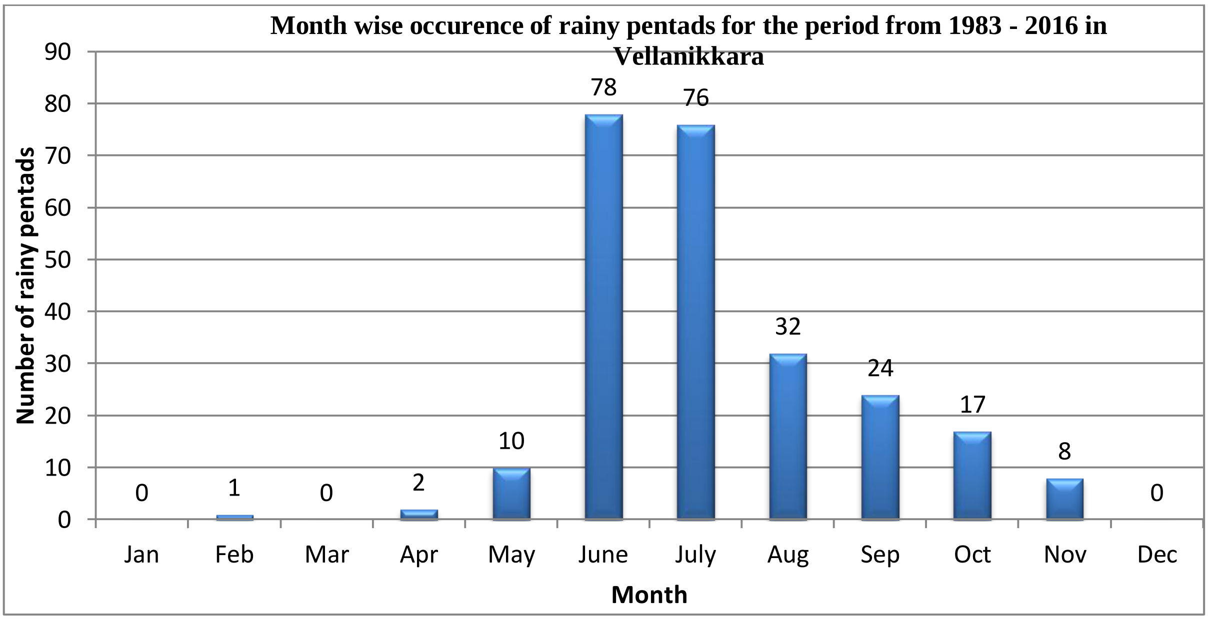


Fig. 5.4.4

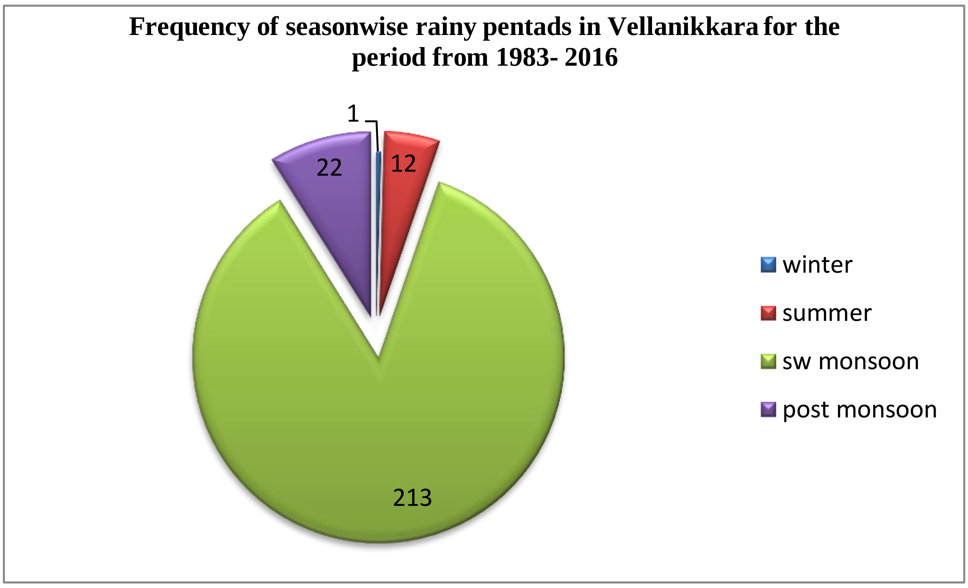


Fig. 5.4.5

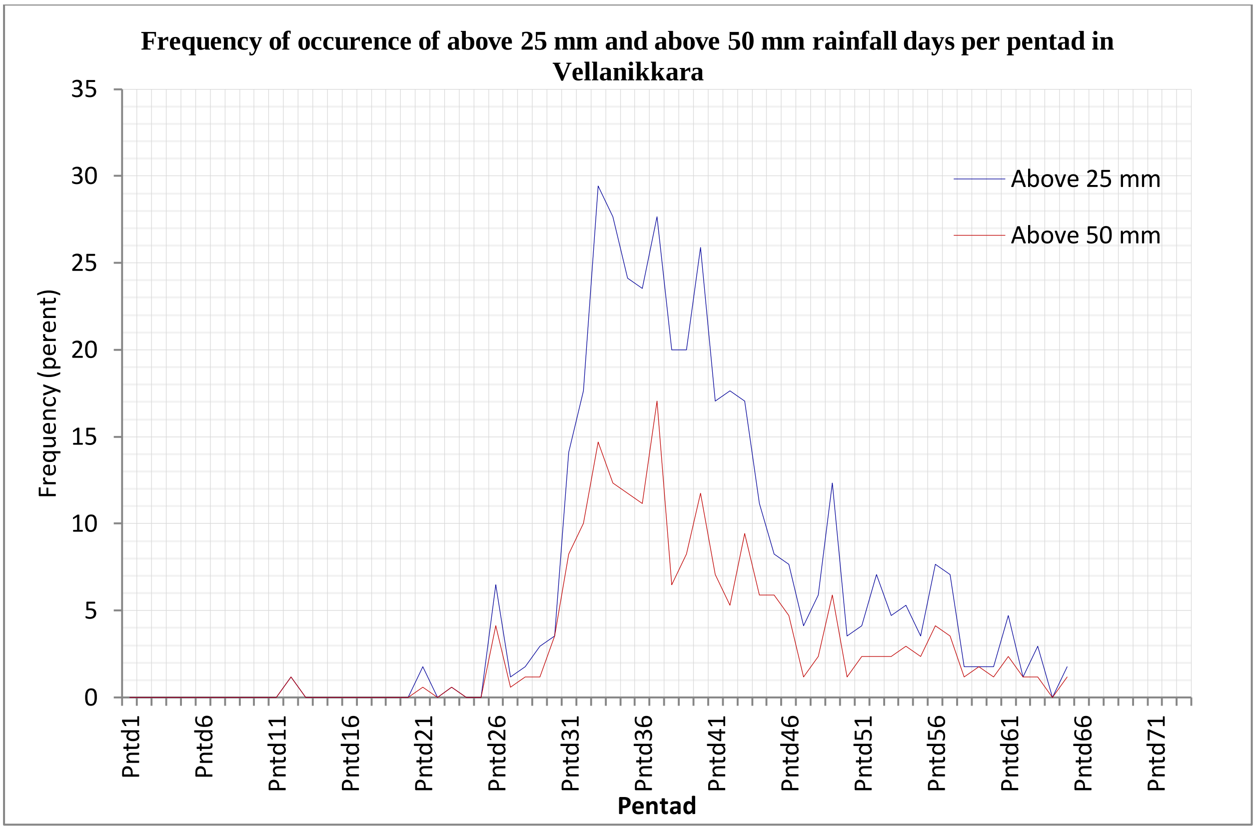


Fig. 5.4.6

The frequency percentage of rainy pentads and occurrence of rainy days with more than 25 mm above and 50 mm above rainfall in a pentad were very small in post monsoon season, zero in winter season and negligibly small in pre monsoon periods. On an average, around 35 pentads recorded an average pentad rainfall of less than 1 mm in a year which is an indication of dry pentads.

Probability distributions identified as best fit to pentad climatic variables

In each pentad, the number of days receiving more than 25 mm rainfall was noticed and the total frequency for all the pentads was computed for all the years. The most suitable distribution selected as a best fit to this series of data was Negative Binomial (2). If the number of pentads with less than 25 mm of rainfall was counted before getting a successful pentad with 25 mm or more rainfall, negative binomial distribution can be considered. The pentad in a year which received maximum rainfall was also identified. It follows Fisher Tippett (2) distribution. The peak rainfall obtained in a year for the pentad-wise data were also recorded. It follows the GEV distribution. The results are shown in Table 5.4.7 to Table 5.4.26 and Fig. 5.4.7 – Fig. 5.4.11.

Table 5.4.7: Fit summary for frequency of above 25 mm rainfall in a year

Distribution	p-value	Distribution	p-value
Negative binomial (1)	0.009	GEV	0.898
Negative binomial (2)	**0.938**	Gumbel	0
Chi-square	0.568	Log-normal	0.838
Erlang	0.037	Logistic	0.755
Exponential	0	Normal	0.381
Fisher-Tippett (1)	0	Normal (Standard)	0
Fisher-Tippett (2)	0.913	Poisson	0
Gamma (1)	0	Student	0
Gamma (2)	0.867	Weibull (2)	0.516
The distribution that fits best the data for the goodness of fit test is the Negative binomial (2) distribution.			

Table 5.4.8: Estimated parameters (Negative binomial (2))

Parameter	Value	Standard error
k	9.029	0.116
p	2.268	0.121

Table 5.4.9: Log-likelihood statistics

Log-likelihood(LL)	-118.132
BIC(LL)	243.318
AIC(LL)	240.265

Table 5.4.10: Statistics estimated on the input data and computed using the estimated parameters of the Negative binomial (2) distribution

Statistic	Data	Parameters
Mean	20.471	20.474
Variance	71.226	66.903
Skewness (Pearson)	0.688	0.677
Kurtosis (Pearson)	-0.241	0.679

Table 5.4.11: Chi-square test

Chi-square (Observed value)	9.200
Chi-square (Critical value)	14.067
DF	7
p-value (Two-tailed)	0.239
alpha	0.05

Table 5.4.12: Comparison between the observed and theoretical frequencies of rainy pentads

Class	Lower bound	Upper bound	Frequency (Data)	Frequency (Distribution)	Chi-square
1	0.000	4.300	0	0.155	0.155
2	4.300	8.600	0	1.365	1.365
3	8.600	12.900	6	3.937	1.080
4	12.900	17.200	6	7.989	0.495
5	17.200	21.500	11	6.732	2.705
6	21.500	25.800	2	5.463	2.195
7	25.800	30.100	4	4.433	0.042
8	30.100	34.400	2	1.957	0.001
9	34.400	38.700	2	1.042	0.880
10	38.700	43.000	1	0.592	0.281

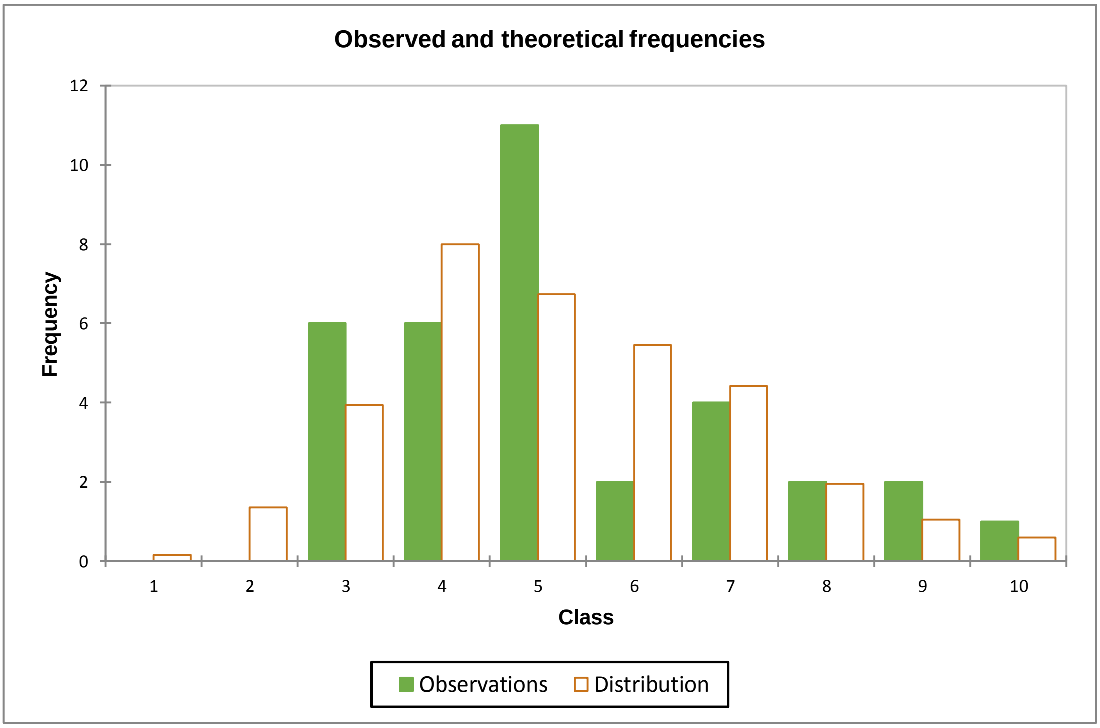


Fig. 5.4.7

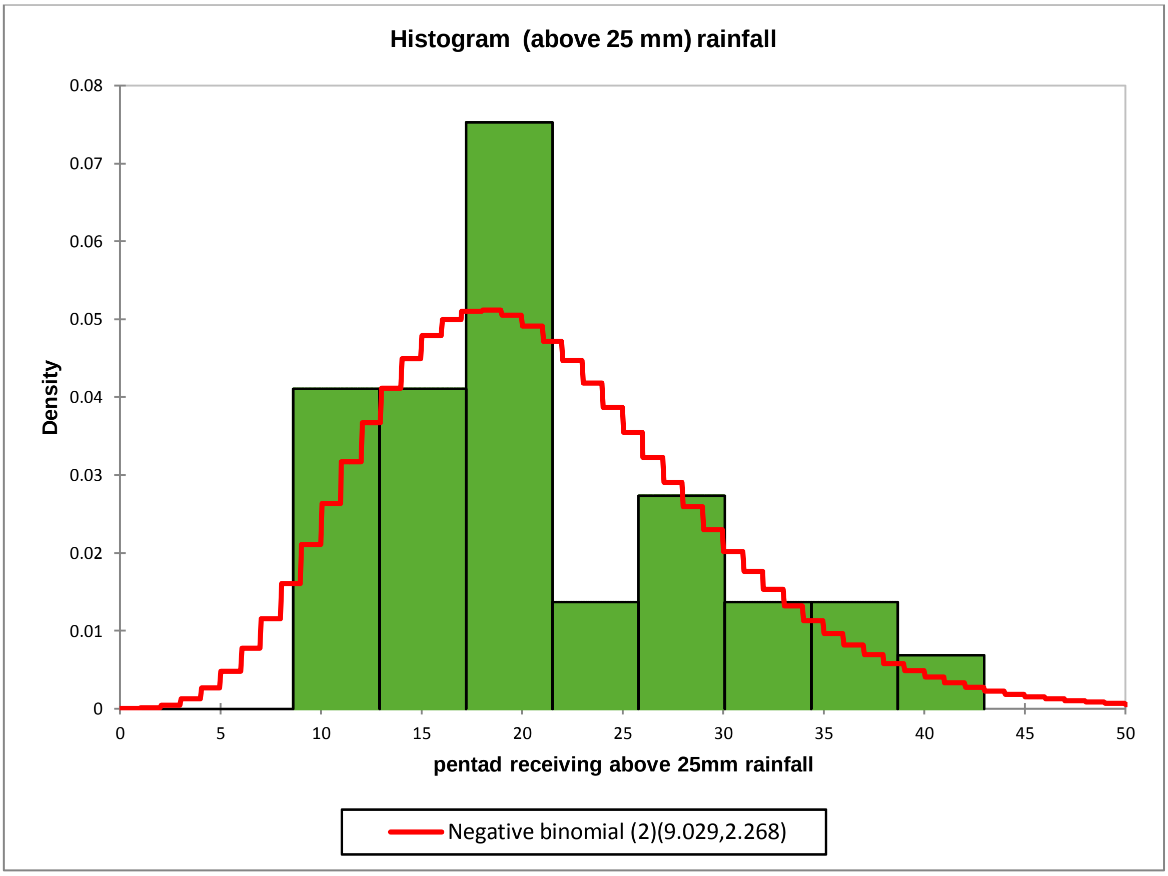


Fig. 5.4.8

Table 5.4.13: Descriptive statistics for the intervals (above 25 mm rainfall)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
0	4.3	0	0.000	0.000	0.005
4.3	8.6	0	0.000	0.000	0.040
8.6	12.9	6	0.176	0.041	0.116
12.9	17.2	6	0.176	0.041	0.235
17.2	21.5	11	0.324	0.075	0.198
21.5	25.8	2	0.059	0.014	0.161
25.8	30.1	4	0.118	0.027	0.130
30.1	34.4	2	0.059	0.014	0.058
34.4	38.7	2	0.059	0.014	0.031
38.7	43	1	0.029	0.007	0.017

Table 5.4.14: Fit summary for peak rainfall pentad

Distribution	p-value	Distribution	p-value
Beta4	0.393	GEV	0.511
Negative binomial (1)	0	Gumbel	0
Negative binomial (2)	0.043	Log-normal	0.258
Chi-square	0.21	Logistic	0.351
Erlang	0.324	Normal	0.122
Exponential	0	Normal (Standard)	0
Fisher-Tippett (1)	0	Poisson	0
Fisher-Tippett (2)	**0.538**	Student	0
Gamma (1)	0	Weibull (2)	0.133
Gamma (2)	0.201		
The distribution that fits best the data for the goodness of fit test is the Fisher-Tippett (2) distribution.			

Table 5.4.15: Estimated parameters (Fisher-Tippett (2)

Parameter	Value	Standard error
beta	5.022	0.906
µ	34.958	0.656

Table 5.4.16: Log-likelihood statistics

Log-likelihood(LL)	-108.259
BIC(LL)	223.570
AIC(LL)	220.518

Table 5.4.17: Statistics estimated on the input data and computed using the estimated parameters of the Fisher-Tippett (2) distribution

Statistic	Data	Parameters
Mean	37.824	37.857
Variance	43.059	41.482
Skewness (Pearson)	1.179	1.140
Kurtosis (Pearson)	1.888	2.400

Table 5.4.18: Chi-square test

Chi-square (Observed value)	5.041
Chi-square (Critical value)	14.067
DF	7
p-value (Two-tailed)	0.655
alpha	0.05

Table 5.4.19: Comparison between the observed and theoretical frequencies of peak rainfall pentad

Class	Lower bound	Upper bound	Frequency (Data)	Frequency (Distribution)	Chi-square
1	20.000	24.100	0	0.006	0.006
2	24.100	28.200	1	0.724	0.105
3	28.200	32.300	4	5.495	0.407
4	32.300	36.400	13	9.829	1.023
5	36.400	40.500	7	8.348	0.218
6	40.500	44.600	4	4.961	0.186
7	44.600	48.700	3	2.503	0.099
8	48.700	52.800	1	1.173	0.026
9	52.800	56.900	0	0.532	0.532
10	56.900	61.000	1	0.238	2.440

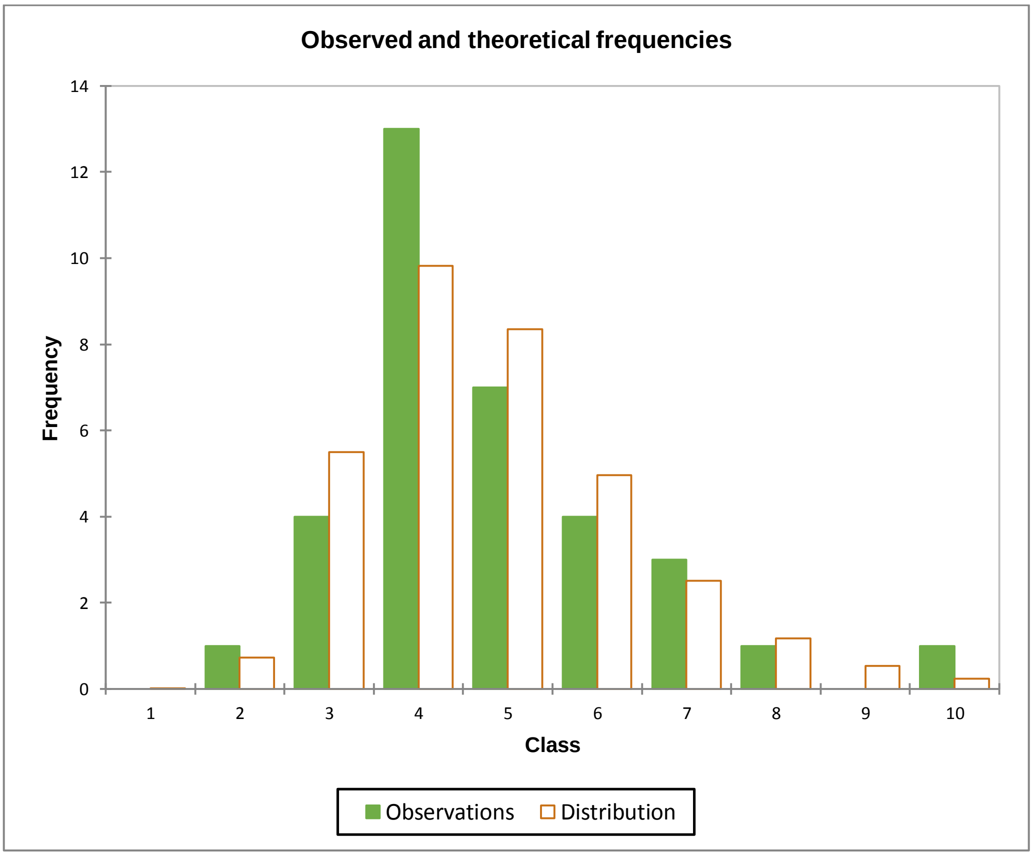


Fig. 5.4.9

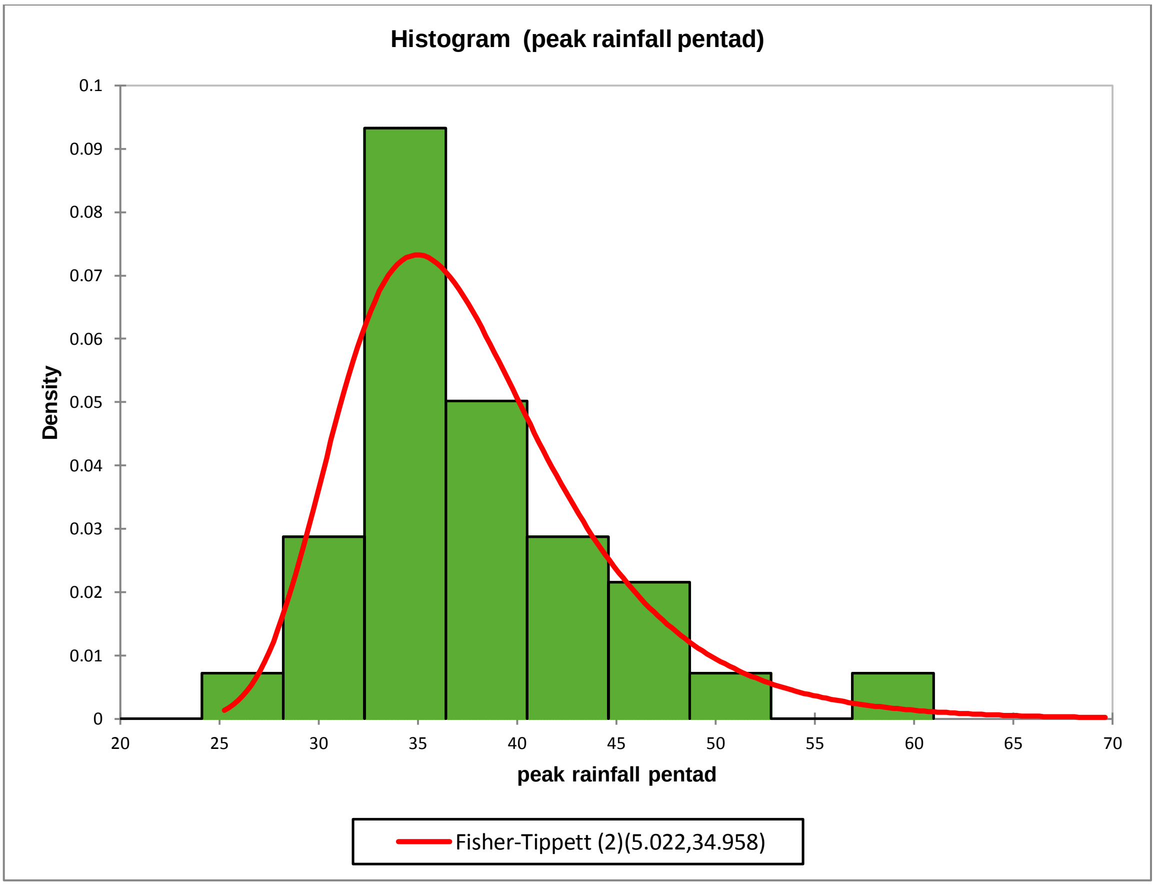


Fig. 5.4.10

Table 5.4.20: Descriptive statistics for the intervals (peak rainfall pentad)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
20	24.1	0	0.000	0.000	0.000
24.1	28.2	1	0.029	0.007	0.021
28.2	32.3	4	0.118	0.029	0.162
32.3	36.4	13	0.382	0.093	0.289
36.4	40.5	7	0.206	0.050	0.246
40.5	44.6	4	0.118	0.029	0.146
44.6	48.7	3	0.088	0.022	0.074
48.7	52.8	1	0.029	0.007	0.035
52.8	56.9	0	0.000	0.000	0.016
56.9	61	1	0.029	0.007	0.007

Table 5.4.21: Fit summary for peak pentad rainfall quantity

Distribution	p-value	Distribution	p-value
Beta4	0.995	Gumbel	0
Chi-square	0.013	Log-normal	0.995
Erlang	0.838	Logistic	0.984
Exponential	0	Normal	0.757
Fisher-Tippett (1)	0	Normal (Standard)	0
Fisher-Tippett (2)	0.995	Student	0
Gamma (1)	0	Weibull (1)	0
Gamma (2)	0.962	Weibull (2)	0.581
GEV	**0.998**		
The distribution that fits best the data for the goodness of fit test is the GEV distribution.			

Table 5.4.22: Estimated parameters(GEV)

Parameter	Value	Standard error
k	-0.054	0.123
beta	51.009	0.596
µ	249.368	0.281

Table 5.4.23: Log-likelihood statistics

Log-likelihood(LL)	-186.414
BIC(LL)	383.408
AIC(LL)	378.829

Table 5.4.24: Statistics estimated on the input data and computed using the estimated parameters of the GEV distribution

Statistic	Data	Parameters
Mean	276.491	276.221
Variance	3857.040	3755.786
Skewness (Pearson)	0.652	0.009
Kurtosis (Pearson)	0.038	305211.989

Table 5.4.25: Kolmogorov-Smirnov test

D	0.063
p-value (Two-tailed)	0.998
alpha	0.05

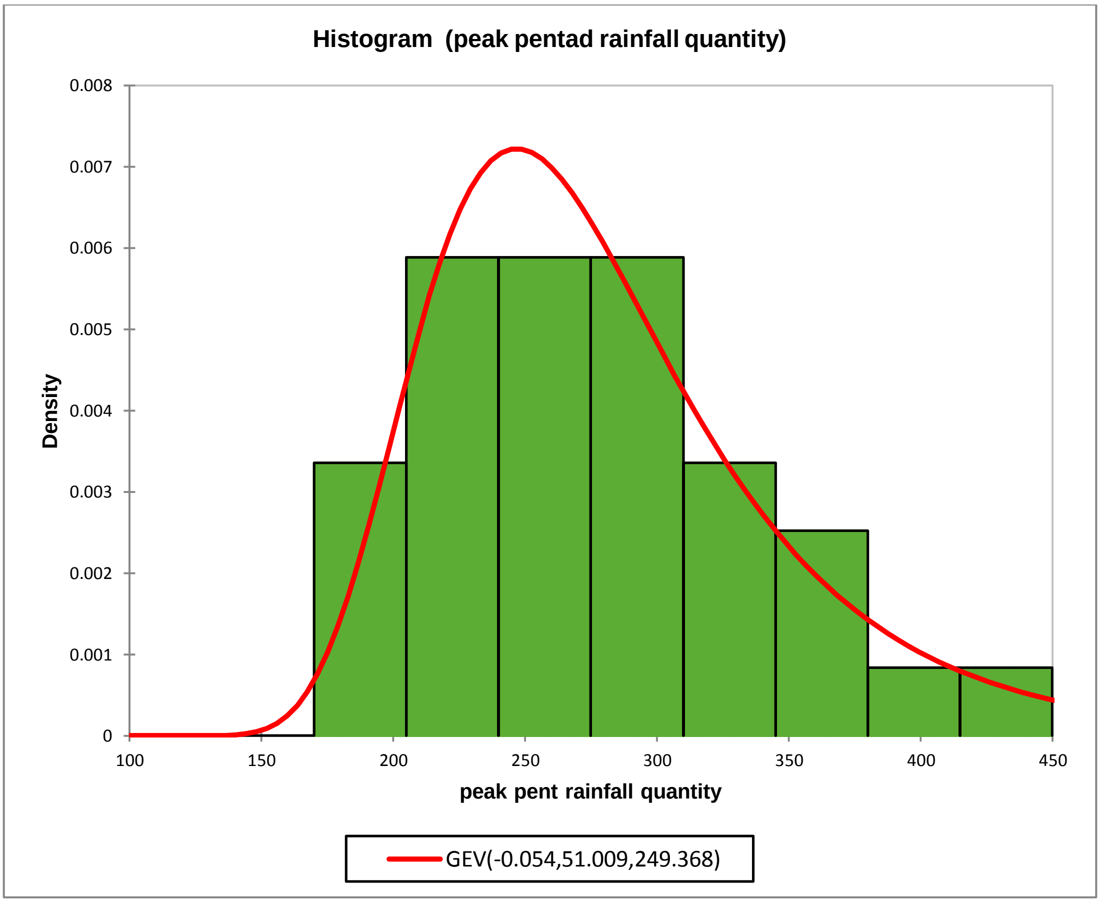


Fig. 5.4.11

Table 5.4.26: Descriptive statistics for the intervals (peak pentad rainfall quantity)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
100	135	0	0.000	0.000	0.000
135	170	0	0.000	0.000	0.006
170	205	4	0.118	0.003	0.081
205	240	7	0.206	0.006	0.213
240	275	7	0.206	0.006	0.243
275	310	7	0.206	0.006	0.185
310	345	4	0.118	0.003	0.117
345	380	3	0.088	0.003	0.068
380	415	1	0.029	0.001	0.038
415	450	1	0.029	0.001	0.021

Pentad analysis of different climatic variables in Vellanikkara

The movement of different climatic variables over different pentads in Vellanikkara was examined in detail. The line curves are shown for each variable separately from Fig. 5.4.7 - 5.4.11.

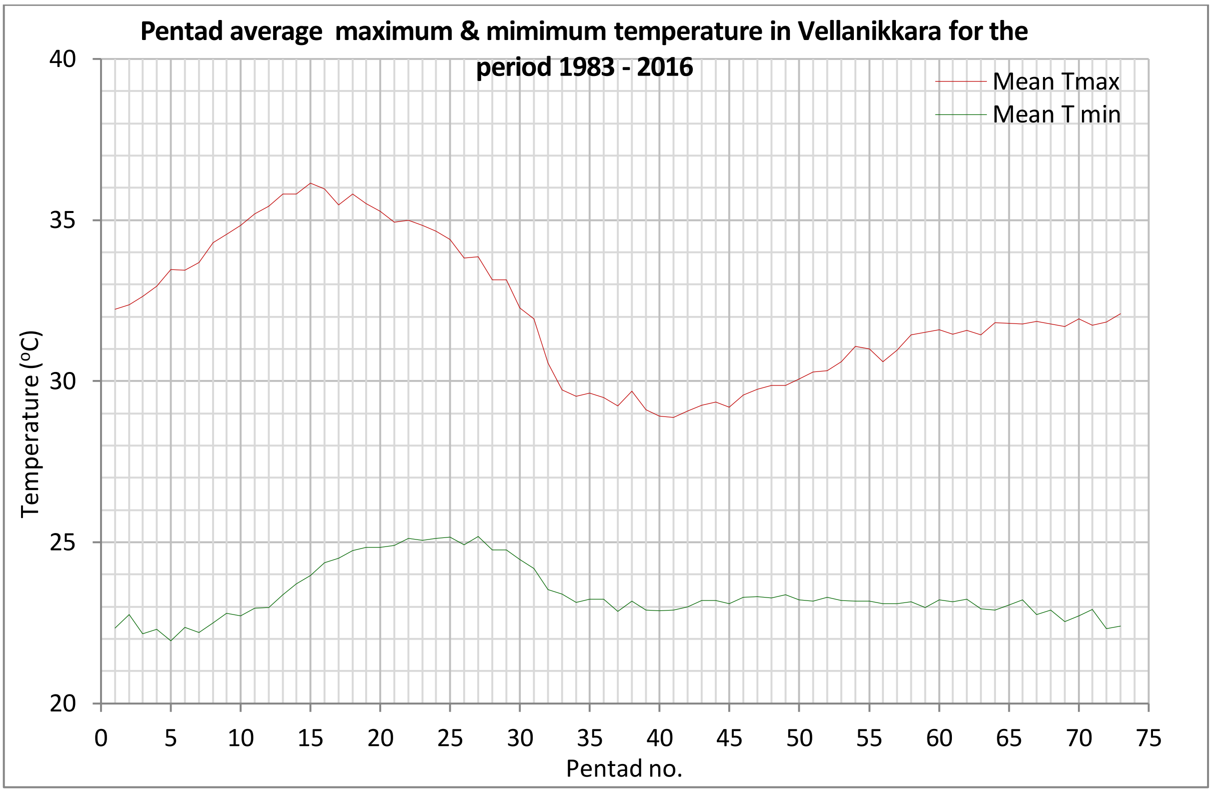


Fig. 5.4.12

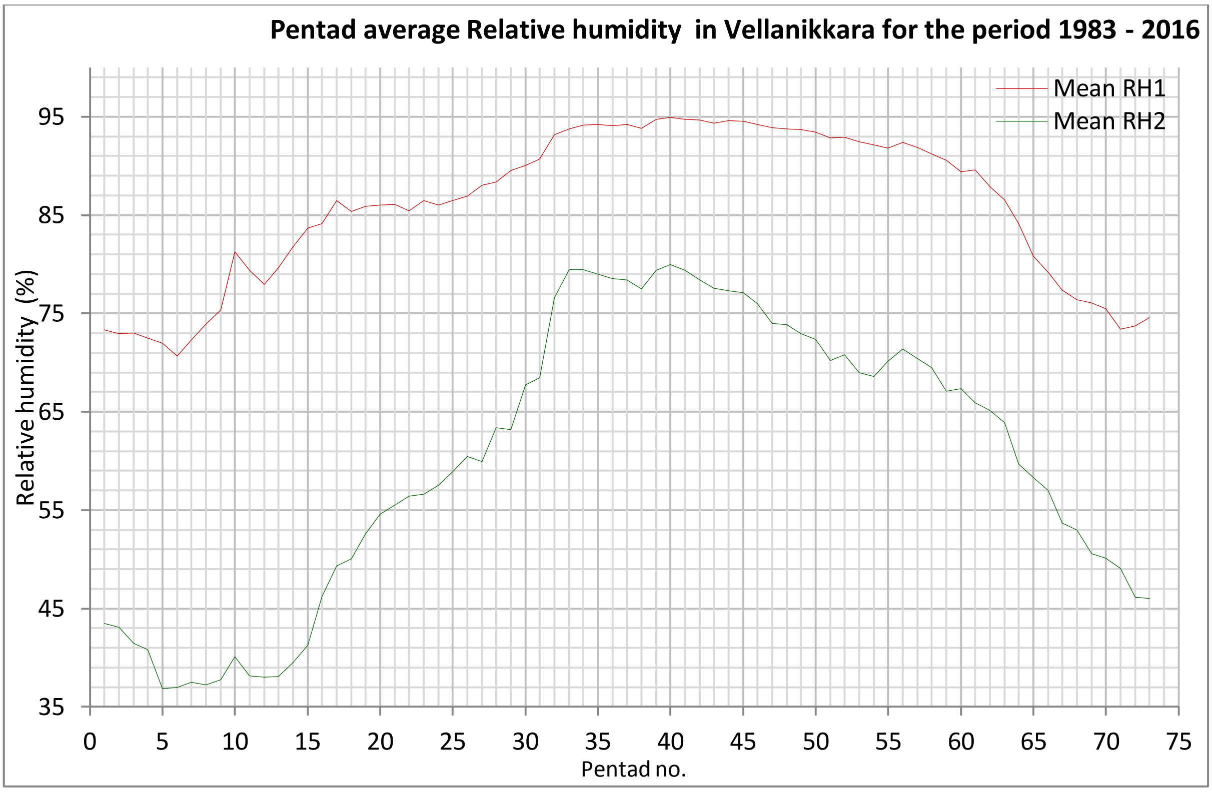


Fig. 5.4.13

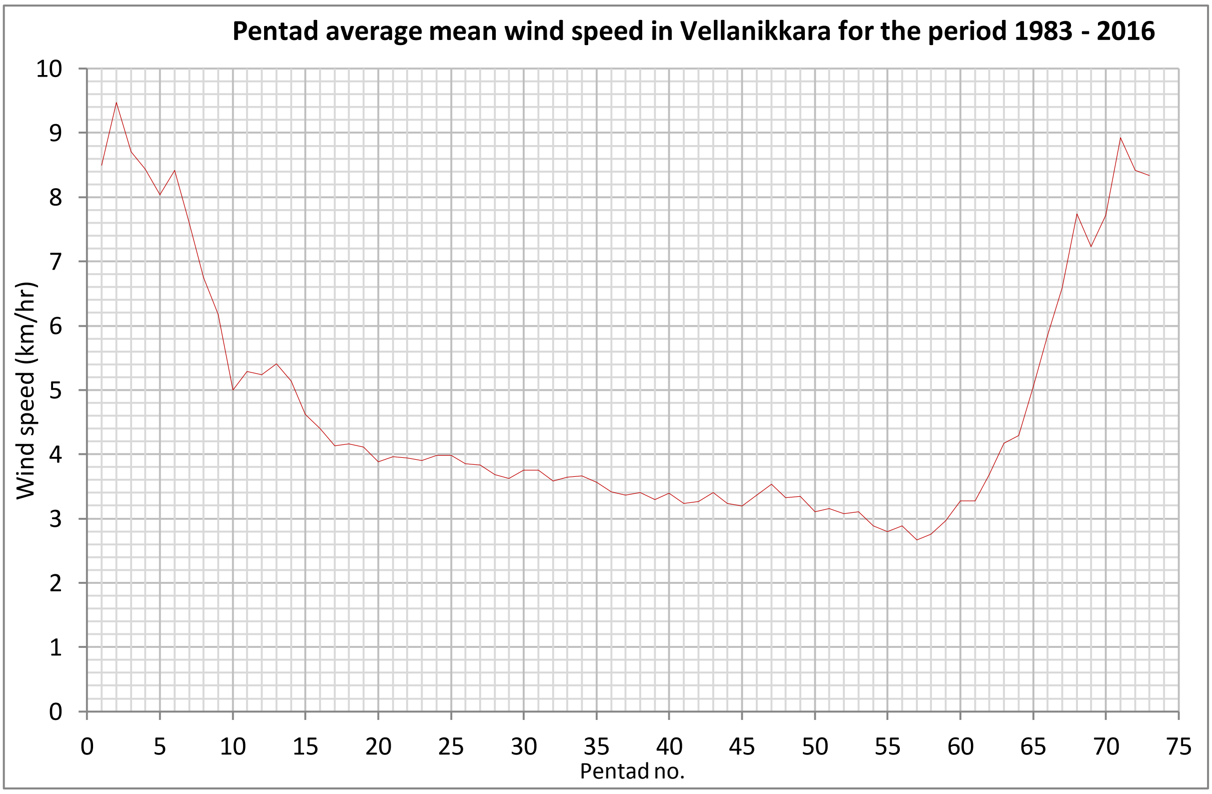


Fig. 5.4.14

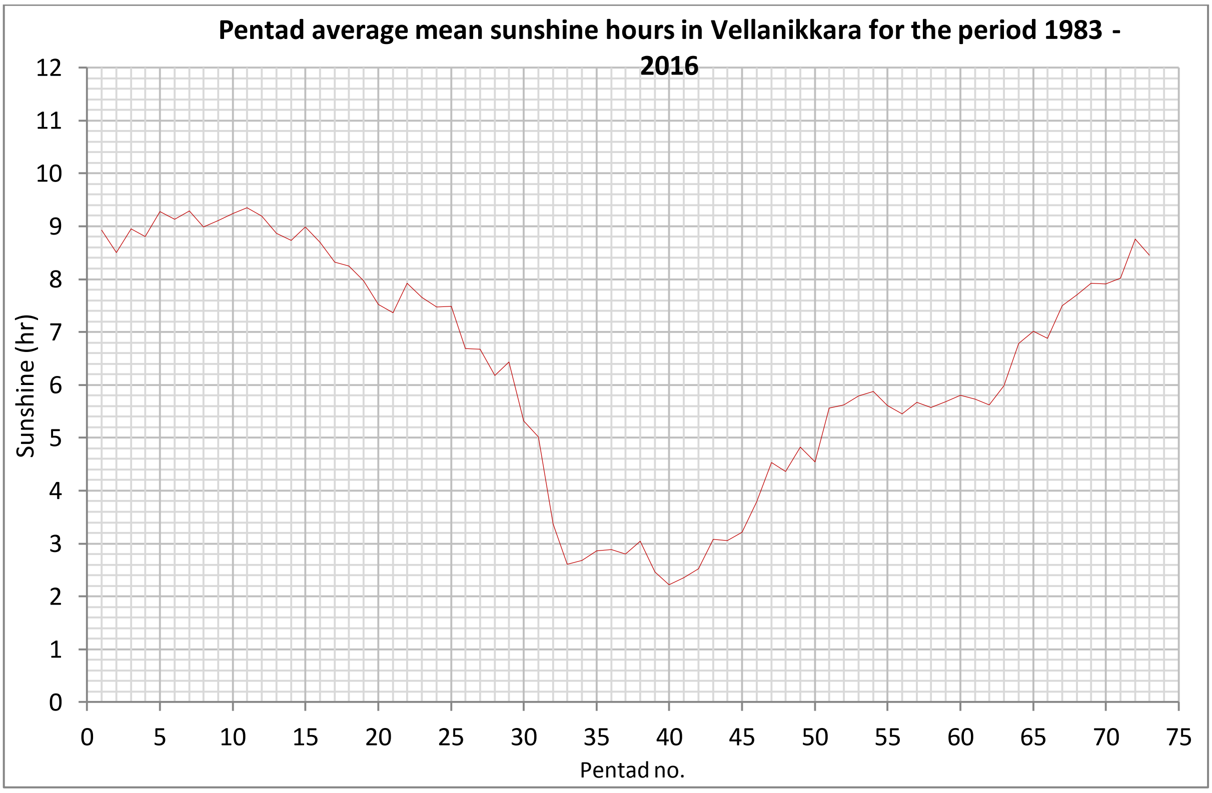


Fig. 5.4.15

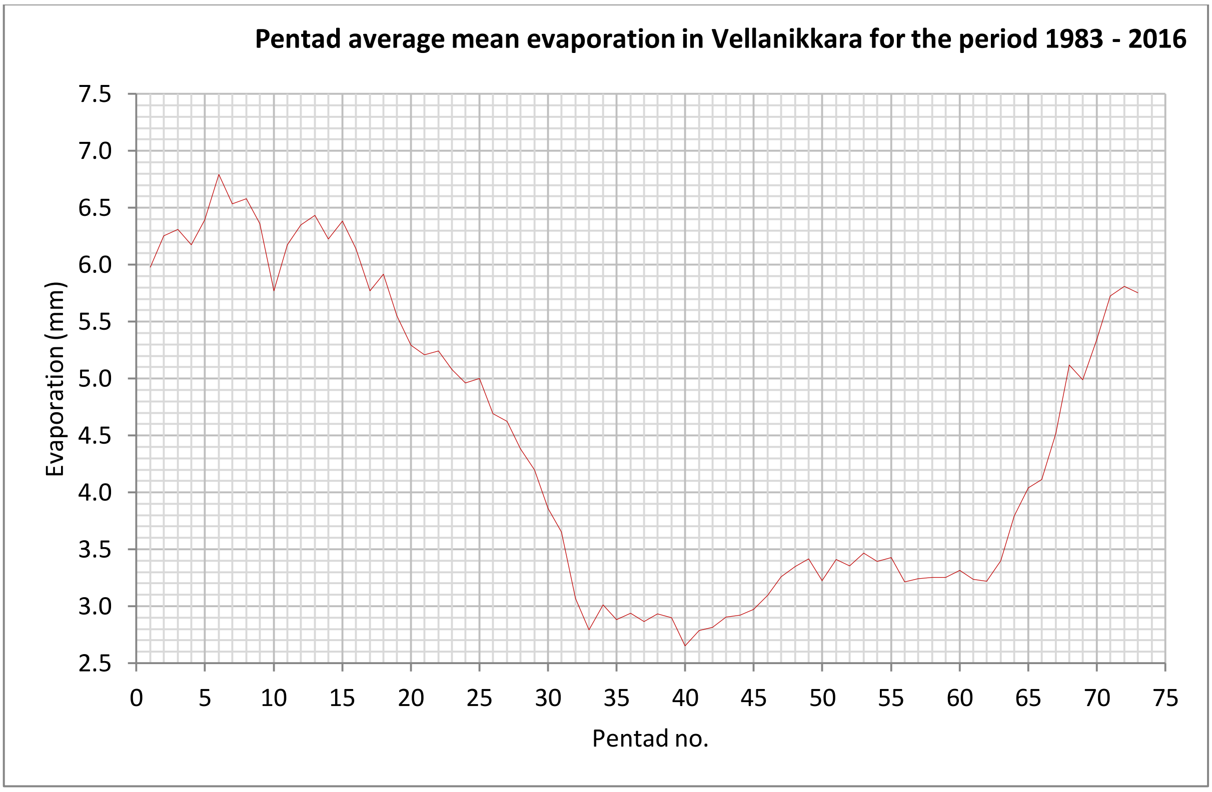


Fig. 5.4.16

Trend in pentad distribution of climatic variables in Vellanikkara

The significance of presence of trend in the pentad values of different climatic variables in Vellanikkara has been tested and the summary statistics are furnished in Tables 5.4.7 to 5.4.14. There was a significant positive trend for total rainfall in pentad 51 *ie* in the month of September which was evident from the monthly trend test and p - 51 is from 8th September to 12th September. These type of trend detections for minute intervals are possible only through pentad analysis of climatic variables.

There was a significant positive trend in minimum temperature during the pentads p-2, p-13, p-14, p-29 and p- 65 *ie* during January 6th – 10th, March 2nd - 6th, March 7th -11th, May 21st - 25th and November 17th – 21st and negative significant trends in p - 48 *ie* during August 24th – 28th.

The maximum temperature showed significant positive trend in p -2, p - 45, p - 46, p-47 *ie* during January 6th – 10th, August 9th -13th, August 14th – 18th, August 19th – 23rd and significant negative trends also were shown during p-14, p-18, p-19, p-21, p-25, p-26, p-27, p-28 and in p-29.

Table 5.4.27 Summary statistics of trend test of pentad total Rainfall in Vellanikkara

Pentad	Kendall's tau	p-value	Sen's slope	Pentad	Kendall's tau	p-value	Sen's slope
1	-0.284	0.101	0.000	38	-0.068	0.556	-0.492
2	-0.140	0.359	0.000	39	0.109	0.374	0.912
3	*	*	0.000	40	-0.070	0.573	-0.900
4	-0.009	0.976	0.000	41	-0.075	0.495	-0.743
5	*	*	0.000	42	0.016	0.906	0.192
6	0.081	0.610	0.000	43	-0.055	0.657	-0.440
7	0.058	0.773	0.000	44	0.098	0.423	0.631
8	0.026	0.905	0.000	45	-0.055	0.618	-0.294
9	0.147	0.388	0.000	46	-0.182	0.134	-1.415
10	-0.105	0.528	0.000	47	-0.077	0.533	-0.361
11	-0.008	0.982	0.000	48	0.038	0.767	0.069
12	-0.010	0.961	0.000	49	0.088	0.477	0.300
13	-0.121	0.431	0.000	50	0.114	0.350	0.679
14	-0.047	0.763	0.000	51	0.258	**0.015**	0.683
15	0.303	0.089	0.000	52	0.109	0.436	0.400
16	0.071	0.628	0.000	53	0.022	0.870	0.007
17	0.115	0.419	0.000	54	-0.134	0.341	-0.400
18	-0.075	0.592	0.000	55	-0.025	0.847	-0.100
19	0.068	0.612	0.000	56	-0.122	0.320	-0.422
20	0.045	0.735	0.000	57	-0.066	0.593	-0.400
21	0.014	0.926	0.000	58	0.068	0.583	0.258
22	-0.004	0.985	0.000	59	0.095	0.441	0.594
23	-0.034	0.797	0.000	60	-0.213	0.080	-0.760
24	0.073	0.568	0.000	61	-0.083	0.269	-0.257
25	0.177	0.164	0.067	62	-0.136	0.266	-0.144
26	0.047	0.721	0.000	63	0.036	0.778	0.035
27	0.032	0.640	0.000	64	0.044	0.720	0.000
28	0.084	0.502	0.096	65	-0.043	0.756	0.000
29	-0.099	0.130	-0.080	66	0.075	0.565	0.000
30	0.132	0.279	0.592	67	0.113	0.460	0.000
31	-0.039	0.801	-0.275	68	0.130	0.338	0.000
32	0.068	0.583	0.900	69	0.014	0.931	0.000
33	0.059	1.000	0.614	70	-0.038	0.796	0.000
34	-0.005	0.976	-0.100	71	0.053	0.753	0.000
35	0.000	1.000	0.000	72	-0.310	0.083	0.000
36	-0.039	0.756	-0.622	73	0.111	0.435	0.000
37	0.020	0.882	0.156				

* Denote average rainfall =0 in the pentad

Table 5.4.28 Summary statistics of trend test of pentad average of minimum temperature in Vellanikkara

Pentad	Kendall's tau	p-value	Sen's slope	Pentad	Kendall's tau	p-value	Sen's slope
1	-0.125	0.306	-0.027	38	-0.061	0.489	-0.007
2	0.253	**0.010**	0.040	39	-0.082	0.505	-0.010
3	-0.041	0.744	-0.006	40	0.111	0.366	0.010
4	-0.234	0.054	-0.043	41	0.155	0.202	0.015
5	0.107	0.382	0.021	42	-0.039	0.755	-0.004
6	0.123	0.209	0.015	43	-0.152	0.213	-0.019
7	0.191	0.116	0.044	44	-0.050	0.689	-0.005
8	0.055	0.657	0.013	45	0.102	0.356	0.011
9	0.036	1.000	0.006	46	0.057	0.646	0.007
10	0.005	0.976	0.001	47	0.039	0.679	0.003
11	0.036	0.778	0.004	48	-0.113	< **0.0001**	-0.010
12	0.016	0.906	0.005	49	-0.130	0.286	-0.017
13	0.284	**0.019**	0.042	50	0.027	0.836	0.003
14	0.295	**0.015**	0.038	51	-0.170	0.163	-0.014
15	0.088	0.224	0.015	52	0.014	0.917	0.002
16	-0.100	0.415	-0.010	53	0.032	0.781	0.003
17	0.209	0.094	0.029	54	-0.136	0.266	-0.010
18	0.226	0.064	0.019	55	0.048	0.637	0.004
19	0.116	0.342	0.012	56	-0.195	0.109	-0.016
20	0.064	0.604	0.007	57	-0.020	0.856	-0.002
21	-0.036	0.778	-0.004	58	0.186	0.127	0.019
22	0.130	0.117	0.015	59	0.147	0.229	0.012
23	0.059	0.635	0.009	60	0.139	0.054	0.016
24	0.000	1.000	0.000	61	0.068	0.583	0.006
25	-0.144	0.090	-0.013	62	-0.020	0.819	-0.003
26	-0.114	0.350	-0.015	63	0.093	0.449	0.008
27	-0.095	0.441	-0.010	64	0.197	0.106	0.026
28	-0.122	0.320	-0.017	65	0.144	**0.004**	0.025
29	0.127	**0.011**	0.013	66	0.136	0.387	0.018
30	-0.039	0.756	-0.006	67	0.029	0.821	0.004
31	0.061	0.625	0.010	68	-0.109	0.374	-0.016
32	0.077	0.384	0.009	69	0.027	0.836	0.004
33	0.018	0.894	0.002	70	0.045	0.722	0.012
34	0.116	0.343	0.017	71	0.093	0.327	0.017
35	0.043	0.733	0.005	72	-0.077	0.534	-0.020
36	0.004	0.988	0.000	73	-0.086	0.393	-0.016
37	0.111	0.074	0.009				

Table 5.4.29 Summary statistics of trend test of pentad average of maximum temperature in Vellanikkara

Pentad	Kendall's tau	p-value	Sen's slope	Pentad	Kendall's tau	p-value	Sen's slope
1	0.148	0.224	0.015	38	0.079	0.524	0.011
2	0.159	**0.050**	0.016	39	0.007	0.964	0.000
3	-0.038	0.767	-0.004	40	-0.016	0.906	-0.004
4	0.055	0.656	0.006	41	0.123	0.313	0.027
5	-0.034	0.790	-0.007	42	0.066	0.593	0.009
6	-0.130	0.286	-0.016	43	-0.007	0.965	-0.002
7	-0.221	0.068	-0.029	44	0.116	0.343	0.018
8	-0.013	0.929	-0.002	45	0.211	**0.037**	0.040
9	-0.086	0.343	-0.012	46	0.267	**0.028**	0.040
10	0.002	1.000	0.000	47	0.408	< **0.0001**	0.051
11	-0.014	0.882	-0.001	48	0.155	0.088	0.020
12	-0.043	0.789	-0.009	49	0.050	0.600	0.009
13	-0.173	0.155	-0.024	50	-0.005	0.976	-0.001
14	-0.213	**0.008**	-0.038	51	-0.032	0.773	-0.008
15	-0.114	0.350	-0.019	52	-0.180	0.138	-0.032
16	-0.061	0.625	-0.010	53	0.016	0.906	0.004
17	-0.134	0.273	-0.027	54	0.102	0.406	0.020
18	-0.240	**0.049**	-0.045	55	0.109	0.374	0.023
19	-0.245	**0.044**	-0.048	56	0.188	0.123	0.035
20	-0.168	0.168	-0.024	57	0.114	0.195	0.023
21	-0.276	**0.022**	-0.037	58	0.148	0.178	0.028
22	-0.225	0.064	-0.034	59	-0.009	0.953	-0.003
23	-0.100	0.415	-0.018	60	-0.156	0.070	-0.026
24	-0.193	0.113	-0.038	61	0.055	0.544	0.010
25	-0.382	**0.002**	-0.064	62	-0.002	1.000	0.000
26	-0.244	**0.044**	-0.061	63	0.216	0.075	0.036
27	-0.350	**0.004**	-0.070	64	0.127	0.199	0.016
28	-0.265	**0.020**	-0.044	65	0.032	0.801	0.004
29	-0.234	**0.001**	-0.047	66	-0.082	0.504	-0.006
30	-0.155	0.202	-0.039	67	-0.023	0.843	-0.004
31	-0.057	0.646	-0.015	68	0.150	0.338	0.018
32	-0.054	0.667	-0.010	69	0.091	0.458	0.012
33	0.018	0.880	0.004	70	-0.073	0.553	-0.008
34	0.120	0.328	0.020	71	-0.184	0.130	-0.020
35	0.029	0.824	0.005	72	0.086	0.486	0.014
36	0.113	0.358	0.026	73	-0.095	0.476	-0.016
37	0.087	0.477	0.019				

Table 5.4.30: Summary statistics of trend test of pentad average of Sunshine hours in Vellanikkara

Pentad	Kendall's tau	p-value	Sen's slope	Pentad	Kendall's tau	p-value	Sen's slope
1	-0.011	0.926	-0.001	38	-0.127	0.299	-0.030
2	-0.085	0.485	-0.016	39	-0.250	**0.041**	-0.058
3	0.000	1.000	0.000	40	-0.070	0.566	-0.020
4	0.142	0.245	0.025	41	-0.089	0.466	-0.017
5	-0.240	0.051	-0.023	42	-0.239	0.052	-0.075
6	-0.277	**0.024**	-0.031	43	-0.135	0.271	-0.046
7	-0.203	0.097	-0.027	44	-0.074	0.546	-0.014
8	-0.226	0.065	-0.032	45	-0.045	0.724	-0.014
9	-0.173	0.158	-0.027	46	0.061	0.634	0.019
10	0.011	0.939	0.002	47	0.140	0.261	0.047
11	-0.118	0.337	-0.016	48	-0.011	0.939	-0.003
12	-0.167	0.173	-0.028	49	-0.199	0.104	-0.079
13	-0.318	**0.009**	-0.050	50	-0.301	**0.014**	-0.105
14	-0.294	**0.016**	-0.065	51	-0.170	0.170	-0.080
15	-0.446	**0.000**	-0.057	52	-0.360	**0.003**	-0.127
16	-0.267	**0.029**	-0.043	53	-0.100	0.411	-0.037
17	-0.409	**0.001**	-0.066	54	0.063	0.609	0.017
18	-0.337	**0.005**	-0.056	55	0.036	0.768	0.014
19	-0.377	**0.002**	-0.076	56	0.154	0.209	0.053
20	-0.284	**0.020**	-0.071	57	0.131	0.285	0.042
21	-0.210	0.085	-0.054	58	-0.190	0.121	-0.041
22	-0.190	0.121	-0.038	59	-0.364	**0.003**	-0.126
23	-0.333	**0.006**	-0.083	60	-0.358	**0.003**	-0.099
24	-0.328	**0.007**	-0.079	61	-0.203	0.097	-0.074
25	-0.216	0.077	-0.070	62	-0.175	0.154	-0.058
26	-0.213	0.083	-0.060	63	-0.004	0.988	-0.001
27	-0.305	**0.013**	-0.080	64	-0.034	0.794	-0.014
28	-0.119	0.329	-0.042	65	-0.098	0.433	-0.030
29	-0.288	**0.019**	-0.104	66	-0.275	**0.025**	-0.102
30	-0.083	0.509	-0.030	67	-0.326	**0.007**	-0.119
31	-0.019	0.877	-0.006	68	-0.068	0.591	-0.020
32	-0.059	0.631	-0.020	69	-0.142	0.245	-0.037
33	-0.099	0.420	-0.019	70	-0.227	0.065	-0.054
34	-0.193	0.118	-0.045	71	-0.292	**0.017**	-0.076
35	-0.237	0.053	-0.054	72	-0.273	**0.026**	-0.044
36	-0.057	0.642	-0.021	73	-0.417	**0.001**	-0.086
37	-0.114	0.352	-0.033				

Table 5.4.31: Summary statistics of trend test of pentad average of RH1 in Vellanikkara

Pentad	Kendall's tau	p-value	Sen's slope	Pentad	Kendall's tau	p-value	Sen's slope
1	0.123	0.313	0.180	38	0.170	0.133	0.040
2	0.201	**0.042**	0.182	39	0.217	1.000	0.046
3	-0.168	0.168	-0.176	40	0.070	0.582	0.011
4	-0.136	0.266	-0.140	41	0.078	0.403	0.020
5	0.047	0.753	0.057	42	0.271	**0.029**	0.064
6	0.158	0.197	0.156	43	0.183	0.137	0.053
7	-0.176	0.150	-0.275	44	0.227	0.065	0.054
8	-0.056	0.656	-0.067	45	0.154	0.131	0.033
9	0.061	0.572	0.155	46	0.181	0.141	0.045
10	0.030	0.812	0.029	47	0.018	0.894	0.000
11	-0.063	0.579	-0.072	48	0.186	0.130	0.050
12	0.093	0.513	0.147	49	0.189	0.059	0.050
13	0.109	0.483	0.122	50	0.199	0.229	0.067
14	0.075	0.633	0.075	51	0.215	0.080	0.067
15	0.000	1.000	0.000	52	0.419	< **0.0001**	0.126
16	0.081	0.514	0.067	53	0.270	**0.027**	0.080
17	0.332	**0.000**	0.200	54	-0.005	0.976	0.000
18	0.334	**0.006**	0.163	55	0.157	0.201	0.046
19	0.538	< **0.0001**	0.260	56	0.144	0.241	0.040
20	0.285	**0.004**	0.178	57	0.113	0.357	0.040
21	0.406	**0.001**	0.200	58	0.205	0.066	0.089
22	0.301	**0.037**	0.180	59	0.244	**0.006**	0.106
23	0.243	**0.047**	0.130	60	0.020	0.882	0.007
24	0.317	**0.009**	0.189	61	0.045	0.722	0.027
25	0.315	**0.010**	0.194	62	0.050	0.689	0.053
26	0.138	0.259	0.100	63	0.143	0.241	0.122
27	0.460	**0.000**	0.200	64	-0.032	0.673	-0.054
28	0.307	**0.012**	0.157	65	-0.107	0.381	-0.163
29	0.343	**0.005**	0.178	66	0.021	0.772	0.043
30	0.293	**0.000**	0.125	67	0.234	0.054	0.240
31	0.169	**0.009**	0.080	68	0.097	0.432	0.133
32	0.222	0.070	0.075	69	0.173	0.155	0.200
33	0.386	**0.002**	0.127	70	0.238	0.050	0.245
34	0.121	0.327	0.029	71	0.102	0.406	0.109
35	0.226	0.065	0.063	72	-0.013	0.884	-0.014
36	0.242	**0.014**	0.067	73	0.034	0.813	0.042
37	0.231	**0.016**	0.055				

Table 5.4.32: Summary statistics of trend test of pentad average of RH 2 in Vellanikkara

Pentad	Kendall's tau	p-value	Sen's slope
1	-0.129	0.292	-0.133
2	-0.029	0.824	-0.039
3	-0.280	0.021	-0.300
4	-0.190	0.119	-0.200
5	0.093	0.449	0.086
6	0.199	0.103	0.192
7	0.043	0.733	0.030
8	-0.039	0.701	-0.067
9	-0.071	0.364	-0.064
10	-0.070	0.444	-0.078
11	-0.082	0.505	-0.169
12	0.025	0.807	0.050
13	0.050	0.576	0.122
14	0.111	0.412	0.133
15	-0.013	0.909	-0.020
16	0.021	0.870	0.024
17	0.239	0.049	0.200
18	0.097	0.432	0.100
19	0.309	0.011	0.242
20	0.160	0.192	0.170
21	0.302	0.052	0.188
22	0.138	0.260	0.120
23	0.311	0.011	0.244
24	0.342	0.001	0.240
25	0.244	0.045	0.168
26	0.303	0.006	0.284
27	0.259	0.034	0.241
28	0.166	0.172	0.178
29	0.275	1.000	0.320
30	0.125	0.306	0.150
31	0.086	0.486	0.083
32	0.147	0.230	0.191
33	0.122	0.404	0.111
34	-0.054	0.667	-0.053
35	0.075	0.452	0.062
36	0.018	0.894	0.030
37	0.009	0.953	0.009
38	0.036	0.778	0.033
39	-0.064	0.604	-0.050
40	-0.057	0.646	-0.050
41	-0.068	0.583	-0.080
42	0.055	0.656	0.071
43	-0.066	0.593	-0.078
44	-0.063	0.614	-0.064
45	-0.131	0.286	-0.120
46	-0.364	< 0.0001	-0.325
47	-0.235	0.054	-0.190
48	-0.122	0.320	-0.092
49	-0.020	0.882	-0.026
50	0.071	0.656	0.058
51	0.134	0.206	0.157
52	0.226	0.064	0.200
53	0.036	0.778	0.053
54	-0.139	0.335	-0.120
55	-0.201	0.097	-0.217
56	-0.191	0.116	-0.286
57	-0.072	0.563	-0.075
58	0.036	0.758	0.032
59	0.132	0.267	0.133
60	0.136	0.266	0.122
61	-0.041	0.585	-0.050
62	-0.004	0.982	0.000
63	-0.129	0.292	-0.221
64	-0.061	0.625	-0.070
65	-0.159	0.192	-0.158
66	0.071	0.563	0.100
67	0.277	0.022	0.258
68	-0.055	0.452	-0.067
69	0.048	0.700	0.042
70	0.144	0.101	0.210
71	0.084	0.377	0.089
72	-0.132	0.385	-0.133
73	-0.055	0.656	-0.057

Table 5.4.33 Summary statistics of trend test of pentad average of Wind speed in Vellanikkara

Pentad	Kendall's tau	p-value	Sen's slope
1	-0.451	< **0.0001**	-0.225
2	-0.358	**0.001**	-0.179
3	-0.408	**0.001**	-0.156
4	-0.430	**0.000**	-0.205
5	-0.298	0.080	-0.123
6	-0.413	**0.001**	-0.173
7	-0.184	0.131	-0.079
8	-0.255	**0.035**	-0.133
9	-0.341	**0.005**	-0.147
10	-0.301	**0.005**	-0.067
11	-0.237	0.050	-0.089
12	-0.404	< **0.0001**	-0.104
13	-0.401	< **0.0001**	-0.077
14	-0.341	**0.036**	-0.075
15	-0.319	**0.036**	-0.059
16	-0.375	**0.002**	-0.060
17	-0.584	< **0.0001**	-0.083
18	-0.554	< **0.0001**	-0.093
19	-0.522	< **0.0001**	-0.092
20	-0.577	**0.000**	-0.086
21	-0.540	< **0.0001**	-0.081
22	-0.565	**0.000**	-0.089
23	-0.528	< **0.0001**	-0.091
24	-0.586	**0.000**	-0.101
25	-0.535	**0.001**	-0.098
26	-0.512	< **0.0001**	-0.099
27	-0.610	< **0.0001**	-0.105
28	-0.639	< **0.0001**	-0.106
29	-0.667	< **0.0001**	-0.106
30	-0.595	**0.001**	-0.093
31	-0.592	< **0.0001**	-0.105
32	-0.697	< **0.0001**	-0.100
33	-0.548	< **0.0001**	-0.089
34	-0.492	< **0.0001**	-0.094
35	-0.467	**0.000**	-0.080
36	-0.580	< **0.0001**	-0.100
37	-0.514	< **0.0001**	-0.083

Pentad	Kendall's tau	p-value	Sen's slope
38	-0.491	< **0.0001**	-0.087
39	-0.476	< **0.0001**	-0.093
40	-0.450	**0.002**	-0.091
41	-0.436	< **0.0001**	-0.079
42	-0.448	**0.000**	-0.081
43	-0.529	< **0.0001**	-0.080
44	-0.380	**0.002**	-0.064
45	-0.412	**0.001**	-0.075
46	-0.499	< **0.0001**	-0.080
47	-0.432	**0.000**	-0.070
48	-0.541	< **0.0001**	-0.080
49	-0.482	< **0.0001**	-0.078
50	-0.473	**0.000**	-0.074
51	-0.421	**0.003**	-0.070
52	-0.552	**0.000**	-0.073
53	-0.467	< **0.0001**	-0.068
54	-0.440	< **0.0001**	-0.076
55	-0.382	**0.000**	-0.051
56	-0.420	**0.003**	-0.068
57	-0.376	**0.000**	-0.049
58	-0.302	**0.013**	-0.044
59	-0.220	0.070	-0.048
60	-0.257	0.090	-0.056
61	-0.297	0.055	-0.062
62	-0.303	**0.012**	-0.083
63	-0.305	**0.012**	-0.098
64	-0.155	0.202	-0.050
65	-0.102	0.406	-0.048
66	-0.205	0.091	-0.082
67	-0.401	**0.001**	-0.197
68	-0.403	**0.001**	-0.214
69	-0.200	**0.027**	-0.109
70	-0.255	0.092	-0.136
71	-0.166	0.173	-0.111
72	-0.294	**0.015**	-0.155
73	-0.328	< **0.0001**	-0.162

Table 5.4.34 Summary statistics of trend test of pentad average of Evaporation in Vellanikkara

Pentad	Kendall's tau	p-value	Sen's slope
1	-0.373	**0.002**	-0.077
2	-0.347	**0.005**	-0.070
3	-0.368	**0.003**	-0.060
4	-0.320	**0.009**	-0.081
5	-0.358	**0.015**	-0.086
6	-0.586	< **0.0001**	-0.117
7	-0.223	0.070	-0.057
8	-0.361	**0.003**	-0.085
9	-0.324	**0.002**	-0.065
10	-0.269	**0.029**	-0.038
11	-0.194	**0.001**	-0.041
12	-0.385	< **0.0001**	-0.080
13	-0.464	1.000	-0.073
14	-0.310	< **0.0001**	-0.067
15	-0.345	**0.005**	-0.059
16	-0.444	**0.000**	-0.075
17	-0.496	< **0.0001**	-0.076
18	-0.593	< **0.0001**	-0.089
19	-0.562	< **0.0001**	-0.092
20	-0.461	**0.000**	-0.067
21	-0.572	< **0.0001**	-0.083
22	-0.370	**0.003**	-0.056
23	-0.472	**0.000**	-0.060
24	-0.458	< **0.0001**	-0.062
25	-0.483	< **0.0001**	-0.080
26	-0.384	**0.001**	-0.061
27	-0.402	**0.001**	-0.074
28	-0.370	**0.001**	-0.068
29	-0.448	**0.000**	-0.076
30	-0.311	**0.012**	-0.048
31	-0.173	0.163	-0.020
32	-0.216	0.062	-0.025
33	-0.066	0.598	-0.004
34	-0.216	0.080	-0.021
35	-0.254	**0.039**	-0.026
36	-0.027	0.739	-0.003
37	-0.221	0.075	-0.026

Pentad	Kendall's tau	p-value	Sen's slope
38	-0.188	**0.036**	-0.019
39	-0.148	0.327	-0.009
40	-0.163	0.127	-0.011
41	-0.087	0.485	-0.010
42	-0.183	0.141	-0.013
43	-0.161	0.064	-0.020
44	-0.291	**0.018**	-0.023
45	0.021	0.818	0.002
46	-0.199	0.107	-0.017
47	-0.126	**0.045**	-0.011
48	-0.205	0.097	-0.017
49	-0.287	**0.002**	-0.027
50	-0.321	**0.009**	-0.041
51	-0.422	**0.001**	-0.051
52	-0.294	**0.017**	-0.037
53	-0.307	**0.032**	-0.030
54	-0.104	0.169	-0.008
55	-0.044	0.783	-0.002
56	-0.019	0.889	-0.002
57	-0.046	0.721	-0.005
58	-0.188	0.129	-0.022
59	-0.254	**0.002**	-0.029
60	-0.252	< **0.0001**	-0.033
61	-0.243	**0.049**	-0.027
62	-0.156	0.209	-0.019
63	-0.178	0.149	-0.020
64	-0.140	0.258	-0.020
65	-0.091	0.466	-0.016
66	-0.328	1.000	-0.057
67	-0.438	**0.000**	-0.077
68	-0.171	0.168	-0.039
69	-0.285	**0.021**	-0.067
70	-0.220	0.132	-0.053
71	-0.364	**0.003**	-0.073
72	-0.373	**0.002**	-0.080
73	-0.428	**0.003**	-0.082

The minute details of the climatic variables can be thoroughly studied through pentad analysis of the variables. In general total rainfall had a positive trend only in p-51(8th to 12th September). Minimum temperature had significant positive trend in p-2 (January 6-10), p-13 (March 2- 6), p-14 (March 7-11), p-29 (May 21-25), p-65 (November 17-21) and significant negative trend in p-48 (August 24 -28). Maximum temperature showed significant positive trend in p-2 (January 6-10), p-45, p-46 and p-47 (August 9-23) and significant negative trend in p-14, p-18, p-19, p-21, p-25, p-26, p-27, p-28, p-29. In general sunshine hours, wind velocity and evaporation had significant negative trends, RH1 had significant positive trend and RH2 had no significant trend at all in any of the pentads.

6 IMPACT OF CLIMATE CHANGE ON RESERVOIRS OF KERALA

6.1 INTRODUCTION

The main impacts of climate change have been discussed globally over last two decades. It would affect agriculture in several ways. As far as water resources are concerned a warmer climate would accelerate the hydrological cycle and it can alter the intensity and timing of rainfall. Global warming and the resulted decline in rainfall may reduce net recharge and can affect ground water levels. Decrease in winter precipitation would reduce the total seasonal precipitation and can impose greater water stress. At the same time, soil erosion would be at a greater rate with increased rainfall amounts. (Goutham, 2012)

In this climate change scenario, distribution of water for agricultural purposes is a complicated issue and its management is generally affected by social, environmental and political factors (Ward *et al.* , 2013). Surplus water during rainy seasons can be stored in reservoirs and can be utilised for irrigation in drought periods. Prevention of floods can also be ensured. So a well organised operation of reservoir system is important for getting maximum net benefit from the available water resources. It will regulate inflows and provide outflows in a regular rate according to demand. Generally water management involves the supply and distribution of the right amount of water at the right time to the right place so that the agricultural, industrial and commercial activities and other day to day domestic needs of the society are satisfied. A serious constraint in this regard is the shortage of reservoir water. For a precise estimate of reservoir yield, simulation models need to be developed.

Hence a study was carried out to develop stochastic models to simulate stream flow as well as reservoir inflow using the long term observed data and to compare the generated flow with the observed values and consequently to anticipate future inflows with reliability.

In general reservoir simulation models may be used directly to forecast the performance of a new reservoir or to model the historical behaviour of an existing reservoir (Anonymous, 2015). Forecasts are made for a variety of operating conditions through the history matched model. Economic models are combined with these models to make decisions concerning the regular operations of the reservoir. The expected performance of the system can be evaluated for a set of given design and policy parameters. Based on given operating rules, the performance of the system for the next 50 or 100 years can be simulated. Determining the sequence of annual operations of irrigation and hydropower, the benefits derived out of it can be estimated.

The sequential nature of the reservoir management decisions, together with the inherent randomness of natural water inflows direct us to use Markov decision processes for modelling reservoir management problems and their optimisation through stochastic dynamic programming (Lamond and Boukhtouta, 2002) . Markov chain model was found to be useful as a predictive device for studying reservoir elevation of Shiroro Dam (Abubakar *et al.* , 2014).

Synthetically generated sequences of the inflow are made use of for simulation of the reservoir operations. This branch of synthetic hydrology is well appreciated by Engineers and hydrologists because it can accommodate complex inflow models. The important elements involved in the modelling are the time unit of operation of the reservoir, the persistence of flows, the seasonality , the unit of volume, the release and finally the finiteness or otherwise of the reservoir (Phatarford, 1989). A monthly time series model incorporating both seasonality and autocorrelation would be resulted if the time unit is a month. Markov processes with seasonality varying transition probabilities can be effectively used to model the persistence and the seasonality. The time unit can be selected as 10 days, 15 days or months according to the situation (Mujumdar, 2012).

6.2 REVIEW OF LITERATURE

Wang *et al.* (2014) were of the opinion that a time series would be considered to be a combination of quasi - periodic signals contaminated by noise. The accuracy of prediction of such a time series could be improved by data pre processes. The original series could be decomposed into filtered series and noises by singular spectrum analysis. Generally SSA selects only filtered series as model inputs without considering noises. Hydrological information might be present in noises and both filtered and noises series together were considered as model inputs. The prediction models using Support vector machine, Genetic programming and seasonal auto regression were employed on the prediction models including noises which influenced model performance.

A hybrid method consisting of artificial neural networks (ANN) and Support vector machine (SVM) was used by Cheng *et al.* (2015) to forecast the reservoir monthly inflow data. Then the processed predictive values of both ANN and SVM were selected as the input variables of a newly built ANN model for refined forecasting. Genetic Algorithm (GA) was employed to choose the parameter of the SVM. Monthly inflow forecasting in Xintengjiang reservoir with 71 years discharge from 1944 to 2014 were performed using ANN, SVM and hybrid method and it was found that the hybrid method was an efficient tool for the forecasting

Moeeni, (2017) has reported that as Seasonal Auto-Regressive Integrated Moving Average (SARIMA) would not consider the random component in the statistical data, monthly inflow data was predicted using a new hybrid method – a combination of SARIMA and Gene Expression Programming (GEP) models. The pre- processed data sets were linearly modelled using SARIMA and the resulted non-linearity of the residual series caused by linear modelling was evaluated. If non-linearity existed, the residuals were modelled by means of GEP. The superiority of SARIMA – GEP over the SARIMA – ANN model was proved using 30 years monthly inflow data with extreme seasonal variations of Janishan Dam in West Iran with R^2 = 78.8 and 68.3 respectively.

Kashid *et al*. (2010) revealed the complicated relationship between the predictors and predictant through statistical technique and artificial intelligence tools by modelling hydro-climatic teleconnections. The non-linear relationship which has flexible functional structure could be captured using A1 level genetic programming. Using different oscillation indices, gridded multi-site weekly rainfall could be predicted using genetic programming. Weekly forecasting of stream flows in Mahanadi River, India were made using the predicted rainfall through genetic programming.

Stream flow for catchment of Savitri river basin was effectively predicted by Kothari and Gharde (2015) using the input vectors viz., daily rainfall, mean daily evaporation, mean daily temperature and lag stream flow for 20 years from 1992 to 2011. The statistical parameters R^2, RMSE, EV, CE and MAD were used to evaluate the performance of the models. Results showed that the ANN model performance was superior to FL algorithms.

Abudu *et al*. (2010) tried to forecast monthly stream flow of the Kizhil river in China by applying ARIMA, SARIMA and ANN modelling for original and de - seasonalised data. The results showed that the ARIMA & SARIMA models with a simple and explicit model structure were as good as ANN models using previous flow conditions as predictors.

Lance *et al.* (2010) determined an appropriate number of time-lagged input data by time series analysis of climate-flow data which provides a transferable and systematic methodology. The recurrent ANN's were trained on climate- flow data from one basin and used to forecast stream flow in a nearby basin with different climate inputs. The change in drainage area from one basin to another could be found out by a scaling ratio based on a relationship between bank full discharge and basin drainage area. For small streams, hourly stream flow predictions were superior to those using daily data.

Van ogtrop *et al.* (2011) used logistic regression through generalised additive models for location, scale and shape (GAMLSS) to determine the probability of flow occurring in any of the river systems. The intensity of the stream flow was modelled using the above regression frame work in combination with a right-skewed distribution, the Box-Cox t distribution. The study revealed that the variability of flow was driven by the sea surface temperatures.

Exogenous climate variables were used by Chen *et al.* (2014) to build hierarchical Bayesian model for one season ahead forecast of summer rainfall and stream flow in East Central China. It helped to consistently model the variability across sites and across variables. Spatial co-variability in seasonal hydrological predictions were modelled using partial pooling hierarchical Bayesian regression considering the potentially common effects of the predictions on regional hydrologic response.

Application of principal component analysis, rotates the original GCM fields into orthogonal components if the precipitation fields obtained from GSM's and SST's are spatially correlated. Stream flow forecasts for various basins were developed considering two candidate predictors viz., precipitation forecasts from ECHAM 4.5 forced with constructed analogue SST forecasts over the South-East versus observed monthly stream flow at the site. Spearman rank-correlation was used to identify the grid points of the precipitation forecasts that correlate well with the observed stream flow which was used as predictors of stream flow. The use of principal component regression in spite of MLR helped to overcome the multicollinearity in using the correlated predictors.

Investigation on the relationships between discharge and hydro-meteorological parameters at Gangotri Glacier was made by Manohar *et al.* (2014) using daily mean discharge, daily mean temperature and daily rainfall. Discharge could be forecasted using the regression equation

$Q_i = 2.962 + 1.011Q_{i-1} - 0.422Ti + 0.203Ri$ with an R^2= 93%. The study revealed that discharge for a particular day is highly dependent on the previous day's discharge.

Seth (2008) used independent component analysis (ICA) for forecasting multivariate time series, transforming the multivariate time series to a set of univariate time series that are mutually independent. Uncertainty was incorporated by boot strapping the error component of each univariate model. By applying the inverse ICA transform to the predicted univariate series, the spatial dependence of the stream flow was captured.

Loukas and Vasiliades (2014) located five different basins in Canada and a well-established hydrological model, the University of British Columbia watershed model was applied for rainfall run off modelling. For watersheds without stream flow gauge data and limited meteorological station data, the UBC watershed model with parameter for water allocation and flow routing and precipitation gradients estimated from the annual precipitation data and distribution of orographic precipitation were used. For pooling gauged watersheds which have limited stream flow measurements a hybrid method coupling UBC watershed model with ANN's were used. The hybrid method was found to be a successful alternative to the conventional calibration of a hydrological model based on the evaluation criteria employed for stream flow modelling and flood frequency estimation.

Location of the study

The study was conducted to simulate reservoir inflow of Idamalyar Dam (10^0 13' 18" N 76^0 42' 21" E). It is a multipurpose concrete gravity Dam built across Idamalayar river, a tributary of Periyar River in Kerala. It originates in the Anamala hills at about 2500 m above sea level. It has an annual rainfall of 6000 mm and inflow of 5539 Mm^3. In addition, the storage is supplemented with water let from Nirar, Tamil Nadu state under interstate agreement and a portion of the excess water from the Poringalkuthu Reservoir of Chalakudy river. The water stored in the reservoir is used for generating electricity at the 75 MW power station and the tail water is led to the Idamalayar river itself and collected at Bhoothathankettu barrage of Periyar Valley Irrigation Project. The irrigation benefits cover an area of 14394 hectares of agricultural land. The cultivable command area here is 13209 hectares.

The next location of study was the Karappara river ($10^0$27'25" ; 76^0 38'51") near Nelliampathy in Palakkad District of Kerala. It is a tributary of Chalakudy river having a catchment area of

47.695km ^{2} for the gauging weir. Karappara- Kuriarkutty multi-purpose project for power generation and irrigation in the Chittur taluk, in Palakkad district which experiences severe shortage of water and power was proposed years ago.

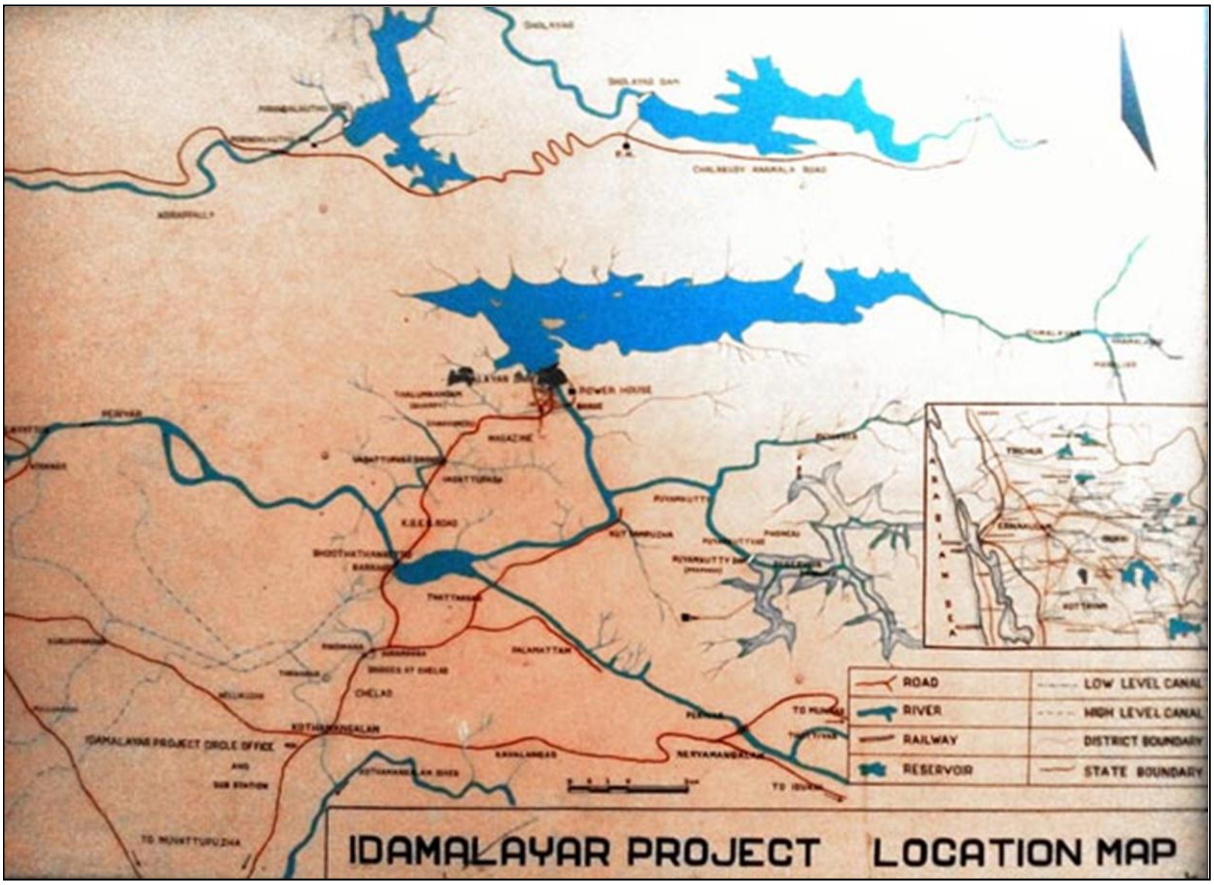


Fig. 6.2.1

6.3 DATA AND METHODOLOGY

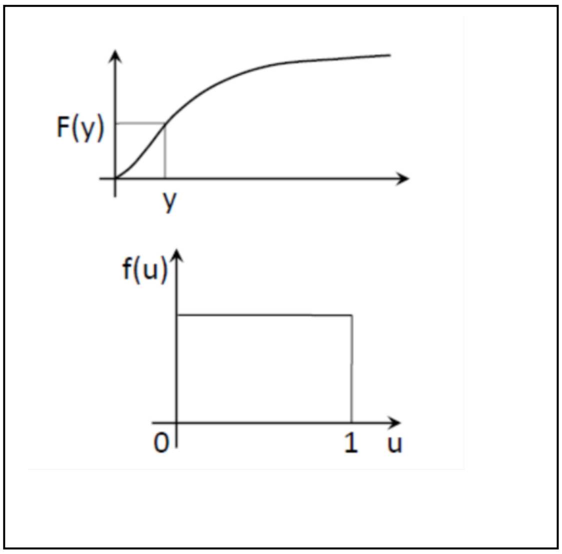
Daily data on Idamalayar Reservoir **i**nflow for a period from 1989 june -2015 May and the daily stream flow at Karappara gauging weir for a period from June ’76 to May 2002 were used for the study.

The main principle behind data generation in hydrology is that there is a statistical regularity of the hydrologic processes unless major changes occur. Information collected from the historical periods are used to make an assessment of how the process is likely to behave in the future and using this principle, data for the future is generated. The essential information content, in terms of probability, general stochastic behaviour of the process and statistical parameters are captured. Using these information of the past data, future sequence of observations are generated. It is always better to base the future decisions upon several sequences rather than basing on a single sequence to avoid the risk of occurrence of extreme events like floods, droughts etc. All the parameters of the historical data would be extended or preserved so that several sequences generated would follow the same distribution as that of the past.

As far as hydrologic processes are concerned, there is persistence in nature. That means there is a tendency of flows to follow the trend of immediate past. The generating models reproduce the statistical distribution and persistence of historical flows and it would possess the same mean, S.D and lag1 correlation as that of the historical data (Mujumdar 2012).

Data Generation Basics

First, the probability distribution of the historical data is assessed. The cumulative distribution function (c.d.f) of the distribution is formed. When random points are picked up on c.d.f, they follow a uniform distribution in the interval 0 and 1.This becomes a useful result in data generation irrespective of distributions. If a particular F(y) is randomly picked up from the uniform distribution, the corresponding value of y can be obtained if the analytical expression for the distribution is known.



It is given by F(y) = Ru = $\int_{-\infty}^{y} f(y)dy$. If a random number is chosen for Ru then solving the analytical expression, a value for y is obtained which is taken as the generated value of y. For the next random number selected, the next generated number is obtained and so on. The random numbers for the computations are obtained from inbuilt scientific programs such as excel or from scientific calculators. So, as long as we have a c.d.f and the c.d.f values themselves follow a uniform distribution in the region 0 and 1 we can use this result to generate values.

In certain cases like Normal distribution, gamma distribution etc. the solution of the analytical expression by taking the inverse transform is very complicated. In the case of Normal distribution, the random numbers corresponding to standard normal variate is available in statistical tables. Ideally a large sequence of values is generated and the parameters are estimated for the generated sequence. They must be as close to the parameters of the observed data.

Data generation – uncorrelated data

If from the correlogram (plot of auto correlations ρ_k for different lags, against lags k), all the autocorrelations are found to be statistically insignificant (purely random stochastic process), then if the distribution of the observed sequence is known or can be estimated, the data can be generated for the future by the specific distribution.

In hydrology, most of the data are serially correlated. The value realised during a particular period may be related to the value of the previous period. In such cases, a method based on lag one correlation can be adopted. The first order Markov process can be effectively used in this case. If X_t is correlated with $X_{t-\tau}$ and if ρ_k (auto correlation) is exponentially decaying, then correlation at any lag can be obtained using correlation at lag1. This also indicates that the memory of the process is short. According to different situations, one time step memory, two time step memory etc. can be used.

The first order Markov process can be defined as

$P[X_t \mid X_{t-1}, X_{t-2, \ldots\ldots,} X_0] = P[X_t \mid X_{t-1}]$. The entire information contained in the history of the process given by $X_{t-1}, X_{t-2, \ldots\ldots,} X_0$ can be expressed by X_{t-1}.

Data generation through first order Markov process

First order stationary Markov model (Thomas Fiering model)

If large time steps like annual time steps are taken neglecting periodicities, then stationary Markov process can be employed as

$X_{t+1} = \mu_x + \rho_1(X_t - \mu_x) + €_{t+1}$

X_{t+1} is the generated value for the time period t+1, μ_x is the long term observed mean of the process, ρ_1 is the lag1 correlation of X_{t+1} with X_t, $€ \approx N(0, \sigma_e^2)$.

This model is stationary with respect to mean and variance.

A sequence is to be generated with the same mean μ_x and variance σ_x^2. € will have a mean 0. But to maintain the same variance σ_x^2' for the process , properties of $€_{t+1}$ are important.

$$E[X_{t+1}] = E[\mu_x + \rho_1(X_t - \mu_x) + €_{t+1}] = \mu_x$$

$$\sigma_x^2 = E[X^2] – (E[X])^2 = E[(\mu_x + \rho_1(X_t - \mu_x) + €_{t+1})^2]- (E[X_{t+1}])^2 = \rho_1^2 \sigma_x^2 + \sigma_e^2$$

Therefore $\sigma_e^2 = \sigma_x^2 (1- \rho_1^2)$ ie the variance of $€_{t+1}$ would be $\sigma_e^2 = \sigma_x^2 (1- \rho_1^2)$

If X_t follows Normal distribution with mean μ_x and variance σ_x^2 and € should also be normally distributed with mean 0 and variance σ_e^2 , let a new variable U_t be introduced which follows N(0,1), then $U_t \sigma_e$ ie $U_t \sigma_x \sqrt{1- \rho_1^2}$ is $N(0, \sigma_e^2)$.

Thus it can be ensured that the random component has 0 mean and variance σ_e^2. Introducing a standard normal deviate U_{t+1}, the first order Markov model can be written as

$$X_{t+1} = \mu_x + \rho_1(X_t - \mu_x) + U_{t+1} \sigma_x \sqrt{1- \rho_1^2}.$$

U_{t+1} follows standard normal distribution with mean 0 and variance 1. By using such a random number it can be ensured that the error component will have 0 mean and constant variance σ_e^2. The model would be stationary because the same value of mean and S.D is used to generate different values.

The assumptions made to apply this model is that (1) the process X_t follows normal distribution with mean μ_x and variance σ_x^2 and (2) the process is stationary in mean , S.D and lag1 correlation.

To start the generation procedure, first the moments viz., mean, S.D and lag1 correlation of the historical data are found out. To generate x_2 from x_1 using the model, x_1 is initially assumed to be μ_x so that the second term in the model will immediately be zero. The standard normal deviates U_{t+1} are straight away taken from the statistical tables or inbuilt programs. Once x_2 is generated it is used to generate x_3. Each time X_t and U_{t+1} are changed in the model but all other parameters remain constant.

Since the process was started by assuming X_t as μ_x , the first 100 or 150 values are to be discarded to do away with this effect. By changing the set of random numbers of standard normal deviate, several number of sequences can be generated. In all these sequences first few values are discarded to make it free from the effect of the initial value assumed to start the process. Since standard normal deviates ranges from -3 to + 3, practically, the generated values may contain negative numbers. In such cases retain the negative number as such to generate the next number but in real applications it is taken as zero as the variables in hydrology such as stream flow, rainfall etc. will not assume negative values.

First order Markov model addressing the Non stationarity

In the first order stationary Markov model it is assumed that the mean, S.D and lag1 correlation should be the same for the historical and generated data. But when hydrological time series is considered they exhibit non stationarity especially when monthly data such as stream flow are considered. In this case the mean, S.D and lag1 correlation will be significantly different from one month to another. So it is essential to incorporate these type of variations or non stationarity of the moments in the model. Relaxing the requirements of the first order stationary Markov model usually used for annual flows, seasonal models can be introduced in which the seasons can be either months, or any intra period or intra year variation. There may be periodicities existing in the data. The stream flow during a period may be correlated with a value in the previous periods and so on. In situations where there is a periodicity, it introduces non stationarity in the data. The periodicities would affect not only the mean and S.D but lag1 correlation also all of which appear in the Markov model.

In the stationary Markov model, non stationarity is introduced in the mean, S.D and lag1 correlation by taking one new index $x_{i,\,j+1}$ where i is the year and j is the month. First order Markov model with non- stationarity, for data generation is given by

$$X_{i,j+1} = \mu_{j+1} + \rho_j \frac{\sigma_{j+1}}{\sigma_j}(X_{ij} - \mu_j) + t_{i,j+1}\sigma_{j+1}\sqrt{1-\rho_j^{\,2}}$$

where ρ_j is the serial correlation between flows of j^{th} month and $j+1^{th}$ month, $t_{i,\,j+1} \sim N(0,1)$.

Instead of the stationary mean μ_x , mean of a particular season for which data is generated is expressed as $\mu_{j+1,}$ ρ_j is the lag1 correlation between month j and j+1, ⌐ j indicating S.D for the particular month, $t_{i,\, j+1}$ is drawn from N(0,1) *ie* random variables following standard normal distribution.

To generate the values, first, $\mu_{x,}$ ⌐ $_{j}$ and ρ_j are estimated, then starting with an assumed initial value, a value for the (j+1)th month is generated and so on.

6.4 RESULTS AND DISCUSSION

The first order stationary Markov model as well as the model addressing the non stationarity are demonstrated using the data pertaining to Karappara stream flow and Idamalayar Reservoir Inflow. They were found to be very useful in modelling annual stream flows and reservoir inflows. These types of models can be effectively used in hydrological designing to fix the capacity of a reservoir, simulation of the performance of a reservoir etc. by using several sequences of generated data.

Simulation of Karappara Stream flow

The mean annual flow at Karappara weir was 79.42 Mm^3 with a S.D of 26.81Mm^3 and lag1 correlation of 0.26. The yearly series of stream flow was tested for normality using 4 different test statistic. The data was found to follow normal distribution.

Table 6.4.1: Normality test for the yearly flow at Karappara weir

Name of the test statistic	Computed value	p-value	Computed value excluding value for –'79- '80(extreme value)	p-value
Doornik-Hansen	5.19	0.07	3.09	0.21
Shapiro-Wilk W	0.92	0.04	0.94	0.15
Lillie fors	0.15	0.13	0.13	0.36
Jarque-Bera test	5.01	0.08	1.67	0.43

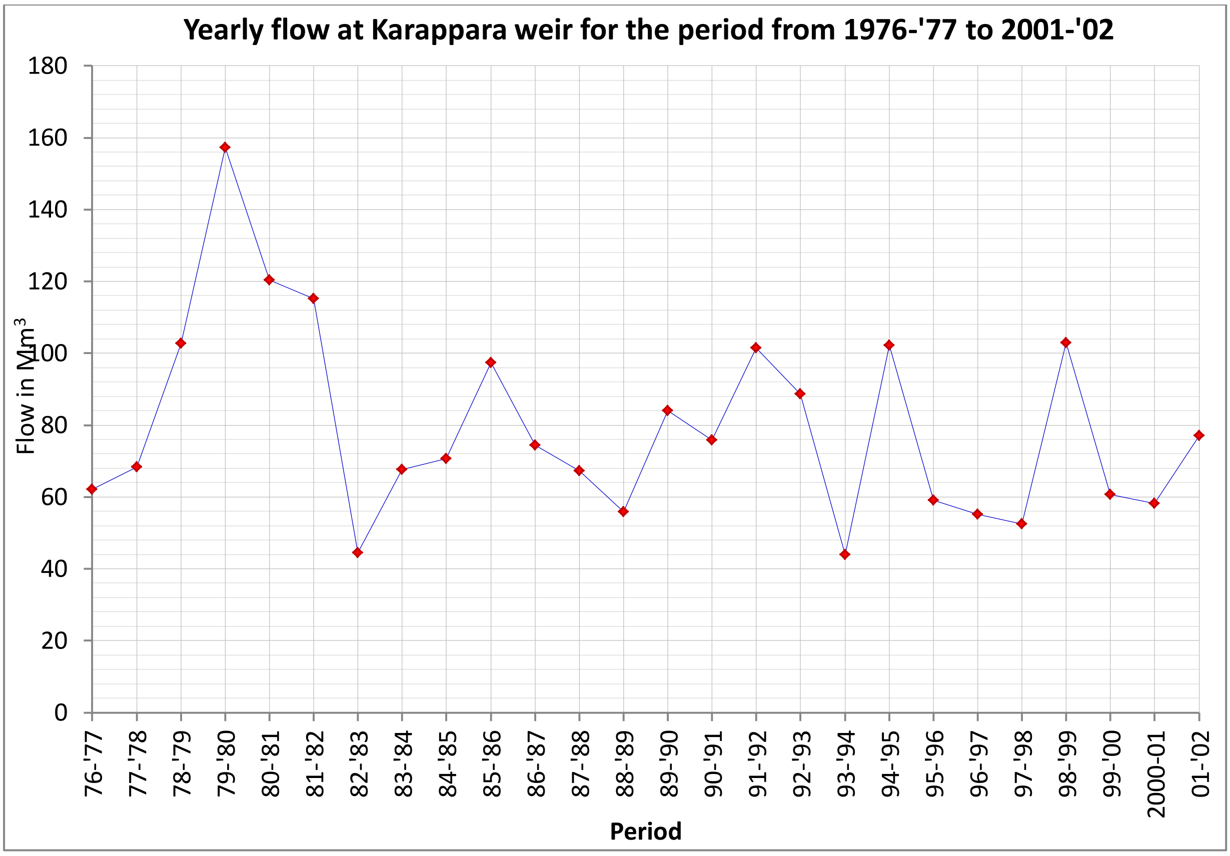


Fig. 6.4.1

The tests for normality of the inflow data showed that the data did not follow exactly the normal distribution when it included the extreme value in 1979- ‘80. This is evidenced by the p values obtained for the test statistic computed excluding the extreme value. So the data cannot be considered as perfectly normal. Even though the data became normal when the extreme value was deleted, it was not practised since the proposed model was based on the lag1 correlation and hence deletion of a value in between was not feasible. So the data was made normal through logarithmic transformation. Therefore simulation of the data using the first order stationary Markov model has been tried for both original and log transformed values using the moments of historical annual stream flow data. First 100 values of the generated data were discarded and the next 50 values were taken. The mean, S.D and lag1correlation of the generated values were very close to that of the existing data.

Table 6.4.2: Moments of the historical and generated series of annual flow at Karappara weir

Annual flow	Mean (Mm^3)	S.D (Mm^3)	Lag1 correlation
Historical data	79.42	26.81	0.26
Generated data	80.37	25.20	0.35

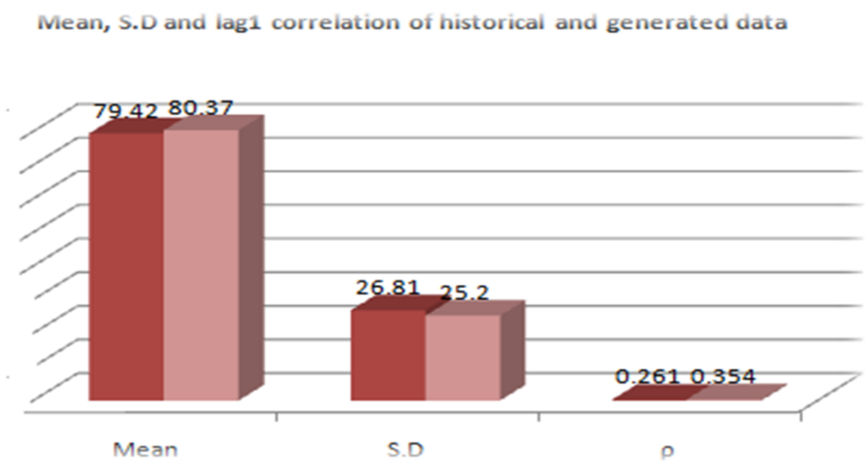


Fig. 6.4.2

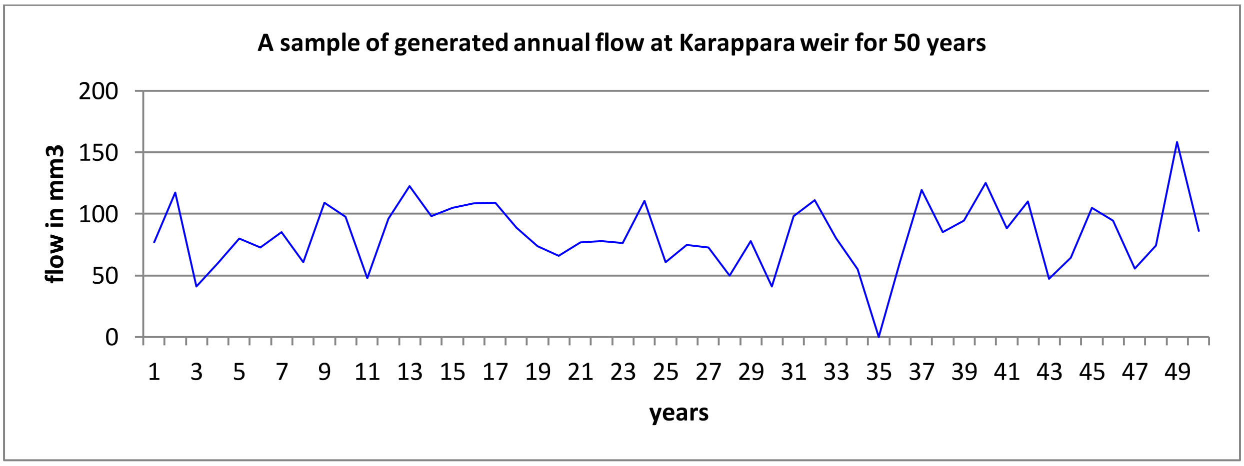


Fig. 6.4.3

Table 6.4.3: Moments of the historical and generated series of log transformed annual flow at Karappara weir

	Mean Mm^3	S.D Mm^3	Lag1 correlation
Historical data	4.32	0.33	0.15
Generated data	4.37	0.34	0.14

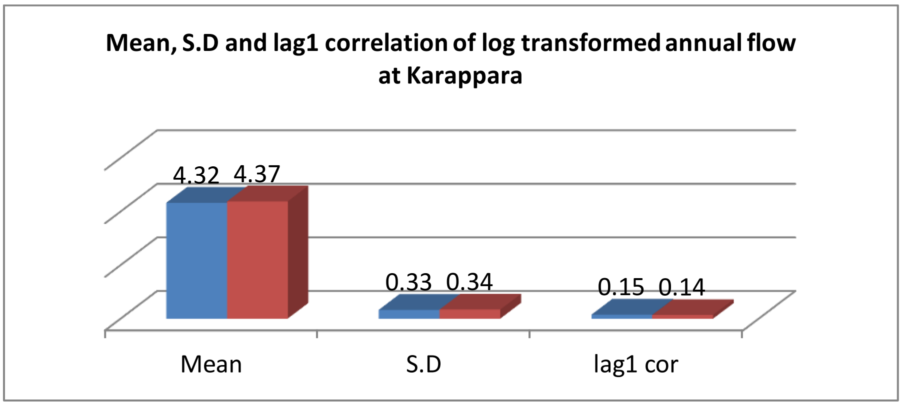


Fig.6.4.4

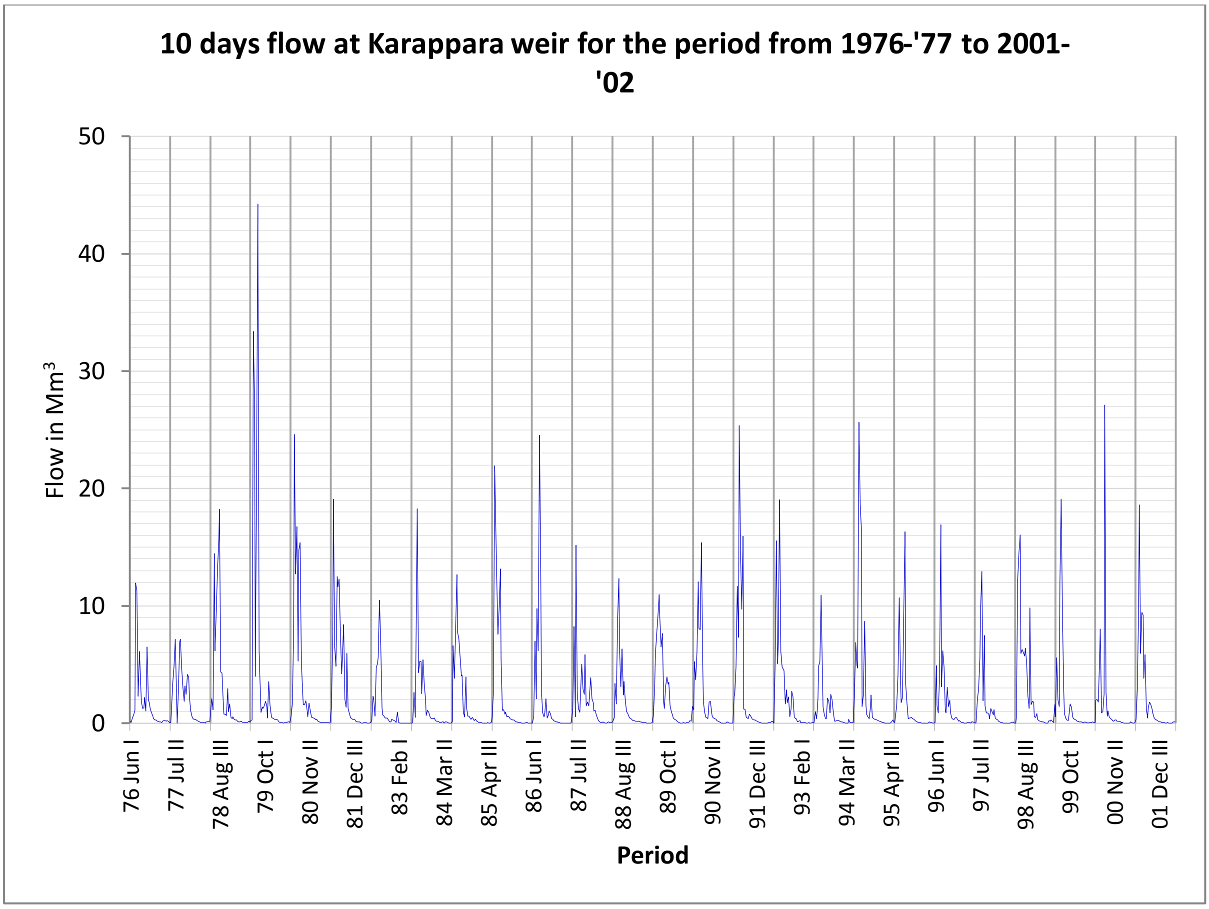


Fig. 6.4.5

The seasonal first order Markov model can accommodate shorter period flows such as 10 day period, weekly etc. to simulate data. But when the model is applied to very short periods like less than 10, the assumption of normality of the data may be violated. When 10 day period is used, the year is divided into 36 time intervals. The time series of the 10 day period flow at Karappara weir is depicted in Fig. (5.4.8). Each month was divided into three viz., June I, June II, June III etc. For each of these periods, the moments viz., mean, S.D and lag1 correlation were found out. Then the simulated values were derived using seasonal Thomas fiering model. First hundred values generated were discarded and the characteristics of the next 50 values generated are summarised. The moments of the historical and generated series compared well as shown in Table (6.4.4). The adequacy of the model is shown in Fig.6.4.9 – Fig. 6.4.11.

Table 6.4.4: Moments of the historical and generated 10 day's flows (Mm^3) at Karappara weir

Period	mean		S.D		lag1 correlation	
	Original	generated	original	generated	original	Generated
June I	0.59	0.58	0.73	0.56	0.49	0.36
June II	2.84	2.87	2.52	2.32	-0.02	-0.08
June III	6.66	6.48	7.94	5.72	0.61	0.59
July-I	7.95	8.14	7.48	6.55	0.02	0.13
July II	8.74	8.73	5.09	5.28	0.15	0.08
July-III	11.06	12.08	6.51	6.71	0.40	0.38
Aug-I	9.72	10.48	8.89	8.79	0.18	0.01
Aug.-II	6.67	6.74	4.65	3.64	0.21	0.30
Aug.III	7.37	6.86	5.79	5.79	0.10	-0.001
Sep.-I	3.46	3.72	3.41	2.99	0.47	0.53
Sep-II	2.06	2.03	1.69	1.65	0.62	0.81
Sep.-III	1.90	2.28	1.84	1.92	0.27	0.19
Oct.-I	1.42	1.36	0.94	1.01	0.25	0.44
Oct.-II	1.62	1.79	1.88	1.47	0.22	0.08
Oct.-III	1.31	1.64	1.17	1.11	0.15	0.06
Nov.-I	1.43	1.80	1.40	1.32	0.48	0.40
Nov.-II	1.19	1.66	1.16	1.07	0.87	0.88
Nov-III	0.81	1.05	0.69	0.64	0.74	0.62
Dec.I	0.49	0.60	0.35	0.35	0.88	0.88
Dec.II	0.39	0.46	0.23	0.22	0.86	0.85
Dec.III	0.32	0.36	0.20	0.19	0.91	0.90
Jan.I	0.23	0.23	0.13	0.12	0.92	0.94
Jan.II	0.18	0.19	0.09	0.09	0.20	-0.03
Jan.III	0.18	0.27	0.18	0.16	0.27	0.07
Feb.I	0.09	0.11	0.06	0.06	0.90	0.91
Feb.II	0.07	0.08	0.05	0.04	0.85	0.86
Feb.III	0.05	0.05	0.04	0.03	0.82	0.79
Mar.I	0.04	0.05	0.04	0.04	0.92	0.93
Mar.II	0.03	0.03	0.03	0.03	0.52	0.53
Mar.III	0.03	0.03	0.03	0.03	0.57	0.53
Apr.I	0.04	0.06	0.06	0.05	0.50	0.44
Apr.II	0.07	0.08	0.08	0.07	0.51	0.36
Apr.III	0.05	0.07	0.06	0.05	0.70	0.82
MayI	0.07	0.08	0.06	0.06	0.67	0.68
MayII	0.07	0.09	0.07	0.06	0.23	0.02
MayIII	0.18	0.27	0.39	0.30	0.12	0.09

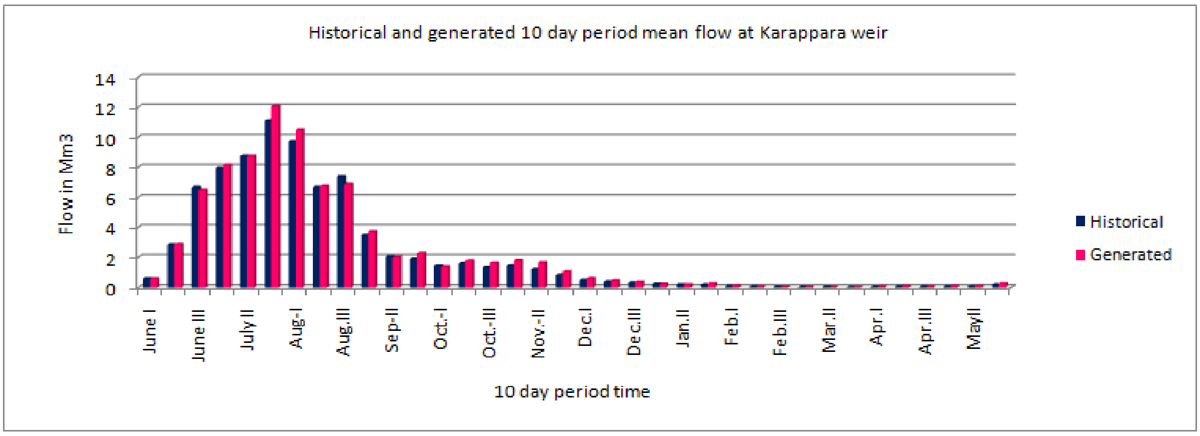


Fig. 6.4.6

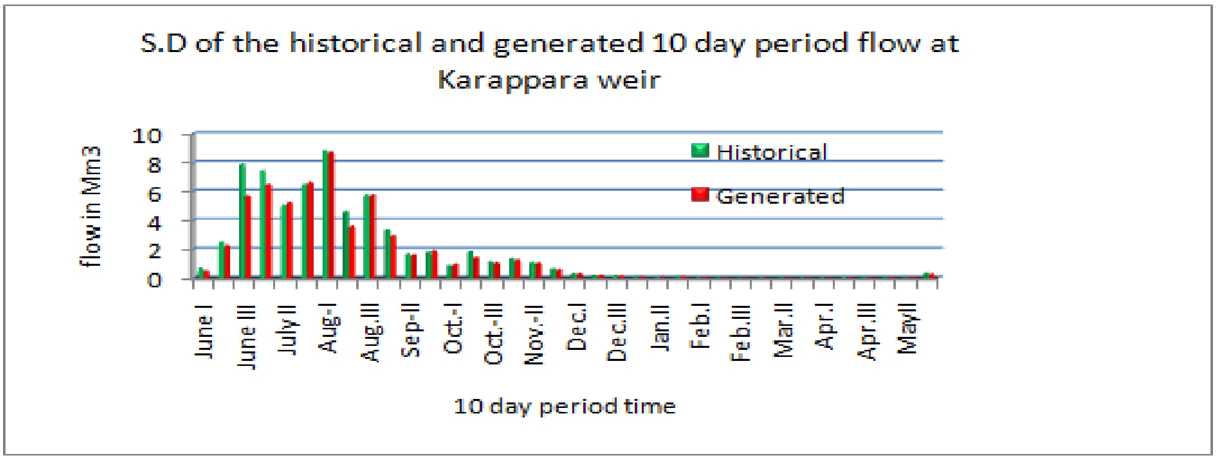


Fig. 6.4.7

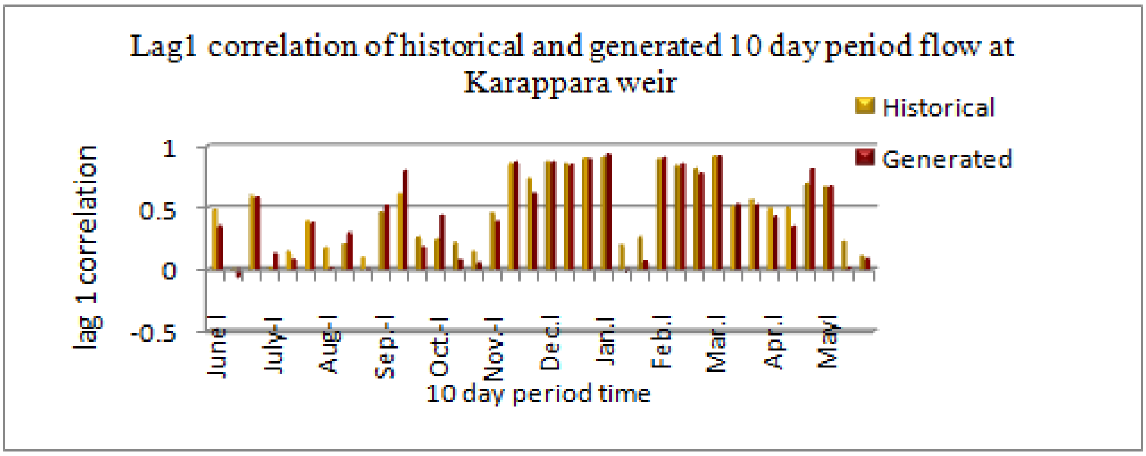


Fig. 6.4.8

Simulation of Idamalayar Reservoir Inflow

The time series of yearly inflow to Idamalayar Reservoir for the period from 1989-'90 – 1915 - '16 is shown in Fig.6.4.9.

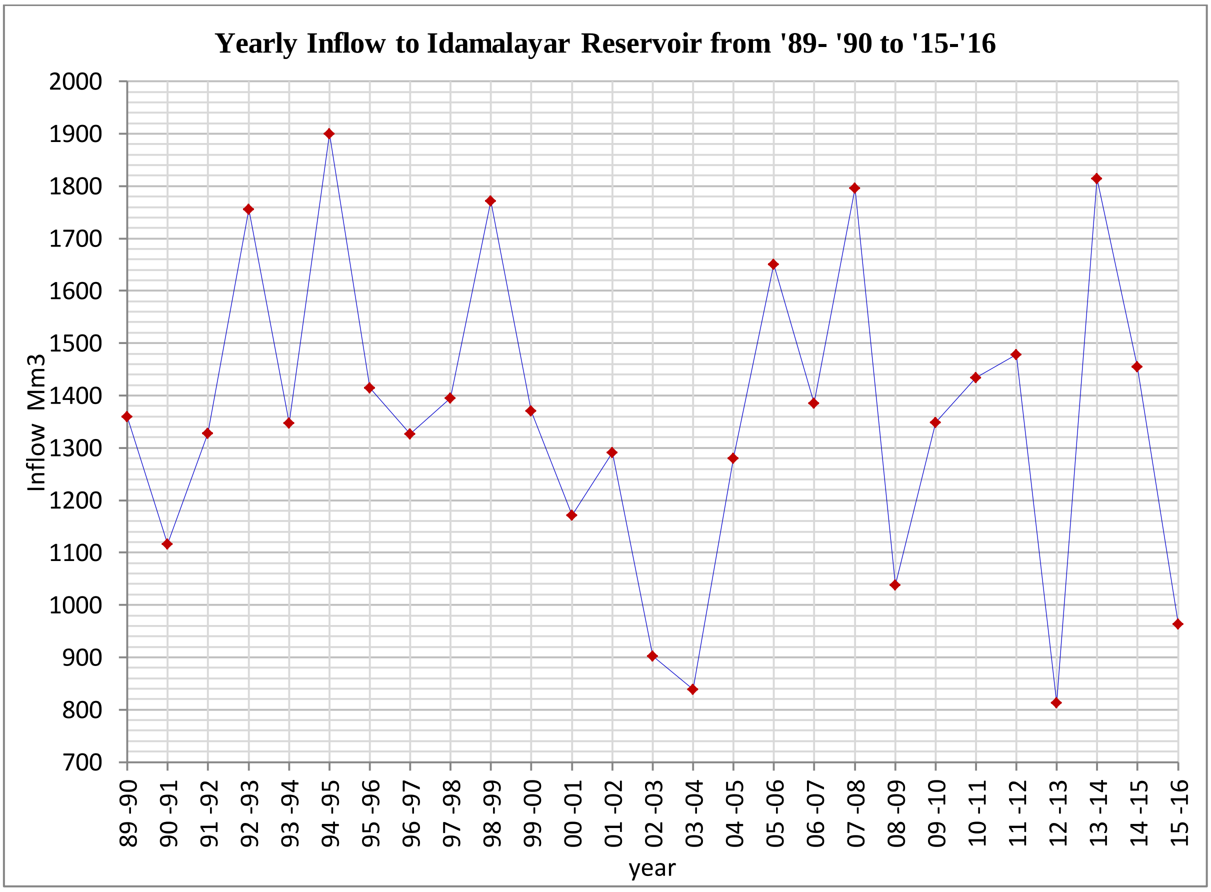


Fig. 6.4.9

Table 6.4.5: Augmented Dickey-Fuller test to check the stationarity of yearly inflow data to Idamalayar Reservoir.

H_0 = There is unit root (a=1)	H_0 = There is unit root (a=1)
test with constant	test with constant and trend
model: (1-L)y = b0 + (a-1)*y(-1) + e	model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + e
estimated value of (a - 1): -1.02739	estimated value of (a - 1): -1.03365
test statistic: tau_c(1) = -4.92187	test statistic: tau_ct(1) = -4.83801
p-value 0.0005804	p-value 0.003592
1st-order autocorrelation coeff. for e: -0.001	1st-order autocorrelation coeff. for e: -0.007

Table 6.4.6: Normality test for the yearly inflow to Idamalayar

Name of the test statistic	Computed value	p-value
Doornik-Hansen	0.17	0.92
Shapiro-Wilk W	0.95	0.20
Lillie fors	0.14	0.21
Jarque-Bera test	0.23	0.89

The efficiency of the first order stationary Markov model in simulating the yearly inflow to Idamalayar is demonstrated using the data for a period from June 1989 to May 2015.

Table 6.4.7: Moments of the historical and generated series of yearly inflow to Idamalayar

	Mean Mm^3	S.D Mm^3	Lag1 correlation
Historical data	1376.18	290.97	-0.027
Generated data	1386.94	298.27	-0.222

Mean, S.D & Lag 1 correlation of historical and generated series of yearly inflow to Idamalayar Reservoir

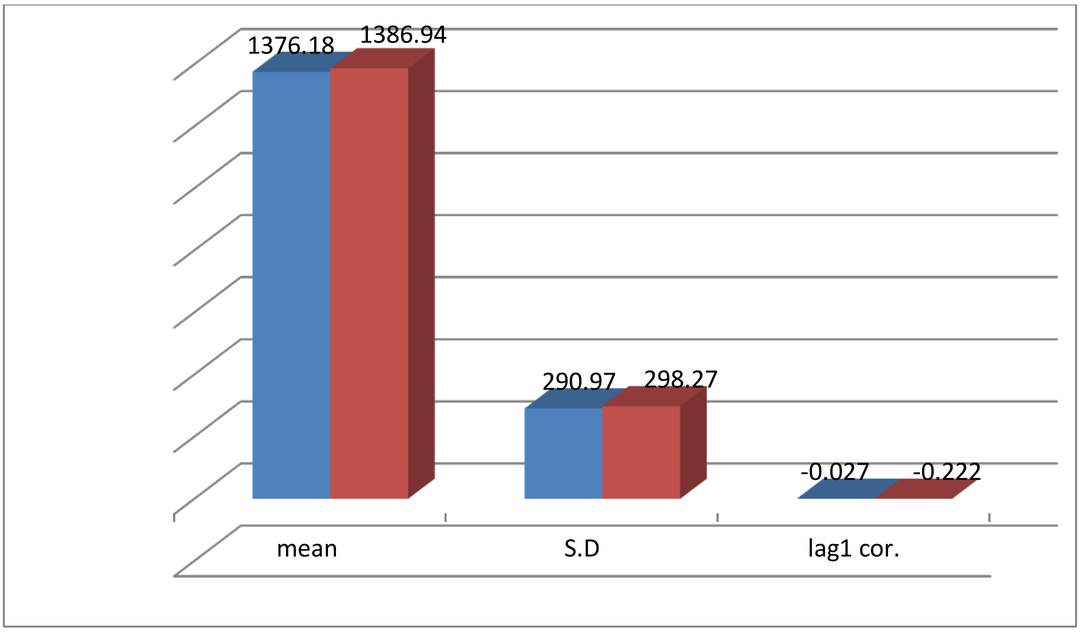


Fig.6.4.10

Table 6.4.8: Moments of the historical and generated series of log transformed yearly inflow to Idamalayar Reservoir

	Mean Mm^3	S.D Mm^3	Lag1 correlation
Historical data	7.20	0.23	0.02
Generated data	7.21	0.23	-0.19

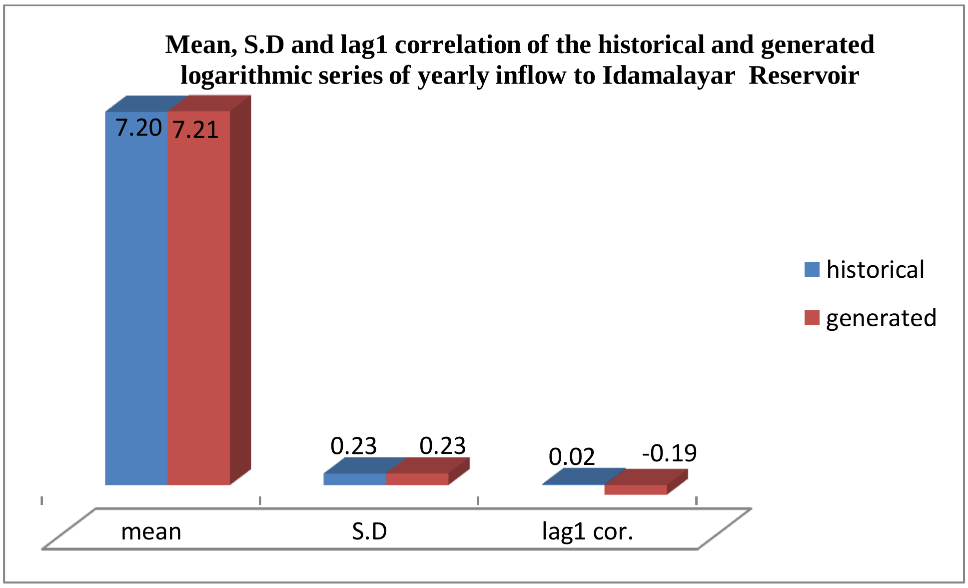


Fig.6.4.11

Simulation of monthly inflow to Idamalayar Reservoir

Augmented Dickey-Fuller test showed that the series of monthly inflow to Idamalayar Reservoir was non stationary (Table 6.4.10) . Also the series was not normal (Table 6.4.9). Therefore the series of inflow was transformed to logarithmic values and the first order Markov model addressing the non stationarity was fitted. The improved simulated series compared perfectly well with the historical data. The prescribed model was fairly acceptable in terms of mean, S.D and lag1 correlation. The results in Table (6.4.11) show the adequacy of the fitted model to account for serial dependence in the data.

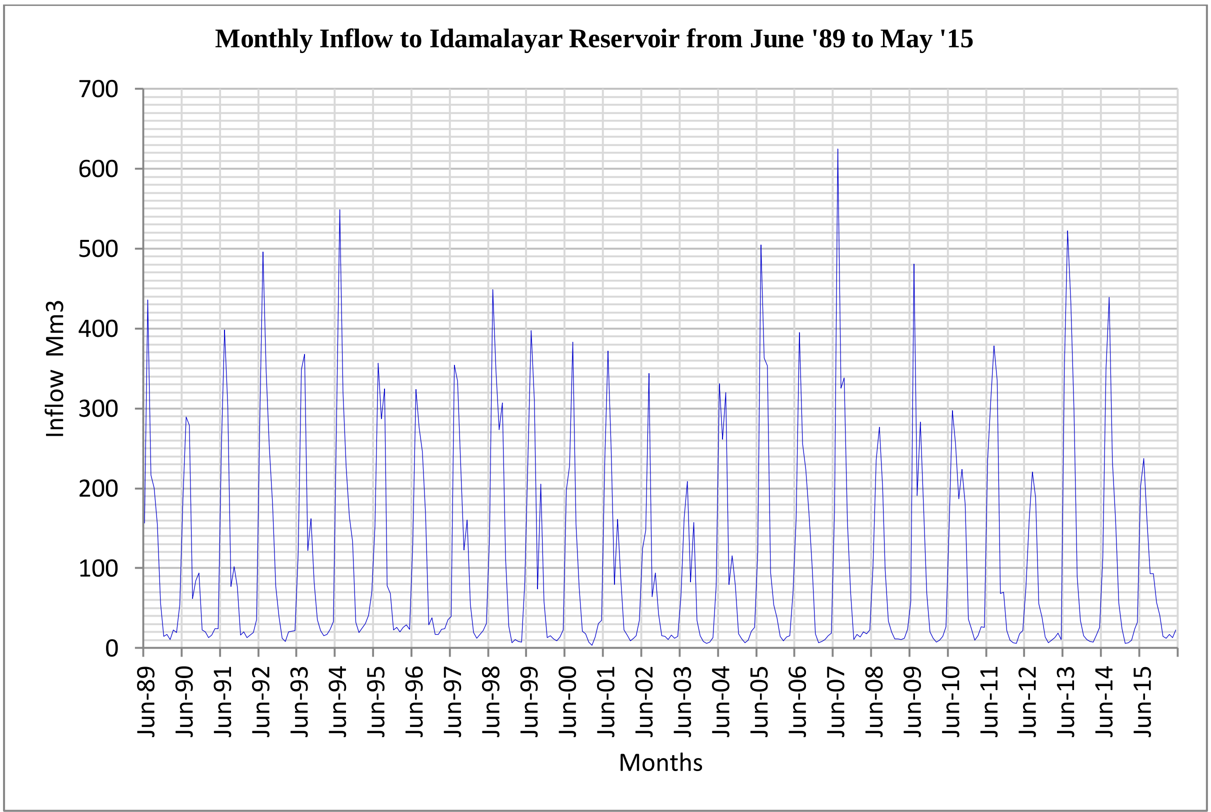


Fig.6.4.12 Monthly Inflow to Idamalayar Reservoir from june '89 to May '15

Table 6.4.9: Normality test for the monthly inflow to Idamalayar

Name of the test statistic	Computed value	p-value
Doornik-Hansen	244.26	9.11739e-054
Shapiro-Wilk W	0.793314	1.3154e-019
Lillie fors	0.216578	0
Jarque-Bera test	100.162	1.77867e-022

Table 6.4.10: Augmented Dickey-Fuller test to check the stationarity of monthly inflow to Idamalayar Reservoir

test with constant	with constant and trend
model: (1-L)y = b0 + (a-1)*y(-1) + … + e	model: (1-L)y = b0 + b1*t + (a-1)*y(-1) + … + e
estimated value of (a – 1): -0.568971	estimated value of (a – 1): -0.573097
test statistic: tau_c(1) = -3.22686	test statistic: tau_ct(1) = -3.23352
asymptotic p-value 0.01851	asymptotic p-value 0.07787
1^{st}-order autocorrelation coeff. For e: 0.018	1^{st}-order autocorrelation coeff. For e: 0.018
Lagged differences:F(11,287)=29.274 [0.0000]	lagged differences: F(11, 286) = 29.153 [0.0000]

Table 6.4.11: Moments of the historical and generated series of monthly inflow to Idamalayar Reservoir

Period	Mean (Mm^3)		S.D (Mm^3)		lag1 correlation	
	Original	Generated	Original	Generated	Original	Generated
June	172.51	163.78	83.41	86.54	0.34	0.38
July	363.52	381.73	123.81	126.59	0.21	0.39
August	308.81	296.74	65.72	62.04	0.25	0.04
September	199.52	189.44	95.00	95.01	0.02	0.22
October	139.49	131.94	56.82	66.25	0.44	0.50
November	73.75	71.04	39.02	41.44	0.55	0.47
December	24.05	23.18	10.70	11.61	0.33	0.22
January	14.36	14.48	5.70	5.51	0.69	0.49
February	10.94	11.44	4.72	4.35	0.79	0.84
March	14.77	14.75	6.21	5.20	0.67	0.62
April	19.88	19.81	7.01	6.53	0.01	-0.13
May	34.57	36.38	19.43	18.68	0.27	0.20

From Table (6.4.11) it could be noticed that the mean, S.D and lag1 correlation of the historical and generated series compared satisfactorily, showing the adequacy of the fitted model to simulate the monthly inflow to the Idamalayar Reservoir.

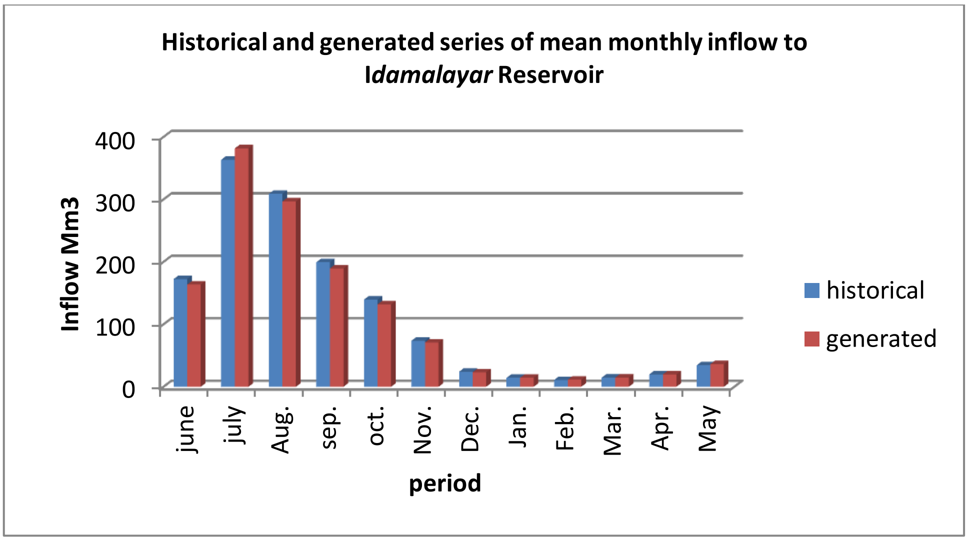


Fig. 6.4.13

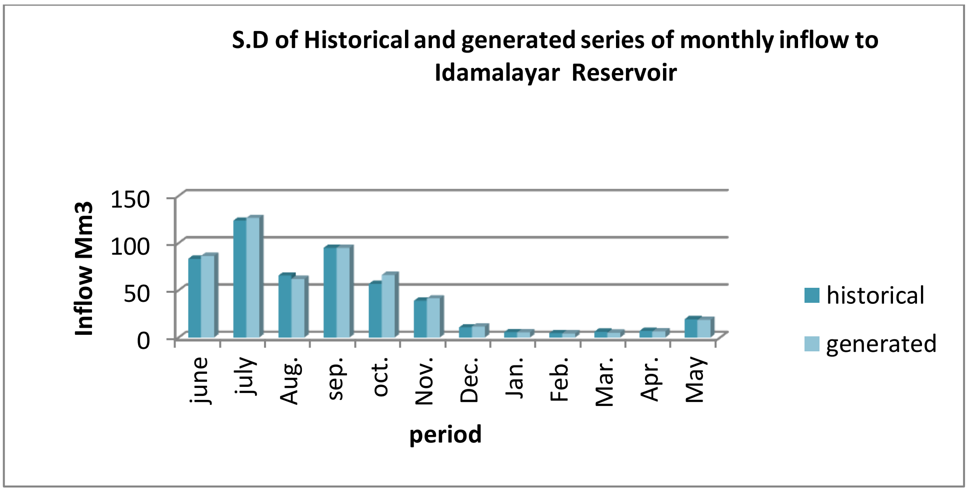


Fig. 6.4.14

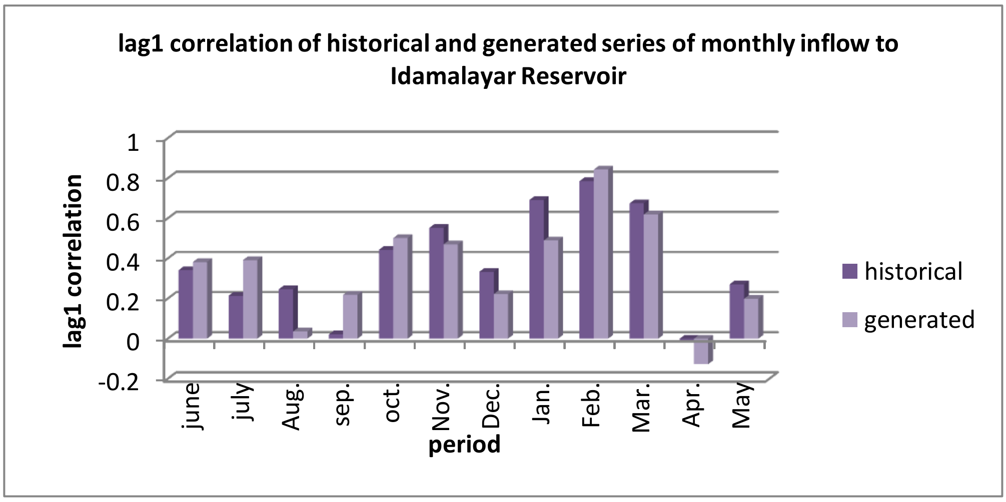


Fig.6.4.15

As it is evident from Table (6.4.9) and Table (6.4.10) that the monthly series of inflow to the reservoir was not normally distributed and strictly stationary, the series of inflow was transformed to logarithmic values and the first order Markov model addressing the non stationarity was fitted. The improved simulated series compared perfectly well with the historical data depicting the advantage of logarithmic transformation through which the inflow data could be made normal. The prescribed model is fairly acceptable in terms of mean, S.D and lag1 correlation. The results in Table (6.4.12) show the adequacy of the fitted model to account for serial dependence in the data.

Table 6.4.12: Moments of the historical and generated logarithmic series of monthly Inflow (Mm^3) to Idamalayar Reservoir

period	mean		S.D		lag1 correlation	
	original	generated	original	generated	original	Generated
June	5.02	4.96	0.55	0.57	0.34	0.38
July	5.83	5.89	0.38	0.39	0.23	0.40
August	5.71	5.67	0.22	0.21	0.18	-0.02
September	5.15	5.10	0.58	0.60	0.03	0.22
October	4.86	4.80	0.41	0.48	0.45	0.50
November	4.17	4.13	0.52	0.57	0.45	0.36
December	3.10	3.06	0.41	0.45	0.28	0.18
January	2.58	2.59	0.44	0.43	0.70	0.52
February	2.31	2.36	0.41	0.38	0.67	0.74
March	2.61	2.60	0.42	0.34	0.60	0.53
April	2.93	2.92	0.35	0.33	-0.05	-0.17
May	3.41	3.46	0.50	0.48	0.23	0.16

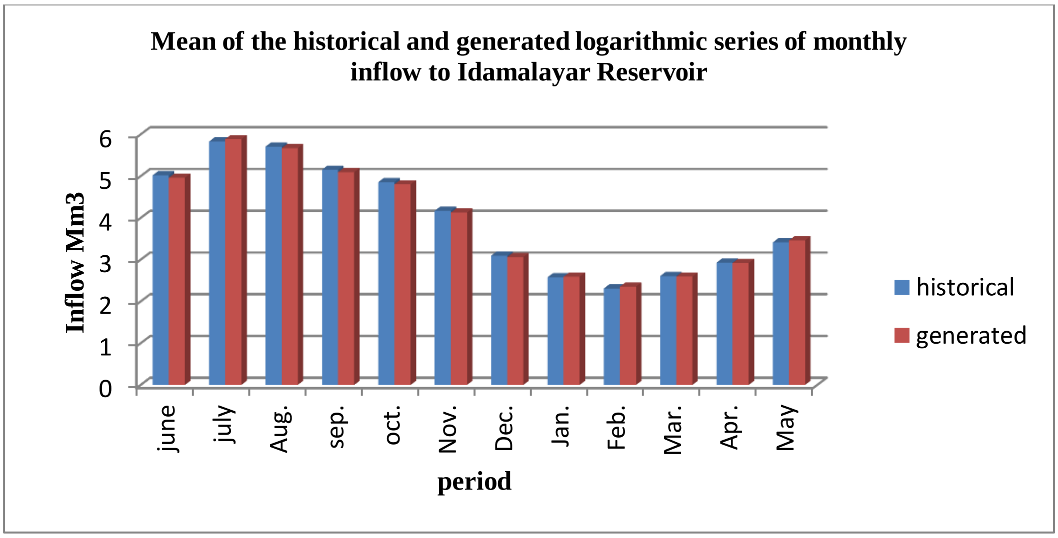


Fig. 6.4.16

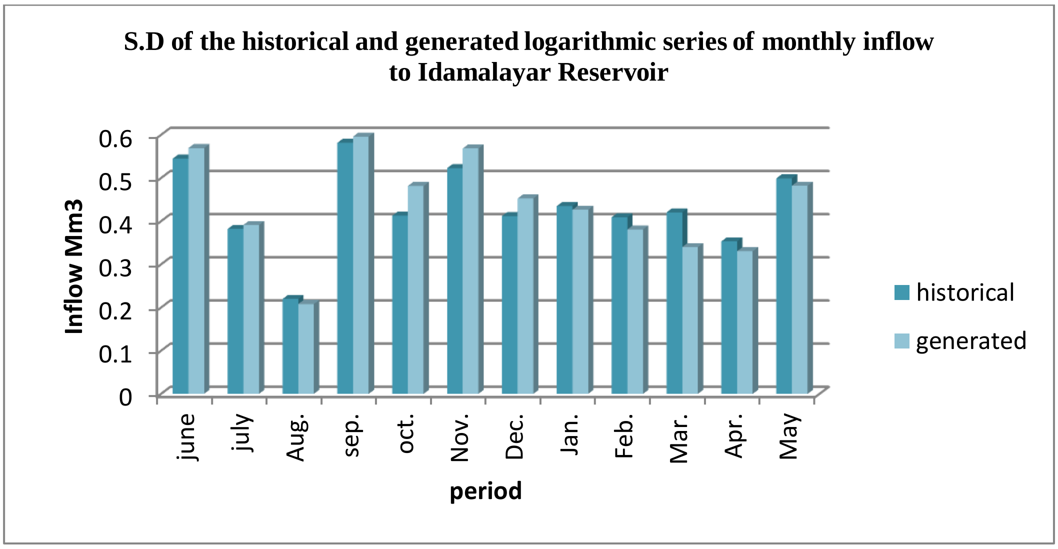


Fig.6.4.17

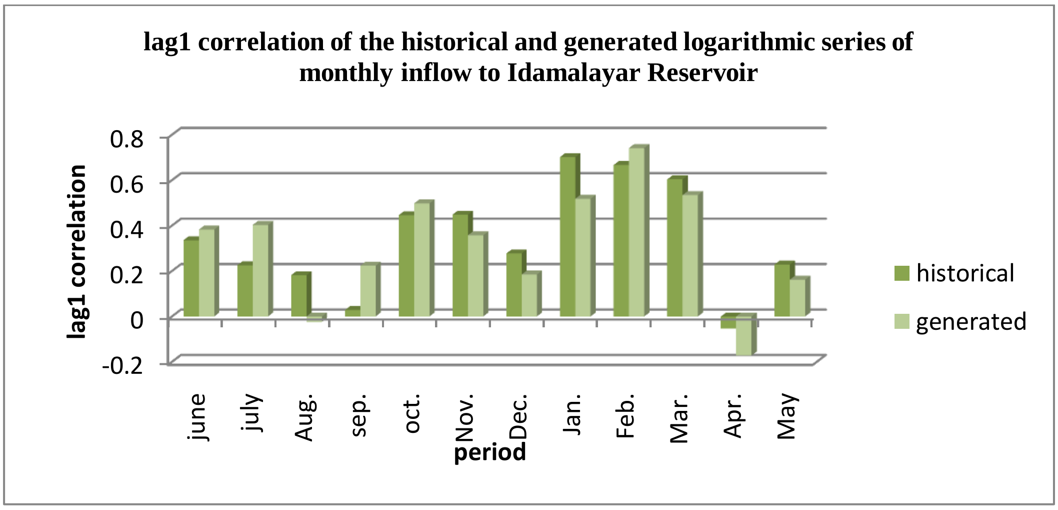


Fig.6.4.18

Several sequences of reservoir inflow can be generated using different sequences of random numbers and this information can be made use of for planning the routine operations of the reservoir and to discuss about how the system would perform in future according to this generated data.

The model described above is meant only for simulating sequences preserving the historical mean, S.D and lag1 correlation. When a stochastic model is selected, the purpose for which it is used is very important. So these models are usually recommended, addressing the issues such as whether it is needed to model peak flows, is it important to include the time and volume of peak flows, duration of flow (daily, weekly, monthly) etc. When the time period is reduced too short, the data may not follow the assumption of normality. Also the data is to be tested for stationarity. If the data is non stationary, a model which could address the non stationarity is to be used. The data is to be checked for the presence of certain trends or jumps. The quality and quantity of the data is also very important. The data must be free from missing values, repetitions and it must be collected from a reliable source. At least 30 years of data is generally needed to develop a meaningful model.

Reservoir Inflow Forecasting

Apart from the long term simulation models, short term prediction models were also tried to forecast reservoir Inflow. The association of monthly inflow with the corresponding month's rainfall is depicted in Fig. 6.4.19. The best fitted linear regression model taking rainfall of the current and previous months as the independent variables could explain 84% of the variation in inflow. Since most of the hydrological variables are serially correlated, the prediction was also done using ARIMA models. ARIMA (4,0,4) model was identified to be the best with stationary $R^2 = 84\%$.

Monthly rainfall and stream flow to Idamalayar Reservoir for the period from 2000 –'01 to 2015 –'16

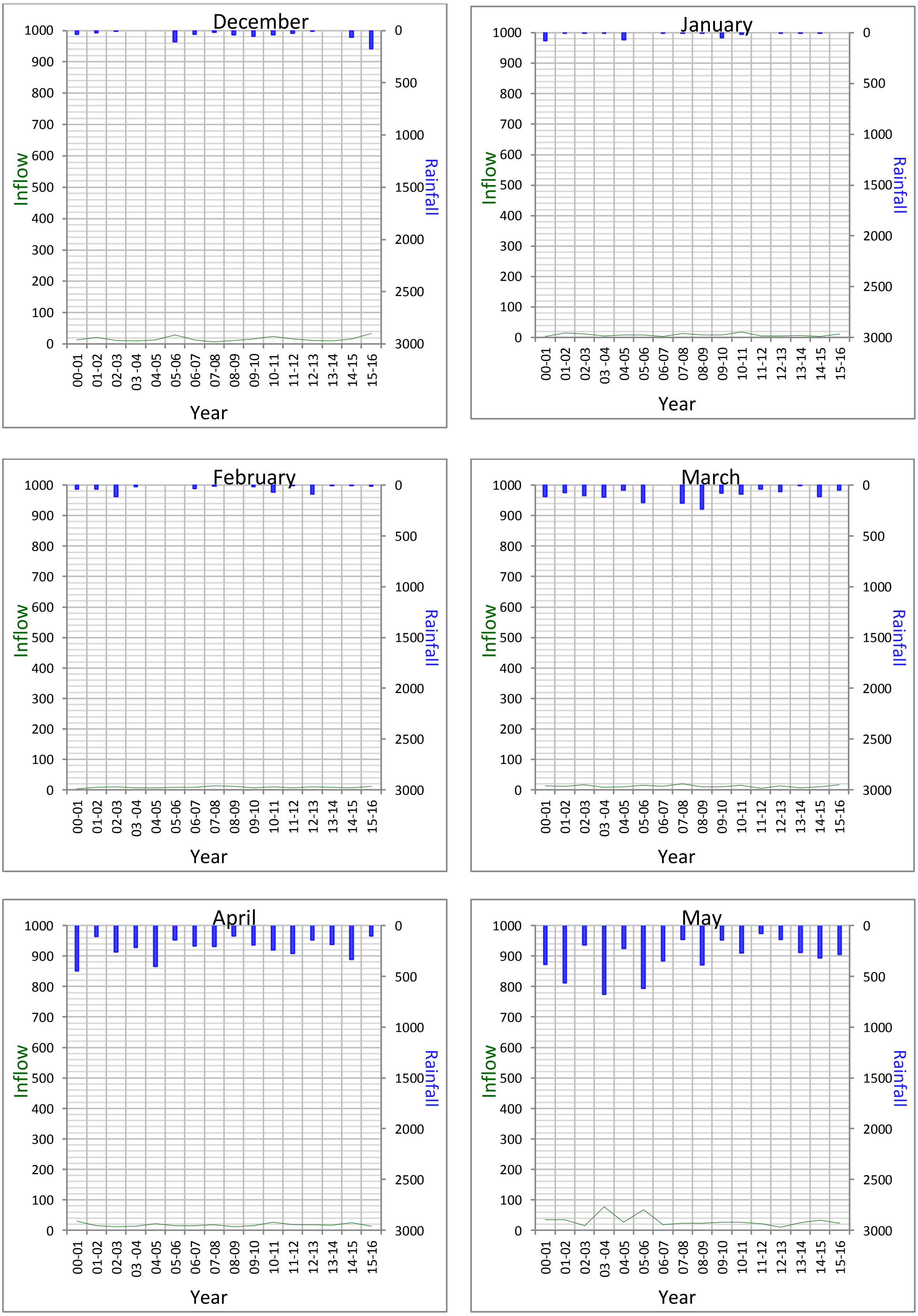

December
January
February
March
April
May
Inflow
Rainfall
Year
1000
900
800
700
600
500
400
300
200
100
0
0
500
1000
1500
2000
2500
3000
00-01
01-02
02-03
03 -04
04-05
05-06
06-07
07-08
08-09
09-10
10-11
11-12
12-13
13-14
14-15
15-16

Fig. 6.4.19

Table 6.4.13: Linear regression forecasting models for Idamalayar Reservoir Inflow

Model	Regression Equation	R^2	Adjusted R^2	SE of the Estimate
1	$Y= 5.94 + \underset{(0.02)}{0.23^{**}} RF_{-1}$	0.56	0.55	69.02
2	$Y= 4.23 + \underset{(0.03)}{0.28^{**}} RF_{-1} - \underset{(0.11)}{0.21^{*}} inflow_{-1}$	0.57	0.56	68.44
3	$Y= - 8.52 + \underset{(0.01)}{0.27^{**}} RF$	0.78	0.78	48.65
4	$Y= - 21.40 + \underset{(0.01)}{0.21^{**}} RF + \underset{(0.01)}{0.10^{**}} RF_{-1}$	0.84	0.84	41.34
5	$Y= - 21.24 + \underset{(0.02)}{0.07^{**}} RF_{-1} + \underset{(0.07)}{0.08} inflow_{-1} + \underset{(0.01)}{0.21^{**}} RF$	0.84	0.84	41.30
6	$Y= - 21.24 + \underset{(0.01)}{0.21^{**}} RF + \underset{(0.01)}{0.08^{**}} RF_{-1} + \underset{(0.01)}{0.02} RF_{-2}$	0.84	0.84	41.21

*and **denote significance at 0.05 level and 0.01 level

ARIMA MODELS

Since most of the hydrological variables are serially correlated the prediction was also done using ARIMA models. Before constructing the ARIMA model, the basic structure of the reservoir inflow data was studied. The correlogram of the data showed that there existed inherent periodicities in the data and the same was confirmed by the periodogram analysis. Periodicities of length 12 months, 6 months etc. existed in the data. The auto correlation and partial auto correlation function together with the periodicities inherent in the data supported by spectral analysis and periodogram analysis of the data are shown in Fig. 6.4.20 & 6.4.21 and Table (6.4.14).

Water released from Nirar, Tamil Nadu district and water diverted from Poringalkuthu were deducted from the inflow data because these may create certain ups and downs in the data. When ARIMA models are tried, the data must be free from all these abnormalities. Therefore

ARIMA model was tried for both raw data and corrected data using the Expert modeller option in SPSS 20. The results were promising for the adjusted data.

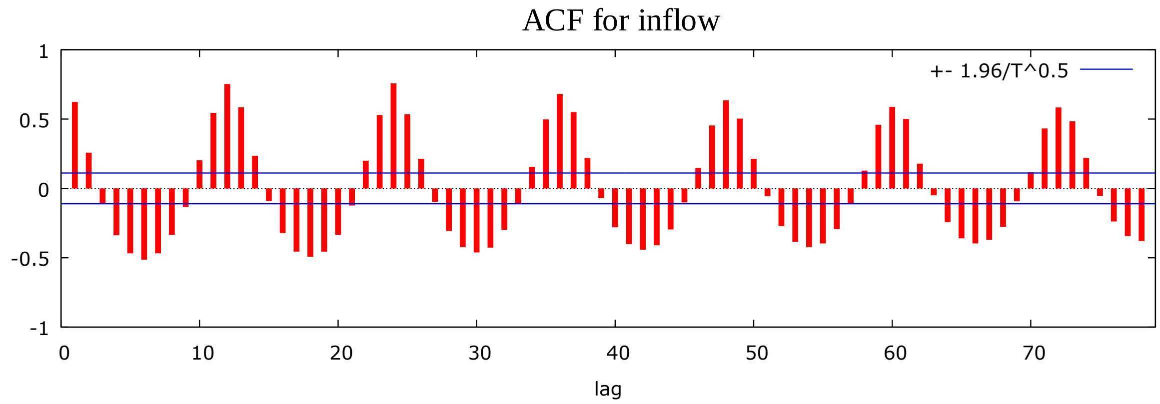
ARIMA (4,0,4) model was identified to be the best with stationary $R^2 = 84\%$ for the corrected data and ARIMA (0,0,7) was best for raw data. A comparison of the fit statistic for the two models showed that the best model which can be recommended with less RMSE and higher value of R^2 was ARIMA (4,0,4) with less number of regressors. The other details of the model summary are given in Table (6.4.15) to Table (6.4.18). A comparison of the residual ACF and PACF plots also showed the efficiency of the correction of data for performing ARIMA.

In general ARIMA (4,0,4) is given by,

$X_t = \phi_1 x_{t-1} + \ldots\ldots + \phi_4 x_{t-4} + \theta_1 e_{t-1} + \ldots\ldots\ \theta_4 e_{t-4} + e_t$

$\phi_{1,\ \ldots\ldots}\ \phi_4$ are the AR parameters and $\theta_{1,\ldots\ldots}\ \theta_4$ are the MA parameters to be estimated.

The ACF and PACF of Idamalayar monthly Inflow (corrected)



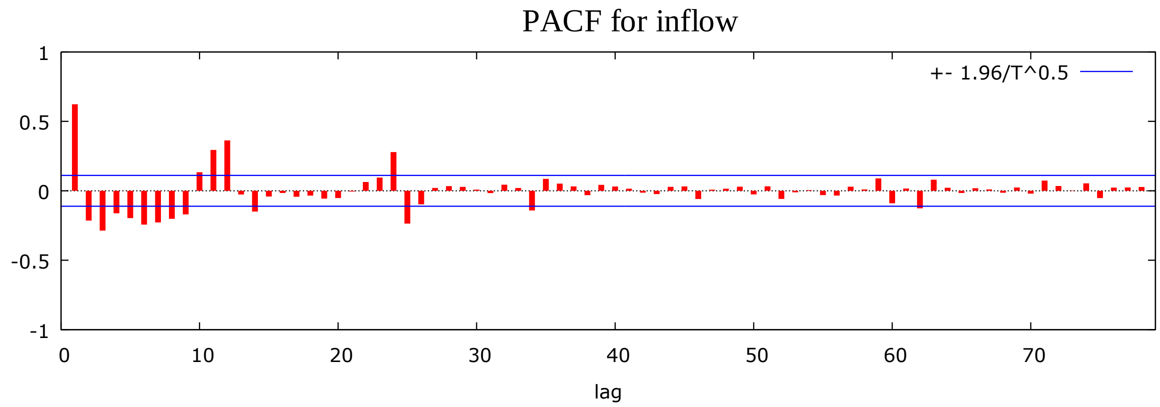


Fig. 6.4.20

Table 6.4.14: Autocorrelation function for corrected monthly Inflow to Idamalayar Reservoir

LAG	ACF		PACF		Q-stat.	p-value
1	0.6234	***	0.6234	***	122.423	0.00
2	0.2577	***	-0.2141	***	143.414	0.00
3	-0.1055	*	-0.2864	***	146.943	0.00
4	-0.3378	***	-0.1617	***	183.249	0.00
5	-0.4678	***	-0.1966	***	253.091	0.00
6	-0.5135	***	-0.2435	***	337.503	0.00
7	-0.4678	***	-0.2275	***	407.807	0.00
8	-0.3346	***	-0.2017	***	443.886	0.00
9	-0.1337	**	-0.1696	***	449.667	0.00
10	0.2026	***	0.1342	**	462.977	0.00
11	0.5446	***	0.2944	***	559.505	0.00
12	0.7528	***	0.3629	***	744.546	0.00
13	0.5848	***	-0.0262		856.618	0.00
14	0.2355	***	-0.1497	***	874.855	0.00

***, **, * indicate significance at the 1%, 5%, 10% levels

The periodicities inherent in the Idamalayar Reservoir monthly Inflow (corrected data)

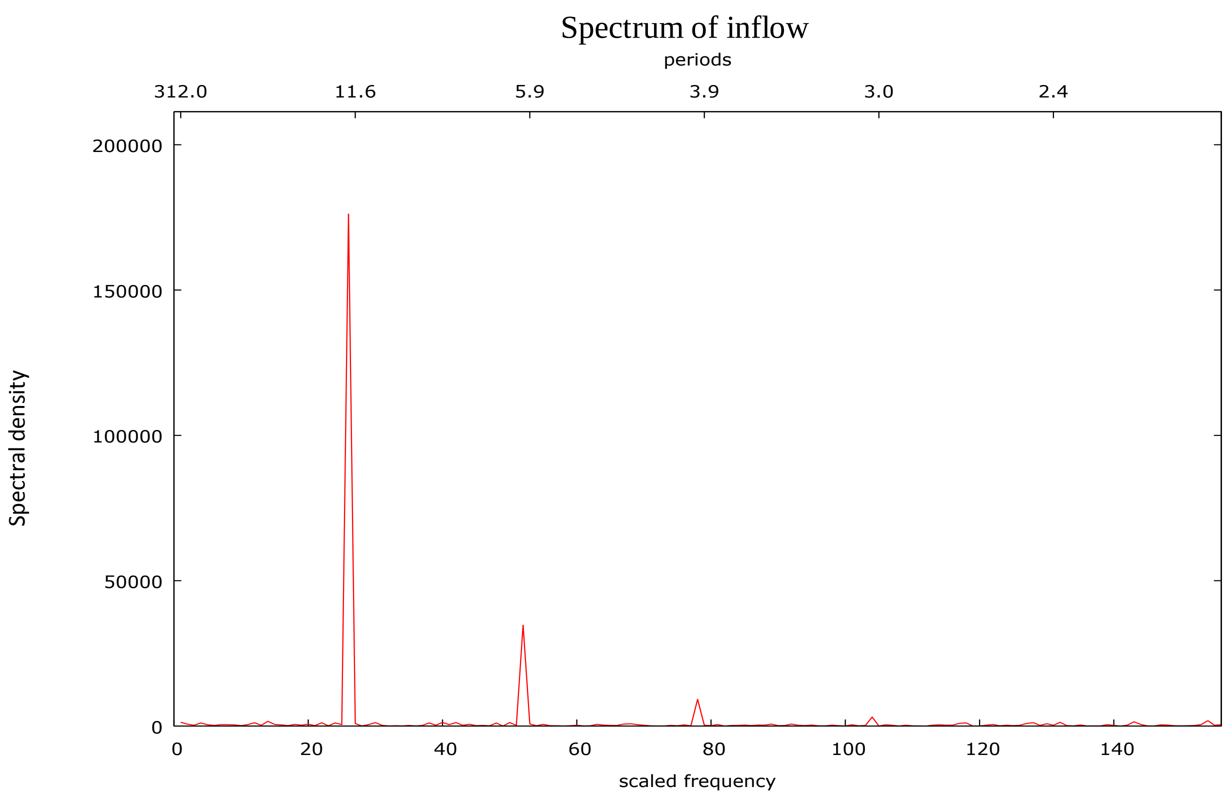


Fig. 6.4.21

The model was tried both for the raw data and corrected data. The results were promising when the model was tried for the corrected data. The results are shown as follows

Table 6.4.15: ARIMA model summary for raw data of monthly Idamalayar Reservoir inflow

Fit statistic	ARIMA (0,0,7)
Stationary R^2	0.74
R^2	0.55
RMSE	88.07
MAPE	77.75
Max APE	352.81
MAE	51.91
Max AE	532.62
Normalised BIC	9.09
L Jung Box Statistic	201.29**

Table 6.4.16:ARIMA model summary for monthly Idamalayar Reservoir inflow (corrected)

Fit statistic	ARIMA (0,0,7)
Stationary R^2	0.84
R^2	0.69
RMSE	59.42
MAPE	52.34
Max APE	366.16
MAE	34.77
Max AE	265.46
Normalised BIC	8.29
L Jung Box Statistic	40.63**

Table 6.4.17: ARIMA model parameters for raw data of monthly Idamalayar Reservoir inflow

		Estimate	SE
MA	Constant	3.99**	0.066
	Lag 1	-0.84**	0.053
	Lag 2	-0.60**	0.059
	Lag 3	-0.35**	0.052
	Lag 5	0.25**	0.052
	Lag 6	0.52**	0.059
	Lag 7	0.36**	0.055

Table 6.4.18: ARIMA model parameters for monthly Idamalayar Reservoir inflow (corrected)

		Estimate	SE
	Constant	3.784	0.04
AR	Lag 1	1.19	0.001
	Lag 2	-0.38	0.001
	Lag 4	-0.31	0.000
MA	Lag 1	0.88	0.029
	Lag 4	-0.49	0.048

Residual ACF and PACF for raw Inflow data

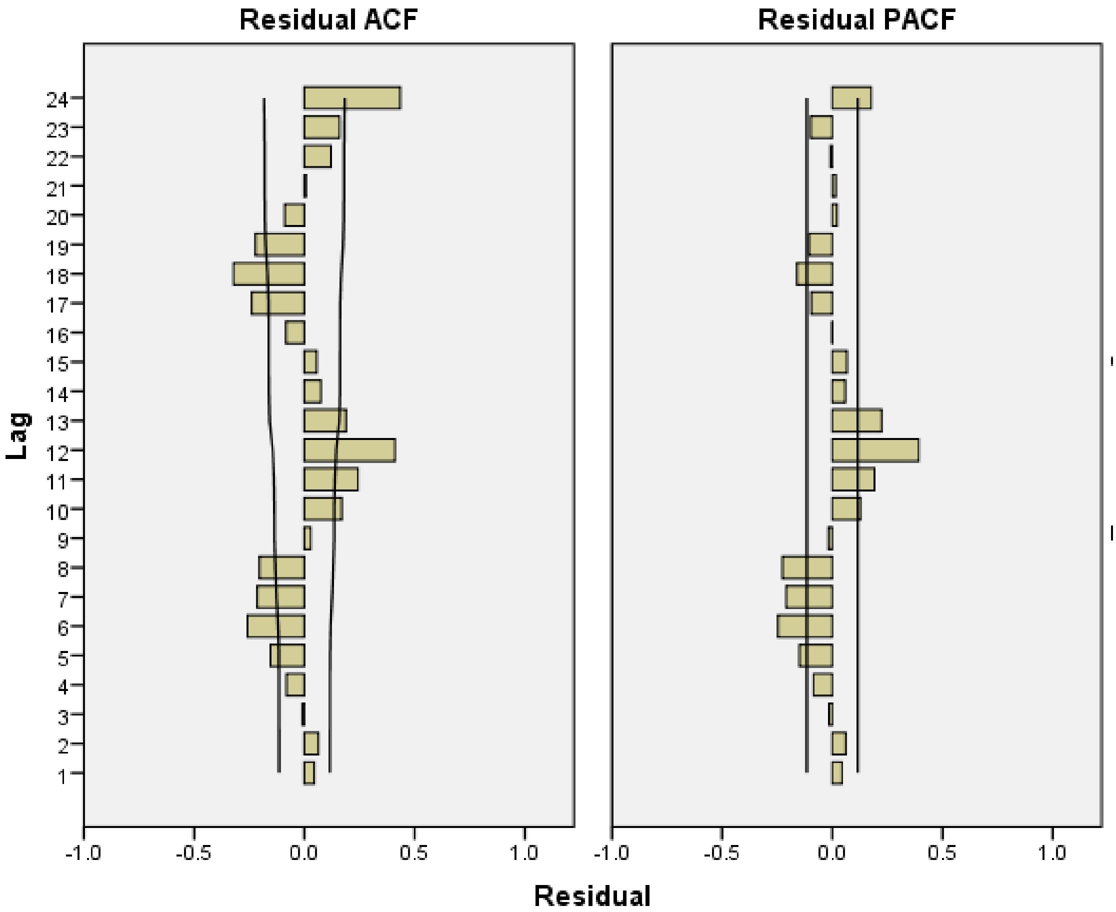


Fig. 6.4.22

Observed and predicted monthly Idamalayar Reservoir Inflow for raw data

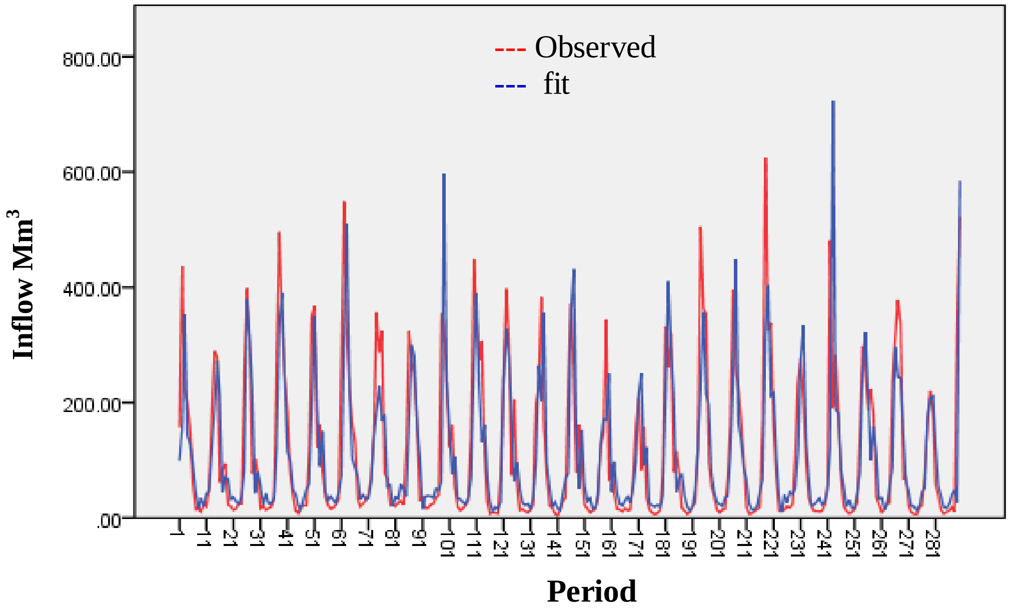


Fig. 6.4.23

Residual ACF and PACF for corrected Inflow data

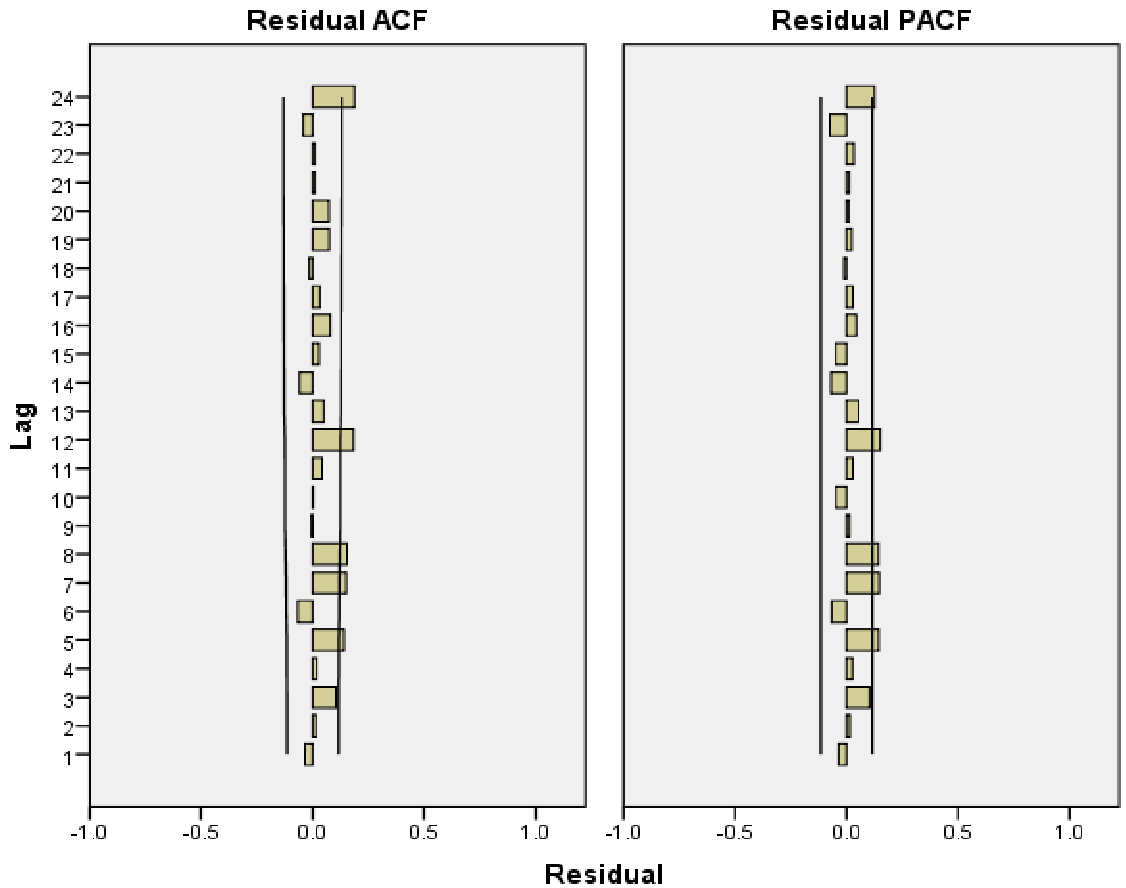


Fig. 6.4.24

Observed and predicted Idamalayar Reservoir monthly Inflow for corrected data (training period)

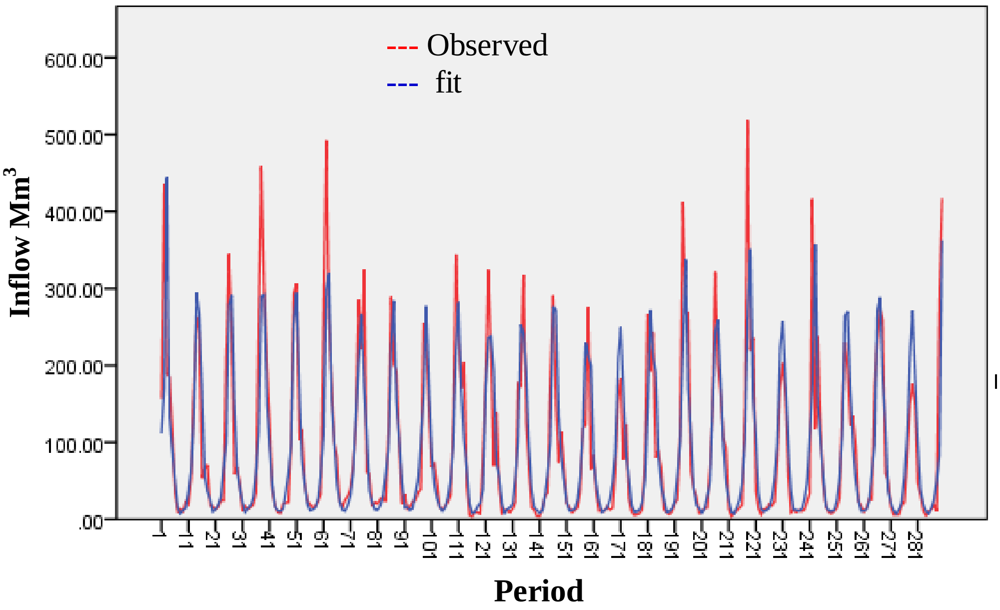


Fig. 6.4.25

The model was fitted taking the monthly data from June 1989 to July 2013 and the results were validated for the period from August 2013 to December 2017. The predictions were not tried as the data with respect to the release and diversion from Nirar and Poringalkuthu were not available. The line graph for the actual and predicted inflow for the validation period is shown in Fig. (6.4.26) with RMSE = 385.40 which is comparatively high when compared to the RMSE for the training period (59.42). This indicates the importance of using adequate data from the past for modelling purpose.

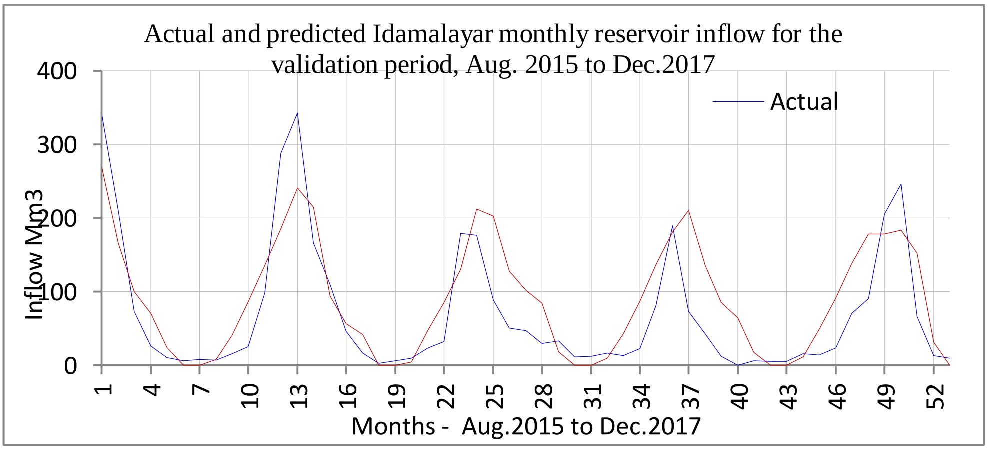


Fig. 6.4.26

Probability distribution fitted to monthly peak Idamalayar inflow

For each year, the quantity of peak monthly inflow to Idamalayar Reservoir was identified and probability distribution suitable for the same was fitted. The best fit model identified for peak Idamalayar inflow was Gamma (2). The results are given in Table 6.4.19 – 6.4.24 and Fig.6.4.27.

Table 6.4.19: Fit summary of peak Idamalayar monthly inflow

Distribution	p-value	Distribution	p-value
Beta4	0.889	Gumbel	0
Chi-square	0.006	Log-normal	0.971
Erlang	0.775	Logistic	0.913
Exponential	0	Normal	0.789
Fisher-Tippett (1)	0	Normal (Standard)	0
Fisher-Tippett (2)	0.922	Student	0
Gamma (1)	0	Weibull (1)	0
Gamma (2)	**0.974**	Weibull (2)	0.675
GEV	0.811		

The distribution that fits best the data for the goodness of fit test is the Gamma (2) distribution.

Table 6.4.20: Estimated parameters (Gamma (2)

Parameter	Value	Standard error
k	14.473	4.008
beta	26.713	7.529

Table 6.4.21: Log-likelihood statistics

Log-likelihood(LL)	-162.331
BIC(LL)	331.253
AIC(LL)	328.661

Table 6.4.22: Statistics estimated on the input data and computed using the estimated parameters of the Gamma (2) distribution:

Statistic	Data	Parameters
Mean	386.402	386.630
Variance	10322.013	10328.119
Skewness (Pearson)	0.272	0.526
Kurtosis (Pearson)	-0.459	0.415

Table 6.4.23: Kolmogorov-Smirnov test:

D	0.088
p-value (Two-tailed)	0.974
alpha	0.05

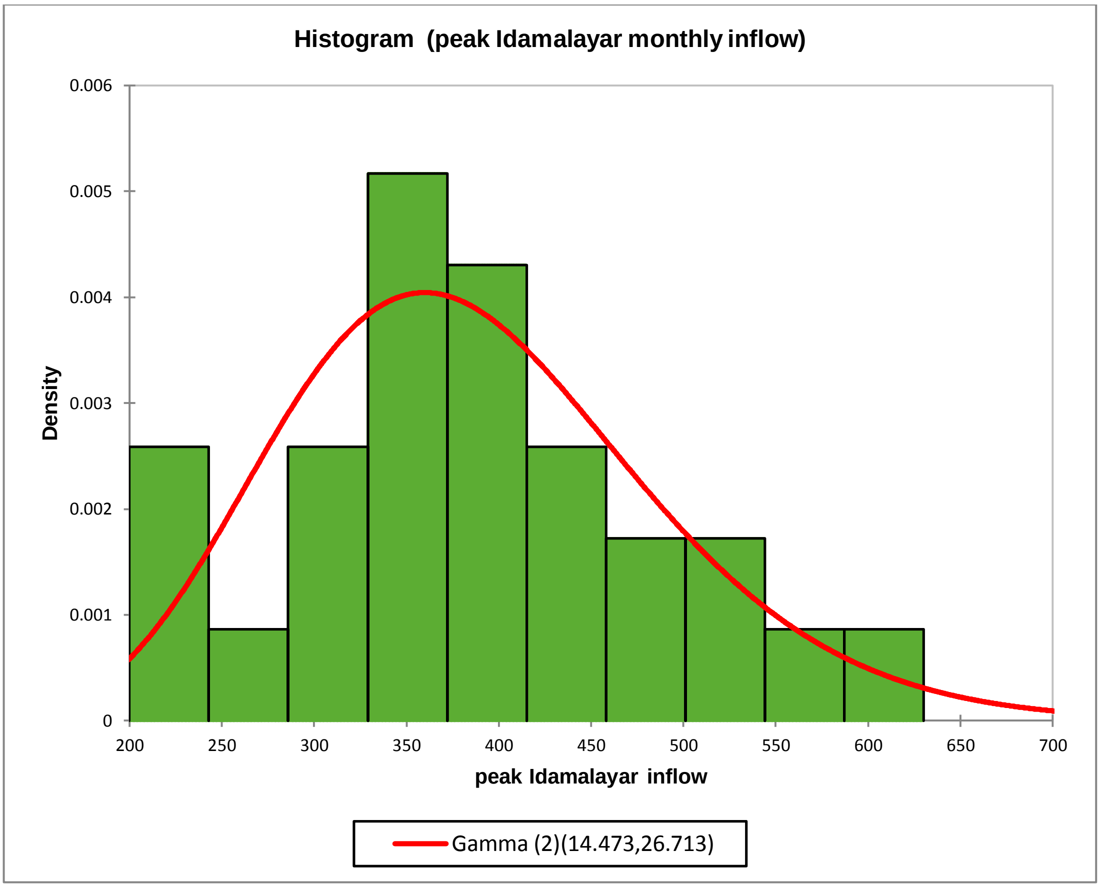


Fig. 6.4.27

Table 6.4.24: Descriptive statistics for the intervals (peak Idamalayar monthly inflow)

Lower bound	Upper bound	Frequency	Relative frequency	Density (Data)	Density (Distribution)
200	243	3	0.111	0.003	0.046
243	286	1	0.037	0.001	0.097
286	329	3	0.111	0.003	0.147
329	372	6	0.222	0.005	0.172
372	415	5	0.185	0.004	0.164
415	458	3	0.111	0.003	0.133
458	501	2	0.074	0.002	0.095
501	544	2	0.074	0.002	0.060
544	587	1	0.037	0.001	0.035
587	630	1	0.037	0.001	0.019

7 SUMMARY

The main occupation of Kerala is Agriculture and it is highly dependent on climatic factors prevailing in a region. Understanding the climatic and hydro-climatic features of wet and dry spells is essential for effective agricultural and hydrological operations. Climate is the weather of a place averaged over a period of time. Climate change is mentioned in terms of years, decades and centuries. Weather conditions are expected to change day to day but climate remain relatively constant. If it does not remain constant then it is termed as climate change. Climate change is one of the greatest economic, social and environmental challenges faced by the world. Impacts of climate change on the water resources are likely to affect irrigated agriculture, installed power capacity etc.. Therefore in recent decades, attempts have been made worldwide to understand this problem on regional – local scales.

Considering the importance of the impact of climate change, a study was carried out for a quantitative assessment of climate change in Kerala. Mainly, statistical techniques involving climate modelling are essential tools for this purpose. A preliminary analysis of the climatic variables are necessary to build up models for the future. The most important climatic variables were found to be rainfall and surface temperature and rainfall is considered to be the most variable element in any meteorological study of a particular region. Keeping in view of these points the objectives of the study were formulated as

1. To Study the variations in onset of South-West monsoon in Kerala and to develop a stochastic model to predict it.
2. To study the spatial and temporal variations of rainfall in Kerala.
3. To explore the capabilities of probability distributions in fitting climatic variables.
4. To navigate through the pentads of climatic variables – a case study of Vellanikkara, Thrissur district.
5. To investigate the impact of climate change on reservoirs of Kerala - a case study of Idamalayar reservoir inflow.

The salient findings of the study are as follows:

The statistical analysis of onset dates of SW monsoon for 147 years from 1870 – 2016 published by IMD and daily climatic variables for 33 years from 1984 – 2016 for the region Vellanikkara (bounded by 10^0 31'; $76^0$13'), Thrissur, Kerala has resulted in the conclusion that the prime variable which can be used for prediction of onset dates is rainfall. The average date of onset was found to be June 1 with a S.D of 7 days. In 74% of the years, the onset was in between 25th May to 8th June. On an average, a pre monsoon rainfall peak (PMRP) was found to occur 8 pentads before onset. The correlation coefficient between dates of PMRP and onset dates of SW monsoon was 0.59 which was highly statistically significant. The study revealed that the agro meteorological data recorded at automatic weather stations are also equally capable like satellite data to predict the onset dates using the details of PMRP. As against this meteorological approach, long term predictions were tried in the statistical approach of prediction using weighted least square method with heteroscedasticity correction. Regression models were fitted to predict onset dates using its own significant auto correlated lags. Promising results with high level of accuracy could be realised using the statistical approach of forecasting.

A detailed investigation of the rainfall data for 146 years from 1871 to 2016 published by IITM revealed that the long term average rainfall in Kerala was 2816.65 mm with a S.D of 415.06 mm and C.V=14.74 . The long term average for different months from January to December ranges from 10.77 mm in January to 679.61mm in June. In February, the average rainfall was 16.35 mm and in March 36.97 mm. For April & May it was 111.66 mm & 243.32 mm. A significant hike was observed in the average rainfall in June as 679.61mm and in July 633.45 mm. Again there was diminishing values as 375.81mm in August and 229.91 mm in September. Due to the North East monsoon, a slight increase was observed as 287.16 mm in October. Again there was a descend to 154.46 mm in November and a steep fall to 37.18mm in December.

The monsoon rainfall is considered to be normal if it is within 1 standard deviation of the long term mean and wet/dry if it is beyond 1 standard deviation of the long term mean. Out of the 146 years under study, 99 years received normal rainfall, 21 years were wet and 26 years were dry. In Kerala, the frequency of year after year dry years were more than consecutive wet years. After 1997 a wet year has not occurred in Kerala whereas frequency of occurrence of dry years was increasing. From 2000 onwards, dry years occurred in Kerala with an average gap of 3 years. In 2016, the government declared the entire State drought hit, with all the 14 districts witnessing successive monsoon failures. Reservoir levels were at least 22% lower than the average. The worst affected years in Kerala due to flood and drought were 1924 and 2016 respectively.

The one way ANOVA to compare the different decades with respect to the monthly, seasonal and annual rainfall showed that even though there was no significant variation between the annual rainfall in different decades starting from 1871 to 2016, there was a highly significant decadal variation in the post monsoon period.

The non parametric Mann- Kendall test was used to examine the significance of trend in monthly , seasonal and annual rainfall in Kerala for the period from 1871 - 2016. The results showed that there was no significant trend for the annual rainfall in Kerala. But when the individual months were studied in detail there was a significant negative trend for the occurrence of rainfall in the month of June (sen's slope = -1.122 significant at 0.01 level of significance) and July (sen's slope = -0.642, significant at 0.05 level of significance) both these have resulted in a significant negative trend for the SW monsoon as a whole *(*sen's slope = -1.283, significant at 0.10 level of significance). In contrary to this, a significant positive trend was found in the month of January *(*sen's slope = 0.008, significant at 0.01 level of significance) and in September (sen's slope = 0.396, significant at 0.10 level of significance). Thus there is a slight shift in the rainfall pattern in Kerala over different months.

Since there exists variability in the annual rainfall received in different time periods, the management of irrigation, water supply and operations related to reservoirs are done, not based on the long term average of rainfall records but on particular rainfall depths that can be expected for a specific probability or a return period. The expected estimates of rainfall depths (Xp) or intensity of rainfall for a specific probability with respect to a reference period (hour, day, week, month, year etc.) are essential for the management of irrigation and drainage projects. This probability refers to the probability of exceedance which gives the likelihood that the actual rainfall during that particular period would be equal to or higher than the estimated rainfall depth Xp . This is termed as 'dependable rainfall' in irrigation science as it is the maximum amount of rain one can rely on during the reference period.

The weather condition in a period is said to be dry if the probability of exceedance is 80 % or more and normal if there is 50% of probability of exceedance and humid if it is 20 % or less. The Weibull, Sevruk and Geiger and the Grimgorten methods of finding the probability of exceedance were found to be theoretically sound. The rainfall corresponding to various probabilities of exceedance can be obtained by plotting an appropriate curve of trend on the plotted points taking rainfall amounts along the X axis and probability of exceedance along the Y axis. The goodness of fit can be evaluated by the coefficient of determination (R^2). Comparison of estimated annual rainfall through Weibull, Sevruk- Geiger and numerical methods were also done.

A typical approach for acquiring an enhanced view of the spatial and temporal variability in precipitation is the detailed analysis of historical rainfall data which will give adequate information on the intensity or spread of rainfall with respect to time and space for a region. The monthly rainfall data for the period from 1990 to 2016 pertaining to 14 districts of Kerala were analysed and salient results are extracted. According to the summary statistics of the district wise rainfall data, it could be observed that the Idukki district was top (in the case of average quantity of rainfall received (3645.91 mm) for the period from 1990 to 2016. Then came Kasaragode (3443.47 mm) and Kannur (3298.56 mm). Kozhikode received an average rainfall of 3262.97 mm. Ernakulam (3258.61 mm), Kottayam (3037.04 mm) and Thrissur (2925.27 mm) were in the 5^{th}, 6^{th} and 7^{th} positions. Pathananthitta (2890.72 mm), Malappuram (2740.37 mm), Alappuzha (2685.74 mm) and Wayanad (2565.96 mm) were the next districts. The last 3 districts in the order of average quantity of rainfall received were Kollam (2507.67 mm), Palakkad (2199.85 mm) and Thiruvananthapuram (1833.63 mm). In all the districts the average rainfall was below the normal rainfall. The corresponding normal rainfall for different districts were Thiruvananthapuram (1923mm); Kollam (2495 mm); Pathanamthitta (2840 mm); Alappuzha (2999 mm); Kottayam (3208 mm); Idukki (3769 mm); Ernakulam (3578 mm); Thrissur (3074 mm); Palakkad (2472 mm); Malappuram (2850 mm); Kozhikode (3671 mm); Wayanad (3409 mm); Kannur (3374 mm) and Kasargode (3613 mm).

In short, the Kasargode district has been subjected to extreme climatic variations as the rainfall received in June, July and August were maximum in this district and during the post monsoon season, the district experienced worst dry conditions attaining a minimum average rainfall in December, January and April, when compared to other districts. Kollam district recorded average maximum rainfall during January, February, October and November. Even though Kasargode district was top in average maximum rainfall received during the SW monsoon period, at the end of the period, *i.e.* in September, Idukki recorded the average maximum rainfall. Idukki receives rainfall in a uniformly distributed pattern during the SW monsoon season, which would be more beneficial for crops. During the summer season, March, April and May, the average maximum rainfall was recorded in Kottayam, Pathanamthitta and Ernakulam districts respectively. Thiruvananthapuram district recorded average maximum rainfall in December. But during SW monsoon period, the lowest average rainfall was recorded in June, July, August and September in this district. Kannur district recorded minimum average rainfall during February and March. Palakkad was worst hit in May with least rainfall and Wayanad also was adversely affected with minimum average rainfall during the months of October and November.

In 2016 almost all the districts were reported to be drought hit and Wayanad was the most seriously affected district due to drought throughout the study period.

Average annual rainfall for the period from 1989-‘90 to 2014-‘15 for selected stations of K.S.E.B was also studied. It was found that the individual station’s rainfall records are highly fluctuating and have no consistency in the amount of rainfall as evidenced by the value of C.V.

In the field of climate research, one of the most challenging and important aspects of climate modelling is with respect to precipitation. Therefore fitting of rainfall probability distributions are of keen interest to fully describe the climate regime and to have a quantitative assessment of climate change for utilising it on other fields such as agriculture, hydrology etc. at a variety of scales.

In order to take protective measures and to deal with the consequences of rainfall anomalies, it is essential to provide a complete understanding about the range and likelihood of monthly or seasonal rainfall totals possibly receive. Modelling of rainfall data using different probability distributions are very much useful for gaining this kind of information. Once the accumulation parameters of the distribution are estimated, different rainfall patterns can be described using them. Distribution parameters can be used as a foundation for monitoring rainfall conditions. An assessment of monthly, seasonal or annual accumulation of rainfall can be made combining distributions with probabilistic forecasts.

Probability distributions were fitted to the monthly, seasonal and annual series of rainfall in Kerala for 146 years from 1871-2016.The parameters of the distributions were estimated by the maximum likelihood method. Once the parameters of the chosen distribution have been estimated, Kolmogorov – Smirnov test was used to test the goodness of fit. Distributions identified for different months, seasons and annual rainfall in Kerala were Fisher Tippett (2) for rainfall series in April, Log Normal for May and Pre monsoon rain, Logistic for June and July rain, GEV for August and September rain, Beta4 fitted well with the October rain series, Gamma (2) for November, Exponential for December and Winter rain, Beta4 for SW and Post monsoon series and Normal distribution for annual rainfall series.

Probability distributions were fitted to hydrologic variables also such as Gamma (2) distribution for fitting the peak inflow to Idamalayar Reservoir. Beta 4 for yearly peak rainfall in Kerala. For Vellanikkara region,Thrissur district,the distributions identified were GEV for peak pentad rainfall, Fisher Tippet (2) for peak pentad in different years and Negative Binomial for rainy days with above 25mm rainfall.

In agriculture and water management studies, more detailed information than just departures from a mean state is required. It is well known that a well distributed rainfall is always better than heavy rainfall for few days over an agriculture region. The consistency of the minimum required rainfall is more important than the total received over time for crop cultivation. Crops perform well with a uniformly spread light rain than with a few heavy rains interrupted by dry periods.

The pentad rainfall reveals finer details of rainfall variations in space and time of individual stations, which may be regarded as spectra of rainfall under high dispersion compared to low dispersion spectra of monthly rainfall. The analysis of daily rainfall by 5-day totals is a satisfactory technique to identify the beginning, end and duration of the rainy pentad groups. Hence the possibility of extracting minute details of variability of weather elements has been tried using the daily data on rainfall, maximum temperature, minimum temperature, relative humidity, sunshine hours and wind velocity pertaining to Vellanikkara, Thrissur district of Kerala for a period from 1983 to 2016.

Since rainfall is the most important meteorological element of a region, investigators have devoted much attention to rainfall studies of a particular area. So the main purpose of this study was to identify the rainy pentads or beginning and end of the heavier rains, using 25 mm of rainfall in 5 days as the identifier. Navigation through the different pentads of different climatic variables also has been attempted.

A comprehensive study of the rainy pentads in Vellanikkara region showed that, on an average the number of rainy pentads in a year is 7 and the average number of days with more than 25 mm rainfall per day is 20. The progressive enhancement of rainfall through different pentads in the active rainy seasons from the month of May 1st to November 1st was computed for each year. The frequency percentage of rainy pentads and occurrence of rainy days with more than 25 mm and 50 mm above rainfall in a pentad were also computed. Probability distributions identified to be a best fit for peak pentad rainfall was GEV, Fisher Tippet (2) for peak pentads and Negative Binomial for number of days with more than 25mm rainfall in rainy pentads.

In this climate change scenario, distribution of water for agricultural purposes is a complicated issue and its management is generally affected by social, environmental and political factors. Surplus water during rainy seasons can be stored in reservoirs and can be utilised for irrigation in drought periods. So a well organised operation of reservoir system is important for getting maximum net benefit from the available water resources. A serious constraint in this regard is the shortage of reservoir water. For a precise estimate of reservoir yield, simulation models need to be developed.

Stochastic models have been developed to simulate reservoir inflow using the long term observed data on inflow from 1989-‘90 to 2016-’17 of Idamalayar Reservoir , Kerala and to compare the generated inflow with the observed values and hence to anticipate future inflow with reliability. The sequential nature of the reservoir management decisions, together with the inherent randomness of natural water inflows direct us to use Markov decision processes for modelling reservoir management problems and their optimisation through stochastic dynamic programming.

First order stationary Markov model assuming stationary mean, standard deviation and lag1 correlation for the historical and generated data resulted in a perfect simulation for annual stream flows and reservoir inflows. Seasonal models can be introduced in which the seasons can be either month or any intra year period variation and here the inherent periodicity would introduce non stationarity in the data. First order Markov model addressing the non stationarity is a better alternative recommended in this situation. Simulations for Karappara (10^0 27’ 25”N 76^0 38’ 51” E) Stream flow and Idamalayar (10^0 13’ 18” N 76^0 42’ 21” E)

Reservoir Inflow belonging to Kerala state have been realised with respect to both stationary and non stationary data.

Apart from the long term simulation models, short term prediction models were also tried to forecast reservoir inflow. The best fitted linear regression model taking rainfall of the current and previous months as the independent variables could explain 84% of the variation in inflow. Since most of the hydrological variables are serially correlated, the prediction was also done using ARIMA models. ARIMA (4,0,4) model was identified to be the best with stationary R^2 = 84%.

Conclusion

A quantitative assessment of climate change in Kerala has been attempted through statistical techniques involving climate modelling. The most important climatic variables in climate modelling were found to be rainfall and surface temperature and rainfall seemed to be the most variable element in the study with respect to a particular region.

From the study of dates of onset of South West monsoon in Kerala using the data for 147 years from 1870 – 2016 published by IMD, it was found that the average date of onset in Kerala is June 1st with a S.D of 7 days. Prediction of onset of SW monsoon could be made with moderate accuracy using pre monsoon rainfall peak of the region. Long term prediction with improved precision is possible by applying the weighted least square method with heteroscedasticity correction using auto correlated lags of the dates of onset.

A detailed study of the rainfall data for 146 years from 1871 – 2016 published by IITM showed that the long term average rainfall in Kerala was 2816.65 mm with a S.D of 415.06 mm and C.V= 14.74. The peak rainfall was in the month of June. During the study period, 99 years received normal rainfall, 21 years were wet and 26 years were dry. The gap between dry years was found to be smaller than that of the wet years showing the enlarged frequency of dry years. Even though the decadal variation was insignificant with respect to annual rainfall there was a significant decadal variation for the rainfall received in the post monsoon period.

The significance of trend in monthly, seasonal and annual rainfall in Kerala was tested using the non – parametric Mann- Kendall test. Even though there was no significant trend with respect to annual rainfall, there existed a substantial negative trend for the june and july rain both contributing to a negative trend for the SW monsoon as a whole. A note worthy positive trend was noticed for the January and September rain. Thus in general there was a slight shift in the pattern of rainfall over different months in Kerala.

The probability of exceedance which is used to estimate the dependable rainfall can be effectitvely applied to describe the wet and dry conditions of a region. A comparison of five standard methods revealed that Weibull and Sevruk & Geiger methods were promising in finding the probability of exceedance and return periods of certain specific quantities of rainfall.

An enhanced view of the spatial variability in precipitation was made by a detailed analysis of historical data from 1990 – 2016 for 14 districts of Kerala which revealed the intensity and spread of rainfall with respect to time and space for a region. The Idukki district was top with respect to the average annual rainfall received (3645.91mm) and Thiruvananthapuram district had the least average annual rainfall (1833.63 mm). In all the districts, the average annual rainfall was below the normal. In 2016 almost all the districts were reported to be drought hit and Wayanad district was the most seriously affected district through out the study period.

To provide a complete understanding about the range and likelihood of monthly, seasonal or annual rainfall possibly receive in Kerala, probability distributions were fitted for the rainfall series for the period from 1871 - 2016. The parameters of the distributions were estimated using the maximum likelihood method and Kolmogorov – Smirnov test was used to test the goodness of fit. The best distribution fitted for onset dates of SW monsoon in Kerala was Logistic distribution. As far as rainfall series was considered logistic distribution was best suited for june and july rain, GEV for September and October rain, log normal for pre monsoon, Beta 4 for SW monsoon and normal distribution for annual rainfall.

As pentad analysis reveals finer details of climatic variables over a region, an attempt was made to study the pentad variations of climatic variables in the region - Vellanikkara, Thrissur district of Kerala for a period from 1983 – 2016. The average number of rainy pentads (above 25 mm rainfall in a pentad) in a year was about 7, the probability distribution to best fit the peak pentad rainfall was GEV, Fisher Tippet (2) for peak pentad and negative binomial for number of days with more than 25mm rainfall in rainy pentads.

Stochastic models have been developed to simulate reservoir inflow pertaining to Idamalayar Reservoir taking observed data on inflow from 1989 – ’90 to 2016 – ’17. First order stationary Markov model with stationary mean, S.D and lag 1 correlation for the historical and generated data resulted in a perfect simulation for annual stream flow and reservoir inflow. The non stationarity in the seasonal inflow data could be addressed through seasonal first order Markov model. Reservoir inflow prediction was tried by regressing previous month’s rainfall received and it could explain 55% of the variation in inflow. The adjusted R^2 was enhanced to 84 % when linear regression of inflow was fitted on the current and two previous months’ rainfall. As the inflow data was highly serially correlated, ARIMA models were also tried and ARIMA (4, 0, 4) was identified to be the best with stationary R^2 = 84%. The best fit model identified for peak Idamalayar monthly inflow was Gamma (2).

In short, climate change which is a present reality would affect the seasonal and annual climatic characters regionally and globally. To face the consequences of the same, the scientific results from various fields related to it are to be integrated in a meaningful way to overcome the adverse situations created. New strategies to study the effect of climate change at local regional levels are to be initiated so that new policy decisions can be made to reduce the ill effects of climate change in future.

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