STATISTICAL MODELLING OF CLIMATE CHANGE IN SOUTHERN KERALA

NEETHU R. S.

(2018-19-003)

DEPARTMENT OF AGRICULTURAL STATISTICS
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM – 695522
KERALA, INDIA.

2020

STATISTICAL MODELLING OF CLIMATE CHANGE IN SOUTHERN KERALA

by

NEETHU R. S.

(2018-19-003)

THESIS

Submitted in partial fulfilment

of the requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRICULTURAL STATISTICS

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM-695 522

KERALA, INDIA

2020

DECLARATION

I, hereby declare that this thesis entitled **"Statistical modeling of climate change in Southern Kerala"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any University or Society.

Neethu R.S

Place : Vellayani

Date : 25-08-2020

NEETHU R. S.

(2018- 19- 003)

CERTIFICATE

Certified that this thesis entitled **"Statistical modeling of climate change in Southern Kerala"** is a record of research work done independently by Ms. Neethu R. S. (2018-19-003) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

Place: Vellayani

Date: 25-08-2020

Dr. Brigit Joseph

(Major advisor, Advisory Committee)

Associate Professor and Head

Department of Agricultural Statistics

College of Agriculture, Vellayani

CERTIFICATE

We, the undersigned members of the advisory committee of **Ms. Neethu R. S. (2018- 19-003)**, a candidate for the degree of **Master of Science in Agriculture** with major in Agricultural Statistics, agree that the thesis entitled **"Statistical modeling of climate change in Southern Kerala"** may be submitted by **Ms. Neethu R. S. (2018-19-003)**, in partial fulfilment of the requirement for the degree.

Dr. Brigit Joseph
(Chairman, Advisory Committee)
Associate Professor and Head
Department of Agricultural Statistics
College of Agriculture Vellayani

Sri. Pratheesh P. Gopinath
(Member, Advisory Committee)
Assistant Professor
Department of Agricultural Statistics
College of Agriculture Vellayani

Sri. T. Paul Lazarus
Assistant Professor,
Department of Agricultural Economics
College of Agriculture Vellayani

Dr. Ajith. K.
Assistant Professor,
Regional Agricultural Research
Station, Kumarakom

ACKNOWLEDGEMENT

First of all I am bound to bow my head before almighty, who has uplifted me and led me to this endeavour.

With enormous preference, I would like to thank all the people who contributed in some way to the work described in this thesis. First and foremost, I would like to express my sincere gratitude to my major advisor ***Dr. Brigit Joseph****, Associate Professor and Head, Department of Agricultural Statistics for accepting me as her student. During my tenure, she contributed to a recompensing graduation experience by giving me endless support and guidance which is so precious for me to go ahead and has served as the major contributor towards the completion of the thesis. So, I am ineffably indebted to her for conscientious guidance and encouragement to accomplish this research work.*

I extend my sincere gratefulness to ***Dr. Vijayaraghava Kumar****, Retd. Professor and former head, Department of Agricultural Statistics, for his valuable advices, suggestions and support for the completion of this work.*

My sincere gratitude to ***Sri. Pratheesh P. Gopinath****, Assistant professor, Department of Agricultural Statistics, for his guidance and critical evaluation throughout my work.*

My heartfelt gratitude to ***Sri. T. PaulLazarus,*** *Assistant Professor, Department of Agricultural Economics, for his guidance and support which condensed to me in formulating the thesis.*

I am grateful to ***Dr. Ajith K.*** *Assistant Professor, Regional Agricultural Research Station, Kumarakom for his unbroken and well-timed advice at all the stages of my research work.*

I express my gratitude to ***Dr. Vijayamohanan Pillai****, visiting professor, GULATI, Institute for Taxation and Finance for his valuable advices in completing the research work successfully.*

I consider it as my privilege in expressing sense of reverence and gratitude to, Department of Agricultural Economics, for their appreciated support during the *course work.*

I express my sincere gratitude to the department staffs; Nisha mam, Asha mam, Muhsina mam and Neethu mam of Department of Agricultural Statistics for their sincere cooperation and timely approach during the course of study.

I am also thankful to my batch mates Nayana Narayanan, Gokul Krishnan, Adarsh, Nithin, Elizabeth and Supriya and my seniors Dhanya chechi, Athulya chechi, Suresh chettan, Murugesh chettan, Abhinav chettan, Arya chechi, Raghi chechi and my juniors Hari, Ardra, Anjana, Haritha, Jerrin, Krishnenthu, Harsha, Meera, Akhila, Venkata Rao for their selfless help, moral support, encouragement and fulfillment of class room environment during the study period.

I heart fully thank my close friends Reshma, Sruthy, Ayisha, Shafna, Anagha, Anju, Remya, Haritha for their selfless support and encouragement. I am also thankful to Veni, Vishnu, Shilpa, KavyaKrishnan for their timely contributions in data collection and thesis completion.

I am most indebted to my father, B. Rajendran, mother B. Sindhu, my brothers Abin, Arjun and Jibin and grandfather and grandmother and all my family members for their affection, selfless love, endless inspiration, caring, and blessings throughout my life. I have no words to express my feelings that how much they mean to me…

Finally, my thanks to all the people who have supported me directly and indirectly to complete my research work.

NEETHU R. S.

TABLE OF CONTENTS

LIST OF TABLES

LST OF FIGURES

LIST OF ABBREVIATIONS

ACF	AutoCorrelation Function
ADF	Augmented Dickey Fuller Test
AIC	Akaike's Information Criteria
AR	Autoregressive
ARIMA	Autoregressive Integrated Moving Average
BIC	Bayesian Information Criteria
CRS	Cardamom Research Station
CV	Coefficient of variation
DW	Durbin – Watson
Fig.	Figure
GOI	Government of India
GOK	Government of Kerala
HQIC	Hannan-Quinn Criteria
KAU	Kerala Agricultural University
KPSS	Kwiatkowski-Phillips-Schmidt-Shin
ln	Natural logarithm
MA	Moving average
MLE	Maximum Likelihood Estimator
PACF	Partial Autocorrelation Function
RARS	Regional Agricultural Research Station
RRS	Rice Research Station
SARIMA	Seasonal Autoregressive Integrated Moving Average
SD	Standard Deviation
SIC	Schwarz information criteria
SPSS	Statistical Package for Social Sciences
SS	Sum of Square
OLS	Ordinary Least Square
VIF	Variance Inflation Factor

LIST OF ABBREVIATIONS AND SYMBOLS

%	Per cent
°C	Degree Celsius
etc.	et cetera
i.e.	that is
et al.,	Co-workers
E	Expected value
mm	Millimetre
t	time
V	Variance
*	10% level of significance
**	5% level of significance
***	1% level of significance

INTRODUCTION

1. INTRODUCTION

Climate change nowadays is one of the biggest environmental problems ever faced by all the countries in the world. It has created a lot of problems to water resources, livelihoods and forest diversity. The long-term analysis of data sets on hydro climate plays a key role in climate studies. In the current scenario, it has become a major field of interest to the scientific community worldwide. But it is a difficult task to analyse the changing pattern of climate as it is happening due to various reasons, some of which are local and some are global factors. Analysis on hydro climatic variables can provide information on how the climate has evolved over time. Since, these events have a correlation with respect to time; it is relevant to apply time series analysis on the time dependent data (Goswami *et al*., 2017). As far as India is concerned, its luxurious biodiversity is the gift of the tropical weather conditions. Nowadays these changing weather conditions become a major challenge due to the sophisticated and dynamic nature of the weather system. The day to day changes of weather parameters like pressure, temperature, wind speed and humidity are the meteorological parameters to be monitored on a continuous basis.

1.1 CLIMATIC PARAMETERS UNDER STUDY

Temperature is an important weather parameter which has substantial influence on productivity of the most of the crops. Plant growth is highly correlated with a broad spectrum of temperature limits. There are mainly three distinct fundamental temperature points on which different chemical and biological activities of plants take place: minimum temperature, which initiates the growth; optimum temperature, which is the most advantageous one for all the biochemical activities; maximum temperature, which stops the growth. However, the fundamental temperature points of growth may vary considerably on temperature adaptation, developmental stage, the season and time. Also due to diversity in plant species owing to its own peculiarities and its geographical origin, the specific temperature requirement for its growth and reproduction may vary. For most tropical crops, a rise in temperature up to 25-28^0 C will increase the rate of photosynthesis and beyond this limit may create supposition to biological activities.

Rainfall has a noticeable and surprising effect on agriculture. All plants require at least some amount of water for its survival, so rainfall is the major source of water which is an inevitable component in the crop production system. As considered as an “essential evil”, regular rainfall patterns favors crop growth and yield whereas too much or too low rainfall can devastate the crop. Water requirements of plants vary considerably, for example tropical plants need hundreds of inches of rain per year whereas arid crops like cacti need only a few.

1.2. AGRICULTURE AND CLIMATE

Climate change of a place refers to gradual variations in the average weather conditions over a long period of time. Analysis of climatic parameters would enable the farmers to adopt agricultural practices that minimize the adverse effect created by the changing climate (Jhajharia *et al*., 2007). Thus, it helps the farmers for long term agricultural planning and adoption of suitable location specific technologies developed by the researchers. Changes in temperature and precipitation will adversely affect the crop productivity when there is scarcity during critical period, which in turn affects the food security and livelihood of the poor. Moreover, the reduction in food production and rise in poverty levels created by changing climatic parameters will be major threats for the economic development of several nations. The Intergovernmental Panel on Climate Change (IPCC) predicts that temperatures in India are likely to rise by 3-4^{0}C by the end of the 21st century (Pathak *et al.,* 2012).

Indian agriculture has been historically explained as a gamble with monsoon because agricultural activity in most parts of the country depends mainly on monsoon. India is heavily dependent on South – West monsoon (June – September) for most of its annual rainfall. However, many parts of southern India like Coastal AndraPradesh, South interior Karnataka, Tamilnadu, Pondicherry and Kerala receive considerable rain from North- east monsoon (October – December).

The Kerala state, known as “Gateway of monsoon in India " is one of the unique regions in the humid tropical monsoon climate which receives high solar radiation and warm temperature throughout the year since it is at a short distance away from the equator. It has an area of 38.86 lakh ha (1.185% of the national land area), and situated west of Western Ghats with latitudes of 8°18’ and 12° 48’N and longitudes of 74°28’ and 77°37’E (Gopakumar, 2011). Unimodal and bimodal distribution of rainfall with undulating topography, varied soil types and sharp changes in physiography (below msl to 2500 m above msl), together with 44 rivers, many freshwater lakes and estuarine backwaters give rise to contrasting ecological units congenial for high biological activity, contribute for its rich biodiversity in Kerala. The principal rainy seasons in Kerala are the South-west monsoon (June- September) and the North-East monsoon (October- November). The pre-monsoon months (March-May) are characterized by major thunderstorm activity in the state and winter months (December-January) are marked by low clouding and low rainfall season.

Agriculture activities in the state are mainly initiated with the arrival of rain during the pre-monsoon months. Kerala is known as a plantation state with the major staple food crops as paddy and tapioca. Cash crops like coconut, arecanut, rubber, cashew, tea, coffee and cocoa and the spices black pepper, cardamom, cinnamon, clove, turmeric, ginger, nutmeg and vanilla are also grown in the state. The low land is ideally suited for the cultivation of coconut and rice, the midland region with hills and valleys and rich in laterite soils favors the production of coconut, paddy, cashew, ginger, tapioca and rubber. However, the highland region covered by the dense forests is the site for cultivating plantation crops like tea, cardamom, coffee, pepper and rubber.

In Kerala paddy cultivation takes place during three major seasons viz Virippu (autumn) coincides with south west monsoon (June – September), Mundakan (winter) corresponds to North east monsoon (October – January) and Puncha (summer) during March to May. Autumn paddy is sown during April to June and harvested during August to December and winter paddy sowing is during August, September and October and harvesting during December and January. However, summer crop is sowing during November to March and harvesting during February to May.

Paddy cultivation in Kuttanad possesses some unique features. This is known as the rice bowl of Kerala comprising the part of three districts Alappuzha, Pathanamthitta and Kottayam. The land is located 2 – 3 m below MSL, which is one of the few places in the world where farming is practiced in 2.5 to 3 meters below sea level. Paddy fields in Kuttanad are known by the name “Puncha vayal” and are distributed in three types of land: Karappadam (upland rice), Kayal (wetland rice) and Kari. Saltwater intrusion due to the presence of Vembanad Lake restricts paddy cultivation in all the three seasons.

Cardamom is known as the queen of spices and is one of the most exotic and highly priced spices raised in the high ranges of Kerala. The crop needs elevated topography with cool and humid climate followed by good amount of sunshine and appropriate rainfall for good growth and economically viable yield. However, it can be raised in low land by providing shade and irrigation. Among the Indian states, Kerala has a dominant role in cardamom production. It accounted for 59 per cent cultivated area and 78 per cent of total production in cardamom to all India. Idukki district in Kerala accounted for 79 percent of cardamom area (32580 ha) and 90 per cent of total production (9080 MT) in Kerala (Mathew and James, 2017).

In this background a study entitled "Statistical modelling of climate change in Southern Kerala" was undertaken by using the secondary data on weather parameters from the different meteorological stations under KAU and production of paddy from Kottayam and cardamom from Idukki district with the following objectives.

- To develop statistical models to analyze climate change overtime across different regions in southern Kerala.
- To determine its impact on the yield of paddy and cardamom.

1.3. SCOPE OF THE STUDY

Through this study, it is possible to develop different models for weather data collected from three research stations of KAU in southern Kerala and then select the most suitable model which is capable of illustrating climate change overtime in the study region. Moreover, an emphasis was given to comparing the regional variation in the weather parameters. Also, this study ensures to give a wider picture about how climate change affects the performance of paddy in Kottayam and cardamom in Idukki irrespective of all other factors which may influence the yield.

1.4.LIMITATIONS OF THE STUDY

The study is based on secondary data collected from three research stations under KAU and from the annual report of the spice board and Department of Economics and Statistics. Some sort of interpolation and outlier eliminations were performed due to the presence of some missing values. However, an attempt has been made to have an in-depth analysis of the data by using suitable statistical tools and techniques to arrive at meaningful conclusions.

1.5.PLAN OF THE THESIS

The whole study has been presented in five chapters. The first chapter deals with the introduction and importance of modelling climate change, objectives of the study and scope of the study. The second chapter includes the review of studies made in the past which are related to the objectives of the present study. The third chapter deals with collection of materials and statistical methods used for the analysis. In the fourth chapter, results and discussions of the study are presented. The last chapter depicts the summary and conclusions drawn from the present study.

REVIEW OF LITERATURE

2. **REVIEW OF LITERATURE**

The findings of previous research works pave the way to understand the methodologies that may adopted for the present study. This chapter includes the critical reviews of literature related to the current study. The research works done by many research workers related to different statistical procedures and its practical applications has been critically reviewed under the subheadings given below.

2.1. Descriptive statistics

2.2. Trend models used for climate changes

2.3. Models for Weather parameters

2.4. Impact of weather parameters on crop yield

2.1. DESCRIPTIVE STATISTICS

Benjamini (1988) discussed the importance of boxplot in summarization of dataset, its properties and also alternative ways of data representation like stem and leaf plot, histogram and density traces. It also discussed that sides of each boxes indicates the variations within data set and density of values. Since the variations are computer insensitive, the easiness in making boxplots by hand should be sacrificed. The result obtained will be a dynamic display of densities and summaries.

Potter (2006) used boxplots as a standard technique for presenting the visual summary of the distribution of a dataset. It consists of construction, origins, and modifications made in boxplots which is helpful to make interpretation about the data presented by the box plot. It also provides insights to the important characteristics of a distribution, and permits the addition of information which helps the customization of the box plot to specific scenarios.

Mate and Arroyo (2006) considered boxplots (BPs) are exploratory charts used to obtain meaning full information quickly. This study indicated that boxplots can be considered as a kind of symbolic variable as they can summarize data retaining the key information and they introduced boxplot variables in this paper and proposed a set of descriptive statistics for these variables based on the principles used in statistics.

Dean and Illowsky (2009) considered box plots or box-whisker plots as a good graphical image to provide concentration of the data. Boxplots helps to detect outlier which was difficult to visualize through nacked eyes for bulky data set. The construction methods, structure, properties, identification of first quartile, median - the second quartile, and the third quartiles and interquartile range and how to use these values to identify the closeness of the values and outliers are discussed in the study.

Sun and Genton (2011) had proposed a simulation-based method for adjusting functional boxplots for correlations for visualizing functional and spatio-temporal data and detecting outliers. As a demonstration the study used information on sea surface temperatures, spatio-temporal precipitation and general circulation model (GCM) and the factor selection process and the modified practical boxplots were performed. The performance of the outlier detection was compared before and after the factor adjustments.

2.2. TREND MODELS USED FOR CLIMATE CHANGE STUDY

Bloomfield (1992) developed different trend and serially correlated noise models for the climate data such as global surface temperature. These models were capable to represent systematic change and other variations in the climatic data. The result of the study indicated that about 0.7 °C to 2.2 °C raise in temperature was obtained.

Katz and Brown (1992) developed statistical theory for incorporating extreme events in weather variables and the result of the analysis suggested that such event had affected variability rather than mean of the climate.

In this study Kumar *et al.* (1992) noted that, seasonal rainfall of the southwest monsoon in India did not follow a significant trend. In a country like India, where the economy depends on agriculture, understanding the regional level of rainfall trend using long-term information is of enormous significance.

Hosking and Wallis (1993) described three statistics useful in regional frequency analysis: a discordancy measure for identifying unusual sites in a region; a heterogeneity measure for to determine the proposed region is homogeneous; and a goodness-of-fit measure to detect a candidate distribution which will adequately fit to the data.

Singh (1999) studied the homogeneity of daily precipitation data of the monsoon season (June–September) for the period 1940–1980 from 50 stations in India. The correlation of individual station rainfall with all India seasonal rainfall is carried out to identify the homogeneity associated with the nature of rainfall based on statistical significances. In order to detect the nature of rainfall distribution in different monsoon categories, like normal, flood and drought years, an empirical orthogonal function (EOF) analysis was used and estimated percentages of variance explained for normal, flood and drought years. The result of the analysis found out that during normal, flood and drought years, the first four (most dominated) principal component with 'significantly positive' correlated stations explained 73%, 77% and 100% of the variance, whereas the remaining PC's for 'weakly correlated' stations explained almost 58%, 66% and 52% of the variance with all India seasonal mean rainfall. The technique applied helped for the identification of pronounced and organized rainfall patterns over Indian subcontinent.

Krishnamurthy and Shukla (2000) analysed the intra-seasonal and inter-annual variability of rainfall over India and concluded that the spatial patterns of rainfall anomalies over India on both daily and seasonal time scales vary considerably.

Simon and Mohankumar (2004) used factor assessment to study the variability in rainfall incidence and discovered it to be considerably affected by the state's overall physiography. The study also noted that there was no correlation between altitude and rainfall in Kerala.

Eslamian *et al.* (2006) used a hierarchical and divisive cluster analysis to categorize rainfall patterns in Iran. The study used cluster analysis technique to classify rainfall spatial time distribution pattern and also to assess annual and seasonal temporal pattern over 28 capitals of provinces of Iran. Based on the results so obtained, the annual rainfall over Iran was categorized into eight main spatial groups. The classification was made based on 3 main seasonal rainfall regimes such as, winter, and winter-spring and fall regimes. The study showed that rainfall pattern of Iran was also influenced by the elevation and presence of sea neighbourhood. A comparison between the Ward and average methods of hierarchical cluster analysis showed that the Ward method performs the spatial pattern better.

Heikkinen *et al.* (2006) reviewed a number of critical methodological issues causing uncertainty in predictions from bioclimatic modelling. The study found out that for to develop an effective bioclimatic models it is inevitable to acquire a good knowledge about the different methodologies adapted as far, which include various modelling techniques, model validation methodologies, concept of collinearity, autocorrelation of the residuals, biased sampling of independent variables, scaling and impacts of non-climatic factors.

Trend analysis surveys conducted for the country's 36 subdivisions indicated that June and July precipitation contributions are declining while August and September contributions are rising (Guhathakurta and Rajeevan, 2008). June rainfall contribution increased in 19 subdivisions and decreased in 17 subdivisions. In the survey an evidence of decline in rainfall especially in July was observed in both Central and Western India, while the contribution of August rainfall was increased in all of these subdivisions such as South Interior Karnataka, East MP, Vidarbha, Madhya Maharashtra, Marathwada, Konkan and Goa, and North Interior Karantaka.

Cryer and Chan (2008) gave an idea about the application of open source software R in performing different time Series Analysis. To understand in depth about the various codes needed to perform a specific action in R different examples from diverse fields were included. The study described the basic concepts in the theory of time series models and introduced the concepts of stochastic processes, mean and covariance functions, concept of stationarity and autocorrelation functions. The study illustrated these concepts with the basic processes like the random walk, white noise, moving average, and a random cosine wave. This book contains chapters related to deterministic trends in time series, regression methods were also used to estimate trends that are linear or quadratic in time. It also includes various methods for modeling cyclical or seasonal trends and the methods to check reliability and efficiency of all of these regression methods. The concept of residual analysis used to determine the accuracy of the fitted model were also included. In addition, the details of autoregressive-moving average (ARMA) time series models, Properties of mixed ARMA models, autoregressive integrated moving average models (ARIMA) and its properties were thoroughly explored here. Concept of Power transformation or Box-Cox transformation for to achieve stationarity and normality were also noted. The procedure used for the estimation of the unknown parameters in the time series models using both minimum AIC (MAIC) criterion and the conditional least squares approach were explained. Also, the concept of making predictions from threshold models, including the calculation and display of prediction intervals.

Krishnakumar *et al*. (2009) studied temporal variation in monthly, seasonal and annual rainfall over Kerala, during the period 1871 to 2005. The long term changes in rainfall was determined by Mann-Kendall rank statistics and linear trend by Sen's slope estimate. The analysis revealed a significant decline in southwest monsoon rainfall whereas an increase in trend was observed for post-monsoon season over Kerala State. Winter and summer rainfall showed an insignificant upward trend. Rainfall in June and July showed a substantial decline in trend as trends increased in January, February and April. Tropical Easterly Jet Stream during the southwest monsoon season is important rain bearing systems. Due to the decline in frequency of this weather systems over the peninsula in current scenario may be one of the important reasons for declining southwest monsoon in Kerala. Moreover, due to man-made interventions in recent decades, there is a drastic change in Kerala's biophysical resources. It indirectly affects the physical processes between the earth-atmosphere continuums and affects the distribution of local rainfall especially in winter and pre-monsoon season. An important reason for increasing post-monsoon rainfall over Kerala may be to increase the frequency of tropical cyclones during the post-monsoon season.

Pai and Nair (2009) used April mean surface temperature and winter snow cover data in Eurasia, developed a regression model for long range prediction of monsoon onset over Kerala. Using principal component regression (PCR) method a set of empirical models for prediction of summer monsoon onset of Kerala (MOK) was developed. Model 1 consists of five predictors pertaining to second half of April; Model 2 used two predictors of Model 3 and four additional predictors pertaining up to the first half of May. For each of the PCR models, Principal Component Analysis (PCA) of the respective predictor data was carried out using regression analysis of first two principle components (PCs). Both models showed good skill for prediction of MOK.

Raj and Azeez (2010) noted that the annual rainfall in the Western Ghats Palakkad Gap indicates altitude variability, showing that the region's annual rainfall is relatively lower than that of the entire state. A substantial decrease in the annual rainfall, winter rainfall and southwest monsoon were observed. The main aim of this study was to examine the general trend of rainfall in the Palakkad plains using monthly rainfall data, collected from four rain gauge stations available in the area. The annual rainfall pattern of all the stations showed a significant decrease in trend. The decrease in rainfall is an indication of actual regional level climate changes compounded by various anthropogenic factors.

Kumar *et al*. (2010) studied monthly, seasonal and annual trends of rainfall using monthly data for a period from 1871 to 2005 for 30 sub-divisions in India. Trend analysis showed that half of the sub-divisions showed an increasing trend, but statistically significant trend was found only for three states Haryana, Punjab and Coastal Karnataka. Magnitude of trend was calculated using Sens slope estimator. The statistical significance of the trend was analysed using the non-parametric Mann-Kendall (MK) test.

Raj and Azeez (2012) analysed the general rainfall pattern in Bharathapuzha basin, using monthly rainfall data for a period of 34 years based on secondary data collected from 28 rain gauge stations. They used Mann- Kendall’s rank correlation and wavelet analysis to identify the trend of rainfall. The annual rainfall, South-West monsoon, and pre-monsoon rainfall of the basin showed a significant decrease in trend.

Chakraborty *et al*. (2013) studied spatial and temporal variability of rainfall at Seonath sub basin in Chhattisgarh State from 1960 to 2008. For detecting trend nonparametric test like Mann-Kendall (MK) or Modified Mann-Kendall (MMK) and parametric test Spearman's rho test were used. A decreasing trend was found for both annual and seasonal rainfall data. Sen's slope estimators provided the direction and magnitude of trend if found significant. The CUSUM and cumulative deviations test were applied to detect change points. To obtain spatial trend ArcGIS 9.3 environment was used. Various descriptive statistical measures were calculated to give a summary of the data set, coefficient of Variation (CV) was used for analyzing the variability.

Sonali and Kumar (2013) tried to detect spatial and temporal trend analysis for Annual, Monthly and seasonal data for maximum and minimum temperature in India for a period from 1901 to 2003. Three time slots were selected viz. 1901 to 2003, 1948 to 2003 and 1970 to 2003 and the study region was divided into seven. Various non-parametric methods were used to detect the significance of trend. From the seasonal and annual anlaysis based on Mann Kendal test revealed that trend in temperature showed a rise from 1970.

Several soft computing approaches for the prediction of rainfall were attempted by Wu and Chau (2013). Two aspects to improve the accuracy of rainfall prediction such as data pre-processing procedure and a modular modelling method were used in the present analysis. The pre-processing techniques consist of moving average (MA) and singular spectrum analysis (SSA). However, modular models were composed of local support vector regression (SVR) models or/and local artificial neural network (ANN) model. For to forecast rainfall, the ANN model was used first to choose data pre-processing method from MA and SSA. In the Modular model's rainfall data was pre-processed into three groups such as low, medium and high levels based on the magnitudes of the rainfall data, and ultimately two SVRs were executed for both medium and high-level subsets since ANN or SVR was used in predicting the low-level subset. The result of the study showed that the as compared to SSA and ANN MA was found to be better. Which indicated that modular models outperformed other models. The ANN-MA also showed higher accuracy for predicting rainfall as compared to other models.

Madsen *et al*. (2014) presented a review of trend analysis based on observations and future climate projections of extreme precipitation and hydrological floods in Europe. It includes summaries, methodologies and key findings from various studies. The result of the analysis revealed that prominent increase in extreme precipitation was noticed, whereas there were no evidence for significant trends at regional or national level of extreme streamflow. The climate projections included in the study gave an indication of an increase in extreme precipitation in future scenario.

Deka (2015) used nonparametric Mann–Kendall statistic and Sen's slope model for identifying and estimating trend in rainfall of Brahmaputra valley over a period of 110 years. Also, to detect significance of decadal shift in precipitation Cramer's test was used. The result of the study revealed an overall decrease in both annual and monsoon rainfall which is a clear indication of a prominent spatial and temporal variation. The declining trends in rainfall in the eastern part of the valley were statistically significant and it was due to significant decrease of July and September rainfall, and the trend was found to be consistent. On the contrary, contribution of pre-monsoon and post monsoon rainfall to annual total in the Brahmaputra valley increased during the study period. The observed trends in monsoon rainfall, associated with large intra-seasonal variation increased probability of drought affected the predominantly rain-fed rice cultivation throughout the Brahmaputhra Valley.

2.3.MODELS FOR WEATHER PARAMETERS

Brereton *et al.* (1995) through this study scrutinized the potential effects of climate change due to enhanced greenhouse on the existence of 42 species of fauna in south-eastern Australia. For the purpose they used BIOCLIM, a bioclimate analysis and prediction system can determine the impact of climate change on fauna distribution. This study provides a regional perspective based on the possible effects of increasing greenhouse resulting climate change on the species in a particular range of habitats.

Saseendran *et al*. (2000) predicted a 1.5 ° C rise in mean surface air temperature during monsoon season in Kerala during 2040-49 century by taking 1980 as a reference. The temperature sensitivity analysis showed that there is a continuous decline in yield for a positive temperature change of up to 5 ° C. The crop maturity period was decreased by 8 percent for each increase in one degree centigrade, with a consequent decrease in yield by 6 percent. They also noted that an increase in the concentration of carbon dioxide leads to a rise in output owing to its fertilizing impact and also improves the water use efficiency of paddy.

Drought forecasting is essential to setup mitigation and recovery strategies. For that purpose, Mishra and Desai (2005) made a study to model drought pattern in Purulia district of West Bengal. Time series models such as ARIMA and SARIMA were used for the purpose. By using Standardized Precipitation Index (SPI) series the drought forecasting using the model was done in Kansabati river basin. By comparing predicted values with actual value and the value of standard error were used to pick up the best model. ARIMA (1, 0, 0) (2, 1, 1) was identified as the best fit model and found ideal for forecasting.

An accurate and efficient model for rainfall in Thailand was developed by Weesakul and Lowanichchai (2005). The data comprised of rainfall from 31 regional stations in Thailand and time series models like ARMA and ARIMA models were fitted over the data collected for a period from 1951 to 1990. The result of the study concluded that ARIMA was the best except for 8 stations which was favoured towards ARMA model. Also, the study revealed that ARIMA model was more capable to portrait inter- annual variations in rainfall pattern.

Using the monthly rainfall data Srivastava *et al*., (2007) constructed a new monthly, seasonal and annual rainfall time series of 36 meteorological subdivisions of India. The new rainfall series developed was temporally as well as spatially homogenous. Linear trend analysis was carried out to determine trend in rainfall over different subdivisions and examined monthly contribution of each of the monsoon months to annual rainfall. During the south-west monsoon season, eight subdivisions showed significant increasing trends and three subdivisions showed significant decreasing trend. Also, the study revealed that for few substations the contribution of

June, July and September rainfall to annual rainfall is decreasing while an increasing contribution of August rainfall observed for few other subdivisions.

Nayagam *et al.* (2008) developed a linear multiple regression model by considering ocean and atmospheric parameters as regressors for long-range prediction of Kerala's monsoonal rainfall. The quality of the forecast and its reliability were analysed using various statistical techniques like Durbin Watson statistics and Variance Inflation Factor (VIF). The model has got a multiple correlation of 0.943 and coefficient of determination as 88.8%. The root mean square error (RMSE) was 6.60% and bias was − 0.26%, absolute error was 5.33% respectively.

For to forecast monthly temperature and rainfall at Mirzapur, Uttar Pradesh (India) Kaushik and Singh (2008) utilized Box-Jenkins time series SARIMA (Seasonal Auto Regression Integrated Moving Average). Using this technique prediction model for temperature and rainfall of next five years was estimated based on last twelve years data (1994-2006). The performance evaluation of the adopted models was done based on squared correlation coefficient (R^2) and root mean square error (RMSE). The results of the analysis indicated that the SARIMA model is more efficient for forecasting monthly rainfall and temperature.

Naill and Momani (2009) used Box-Jenkins methodology to build ARIMA model for monthly rainfall data taken for Amman airport station for the period from 1922-1999. The study developed ARIMA (1, 0, 0) (0, 1, 1) model and forecasted the monthly rainfall for the upcoming 10 years. The result of the analysis showed a seasonal cycle existing in the series. Also, the ACF and PACF plots showed a slow decay gave an indication of non-stationarity nature of data set.

A large data set involving more than 50 years of rainfall and temperature data from coastal areas of Queensland of Australia were examined by Tularam and Mahbub (2010) by using spectral analysis, ARIMA model. Fourier analysis, linear regression and ARIMA based time series models were done using Matlab, SPSS and SAS programs. It was observed that seasonal variation was found for rainfall while temperature was stationary. The result of the analysis showed that a reasonable variation in both rainfall and temperature. Result of linear regression revealed that rainfall and temperature trend had an inverse relationship.

To develop a univariate model for forecasting summer monsoon in India Chattopadhaya, and Chattopadhaya, (2010) made a study using rainfall data for a period from 1877 to 1999. Before fitting the model, stationarity was checked, and trend analysis was performed. ARIMA model was fitted based on the randomness and stationarity test values. ARIMA (0, 0, 1) was found was suitable representative model. A three-three-one architecture of the ARNN model was procured and comparison was made between ARIMA and ARNN models and revealed the supremacy of ARNN over ARIMA (0, 1, 1).

Janhabi and Ramakar (2013) studied monthly rainfall data of each district for the years 1901–2002 of the Mahanadi River Basin of India. ARIMA model (1,0,0) (0,1,1) was found to be most suitable model for rainfall over the Mahanadi river basin. Best model was identified based on Akaike Information Criterion (AIC), goodness of fit (Chi-square), R^2 (coefficient of determination), MSE (mean square error) and MAE (mean absolute error) estimates and appropriate predictions were made using the model. The model was considered appropriate to forecast the monthly rainfall of each district for 12 years.

Bibi *et al*. (2014) tried to analyse spatial and temporal variability and trend in gridded daily rainfall data for a period of 27 years. Temporal variation was assessed using the coefficient of variation (CV) and temporal trends in rainfall was analysed using different plots of linear regression. Frequency and amount of the monthly rainfall were predicted using the ARIMA Model. Overall, the result showed that the model was found good in prediction for areas and months with lower temporal rainfall variability.

Amin *et al.* (2014) developed different time series models such as random walk with drift, constant mean, linear trend, simple exponential smoothing with alpha 0.707, Brown's linear exponential smoothing with alpha 0.197, Holt's linear exponential smoothing with alpha 0.11 and beta 0.66, ARIMA(1, 2, 2), ARIMA(0, 2, 2), ARIMA(1, 1, 2), ARIMA(0, 2, 2) with constant and ARIMA(1, 0, 1) with constant to forecast wheat production of Pakistan on the basis of historical data from 1902-2005. The best model was selected based on various information critereas like AIC and SBIC and found that ARIMA (1, 2, 2) was found as the best model.

John *et al.* (2014) made an attempt to examine the change in monthly temperature data for the period from 1977-2012, South Eastern Nigeria. Box and Jenkin's time series methodology including classical identification methods like ACF and PACF were employed. SARIMA (0, 0, 2) $(2, 1, 1)_{12}$ model was found to be adequate for forecasting monthly temperature from 2013 to 2017. In the model Verification step comparison was made between the actual and forecasted values in the year 2011 – 2012 was made and showed that the model is sufficiently capable to fit the time series data.

Modarres and Ouarda (2014) made an attempt to include time varying variance or the second order moment of hydrologic data since these factors is neglected while performing conventional time series technique for modelling rainfall data. The study introduced multivariate Generalized Autoregressive Conditional Heteroscedasticity (MGARCH) modelling approach which mainly concentrates on variance – covariance relation between hydrologic variables varies according to time. The two types of MGARCH models used were bivariate diagonal VECH-GARCH (1, 1) and CCC-GARCH (1, 1) models. These models were found capable for representing short-run and long-run tenacity in the variance–covariance matrix.

According to the Indian Meteorological Department (IMD) across the west cost of Kerala a clear upward trend of air temperature with a maximum of 0.8^{o}c and 0.2^{o}c minimum and 0.6^{o}c rise in average surface air temperature was observed during the period between 1961 and 2003. Rao et al., (2014) have reported that over the state the maximum and minimum temperature is increased by 0.64^{o}c and 0.23^{o}c during 1956 to 2004 also the overall increase in annual temperature was found to be 0.44^{o}c.

Gikungu *et al.* (2015) used Seasonal Autoregressive Integrated Moving Average (SARIMA) model to forecast inflation rate of Kenya using quarterly data for the period from 1981 to 2013. SARIMA (0, 1, 0) (0, 0, 1)4 was identified as the best model since it had the least Akaike Information Criterion (AIC) and the parameters were estimated through the Maximum Likelihood Estimation method. Normality Test was performed using Jarque-Bera checks which indicated that the data was normally distributed. ACF and PACF plots revealed that there were no autocorrelation and heteroscedasticity. The predictive ability tests RMSE, MAPE and MAE showed that the model was appropriate for forecasting the inflation rate in Kenya.

Dasyam *et al*. (2015) forecasted wheat production in India using annual time series data from 1961 to 2013. Exponential smoothing, parametric regression and Auto Regressive Integrated Moving Average (ARIMA) models was estimated and compared to find out an appropriate econometric model. Goodness of fit criteria like Root Mean Squared Error, Mean Absolute Percentage Error, Mean Absolute Error (MAE), Akaike Information Criterion (AIC), Schwarz's Bayesian Information Criterion (SBC) and R^2 were used to determine best model and ARIMA (1,1,0) model found to be most appropriate model for wheat production in India. The normality assumption of error term was checked using Runs-test and Shapiro- Wilk's test.

Saha *et al*. (2016) used SARIMA model to fit the monthly average maximum and minimum temperature at Giridih, India for the years 1990 to 2011. The autoregressive and moving average term was selected based on autocorrelation function (ACF) and partial autocorrelation function (PACF). The model parameters were finalized with the help of standard error, ACF and PACF of the residuals, Akaike Information Criteria (AIC), Bayesian Information Criteria (BIC), and corrected Akaike Information Criteria (AIC). The suitability of the selected models was determined by diagnostic checking with standardized residuals, residual ACF, normal Q-Q plot of standardized residuals and Jung-Box p-values. The models ARIMA (1, 0, 2) and ARIMA (0, 1, 1) were finally chosen to forecast the monthly average maximum and minimum temperature.

Tur production in Andhra Pradesh was forecasted using ARIMA model by Kotra and Sahik (2016) based on the production data during the period from 1966 – 2012. An ARIMA model was estimated and it was used to modelling the procution utilizing the most popular computer statistical package namely, SPSS. The best-predicted model has been selected based on the maximum R^2, minimum Bayesian Information Criterion (BIC) and Maximum Absolute Percentage Error (MAPE). The result of the analysis was that ARIMA (2, 1, 2) model was found to be most appropriate to describe the Tur production in Andhra Pradesh.

El-Mallah and Elsharkawy (2016) developed time series models to predict annual warming trend at coast Libya using Box-Jenkins method for model fitting through identification, estimation and forecasting. Annual surface temperature data from 16 stations were collected during the period from 1892 to 2010. Trend models like ARIMA (3, 1, 2) and quadratic model ARIMA (3, 2, 3) were found to be suitable for proper prediction.

An attempt was made by Goswami *et al.* (2017) to build an ARIMA model based on a total of 420 points for monthly rainfall data taken from Dibrugarh between 1980 and 2014 using the Box-Jenkins methodology. The best fitted model was ARIMA (0,0,0) (0,1,1) and the model was used to predict the pattern of monthly rainfall in the coming years that can help the decision makers to prioritize agriculture, flood management, management of water demand, etc. The predicted rainfall data showed a decline in rainfall from previous years during the upcoming year.

Murat *et al*. (2018) used ARIMA and regression models for forecasting daily air temperature and rainfall recorded between 1980 and 2010 in four European sites. The study used time series methods like Box-Jenkins and Holt Winters seasonal auto regressive integrated moving-average, ARIMA with external regressors in the form of fourier terms and the time series regression, including trend and seasonality components. Beside these methods, linear regression models were also used to forecast the meteorological time series data. The trend parameters were fitted with polynomial function and the seasonal parameter were estimated with fourier series. Moreover, it was found that air temperature is characterized by a left tailed distribution (negatively skewed) with a small kurtosis value, whereas rainfall pattern is strongly right tailed with higher positive skewness and very high kurtosis values

Unnikrishnan *et al.* (2018) made a novel attempt predict weather parameters of Thrissur District in Kerala using SARIMA models. The major emphasis of the analysis was to identify trend and best model for weather forecasting. The model validity has been evaluated using conventional statistical techniques. The findings of the analysis showed a good agreement with the predicted and real values and the fitted model for maximum temperature, minimum temperature, and wind speed, relative humidity measurements at 7 am and 2 pm and average cloud hours had low MAPE and high R^2 value. However, in the case of rainfall and rainy days, the models were found to have much higher MAPE and low R^2 values may be due to high fluctuation in the data. The selected model will then be checked against the previous data set to find out weather prediction was correct.

Tylkowski and Hojan (2019) made a study to analyse climatic varaibles changes in the natural environment in the South Baltic coastal zone of Poland using time series models. The parameters under study includes monthly data for air temperature, atmospheric precipitation, and average sea level during t period from 1966 to 2015 for three coastal stations in Poland. Study identified the seasonal and non-seasonal parameters that determine both current and future hydro meteorological conditions. They developed different ARIMA models correspond to the parameters under study.

2.4. IMPACT OF WEATHER PARAMETERS ON YIELD

Takahashi *et al.* (1955) noted that rice thermal regime controls the duration of rice tillering. Temperature is the key weather parameter that decide the production of tillers and ultimately the final rice grain yield. The present analysis showed that when temperature increases productivity will reduce.

Mathews *et al.* (1997) reported that an 1 ° C rise in daily temperature will resulted to 5-7% decrease in rice yield because temperature extremes can trigger injury to rice plant also resulted to sterility of the spikelet. Temperatures above 35 ° C reduces pollen viability during anthesis and increasing spikelet sterility ultimately resulted to yileld loss.

Rao *et al.* (2001) reported that excess rainfall during viripu is not favourable throughout the growing period and it adversely affects the yield of the crop especially for rice since it is raised under low-land condition. The occurrence of droughts or dry spell during the reproductive and maturation stages may provide favourable condition as it impart stress, which in turn improve paddy productivity however it delays the transplantation of paddy due to the lack of standing water during June and July.

During the kharif and rabi seasons, Sreenivas *et al.* (2005) performed field experiments to study the impact of weather parameters on low-land rice grain yield. The study revealed that the yield of grain was positively correlated during the reproductive phase with accumulated Growing Degree Days (GDD) during Virippu and bright sunshine hours in rabi season during all three rice phenophases. The results of the study observed that for optimum grain yield of low land rice, an accumulated GDD of 422 ° C day and 9.9 hours of daily mean bright sunshine is required during kharif and rabi seasons.

Yao *et al.* (2006) selected eight rice stations located in the main rice ecological zones of China to determine climatic change impacts on yield. The study used models like RCM (Regional Climate Model) and CERES-rice (Crop Estimation through Resource and Environmental Synthesis and revealed that yield will be reduced if high frequency and high variability in all the climatic parameters.

Khan *et al.* (2007) used Variety Naseer 2000 and variety IRRI-6 to study the relationship between yield of wheat and rice with respect to various dosage of phosphorus in Punjab. The experiment was carried out in RCB design with three replications. The result of regression analysis indicated that Phosphorus application had a significant impact on grain yield of wheat and rice, and they received 22% increase in wheat and 75% increase in rice yield.

Tao *et al*. (2008) tried to develop trend models for seasonal climate and to access their impacts on the yields of major crops like rice, wheat, maize in China over few years. The results of the analysis showed yield was significantly related to seasonal climate for all crops in the main production regions and growing season temperature had a general significant warming trend.

Studies conducted at IRRI by Kumary (2009) have shown that paddy yield decreased by 10 percent for every 1 ° C increase in temperature. The temperature rise is experienced across the state in the projected climate change scenario. A temperature increase by 2 ° C by 2025 would surely affect Kerala's paddy production. Warmer nights have a negative impact on paddy yield. Increasing temperature, rising sea levels, and expected changes in rainfall and distribution as a result of global climate change could result in a considerable change in land and water resources for rice productivity. The impact of climate change on rice production in Kerala will depend on the actual pattern of changes in the country's various rice-growing regions.

The influence of climate change on yield of crops was studied by Kumar *et al.* (2011) using A1b 2030 scenario derived from the Precis regional climate model (RCM). They found out that the crop yield was affected drastically if area receives higher temperature and low rainfall or if the area especially for high rainfall zones faces less rainfall and high rainfall alternately. However, reduction in rainfall in high rainfall zones benefited the crops to some extent.

Prakash *et al.* (2011) made a study to access the effect of climate variables on yield of major food-crops in Nepal, namely rice, wheat, maize, millet, barley and potato using regression model for time series climatic data and yield data for the period from 1978 to 2008. They got a positive result for yield and growth rate for crops under study. The result of regression analysis showed increase in summer rain and maximum temperature increased rice and potato yield in contrast to the yield of maize and millet. Increase in wheat and barley yield was influenced by current trend of winter rain and temperature.

Murugan *et al.* (2012) studied the significance of climate change in the production of spices and plantation crops and spatial and temporal variations in air temperature, rainfall and relative humidity across the stations. The analysis found out the temperature trend coupled with frequent wet and dry spells during the summer favour the pest and disease incidence. The impact of climate changes on the yield of small cardamom and coffee was also analysed using linear regression.

Gopika *et al.* (2014) studied the trend in rice area under cultivation, production and productivity in Kerala to find out relationship between rainfall variability and rice yield. Rainfall trend in kharif seasons showed a declining trend whereas rabi season indicated an increasing trend during the study period. The area under rice and rice production were in decline. It revealed that high rainfall during September and October are advantageous as it intervenes with harvest during kharif and transplanting during rabi. The study reveals that rainfall was in decreasing trend during kharif while increasing in rabi. In both the seasons, floods are not uncommon due to wet spells or single day high rainfall events. High rainfall during September and October are not conducive as it intervenes with harvest during kharif and transplanting during rabi. Overall, the study indicated that high rainfall across the State is not conducive for obtaining better yields.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

A detailed description of methods, procedures and measurement techniques adapted in the study entitled "Statistical modelling of climate change in Southern Kerala" is included in this chapter. Major headlines brought under here are listed below:

3.1 Study area

3.2 Secondary data and its sources

3.3 Descriptive Statistics

3.4 Trend analysis

3.5 Models for rainfall data

3.6 Impact of climate change on yield of paddy and cardamom

3.1. STUDY AREA

The present study is confined to Kerala especially the southern regions of the state. Secondary data required for the study was collected from four agrometeorological stations under KAU in southern region viz., RARS, Vellayani, RARS, Kumarakom, RRS, Moncompu, and CRS, Pampadumpara.

Regional Agricultural Research Station in southern zone is functioning in Vellayani since 1982. The meteorological department under the college was functioning since 1992. The department is undertaking IMD funded project "Gramin Krishi Mausam Seva" covering three districts Trivandrum, Kollam and Pathanamthitta. A class B agro met observatory is maintained which record weather data regularly on a time base and recorded weather data will be automatically send to IMD, New Delhi. RARS functioning in special problematic area comprising Kuttanad, Pokali and Onattukara tract is located in Kumarakom village of Kottayam district in which southern side was surrounded by river Kavanar and lies at an altitude of 0.6 m below MSL. Rice Research Station, Moncompu is situated in the heart of Kuttanad, rice bowof Kerala. Being a low-lying estuarine land, ie. the region consists of deltaic alluvium of four major rivers flowing through it along with the presence of Vembanad lake. RRS, Moncompu is one among the five satellite stations under RARS, Kumarakom. Cardamom Research Station, Pampadumpara was the only research station under KAU dedicated to Cardamom. The station is in Pampadumpara village of Udumbanchola taluk in Idukki district.

Kerala is divided into three geographical regions: Highlands, which slope down from Western Ghats to the Midlands of undulating hills and valleys into an unbroken coastline forming the lowland with many picturesque of backwaters, interconnected by canals and rivers. The Western Ghats are nowhere more than 120 km from the sea. There is a great variety of vegetation around the highland including scrub jungles, grasslands, deciduous forests, semi- evergreen and evergreen forests etc. This is the major hub of plantation crops like coffee, tea, cardamom, rubber, spices etc.

Kerala is a tropical land with a pleasant and equable climate throughout the year due to the presence of coastal lines throughout the length and presence of Western Ghats which act as a protective barrier against dry winds from north. Southern Kerala enclosed with coastal area stretching from north of Alleppey to the far southern border with Tamil Nadu. This region is the home to the state capital Trivandrum, Kollam, Pathanamthitta, Kottayam, Alappuzha and some parts of Idukki.

3.2.SECONDARY DATA AND ITS SOURCES

The secondary data required for the study was collected from four agrometeorological stations under KAU in the southern region. Data on major weather parameters such as maximum temperature, minimum temperature and rainfall was collected from College of Agriculture, Vellayani, Regional Agricultural Research Station (RARS), Kumarakom, Cardamom Research Station (CRS), Pampadumpara for the available period from 1991 to 2019 and from the Rice Research Station, Moncompu for a period of 1997 to 2018. Annual production for paddy from Kottayam district and cardamom from Idukki districts were also collected from the Annual Report of Department of Agriculture and Economics, GOK, and Spices board, GOI.

3.2.1. Weather parameters

3.2.1.1. Maximum temperature

Daily maximum temperature was noted and expressed in degree Celsius (° C). Monthly average temperature was calculated based on daily data for statistical analysis.

3.2.1.2. Minimum temperature

Daily minimum temperature was noted and expressed in degree Celsius (° C). Monthly average minimum temperature was calculated based on daily data to perform statistical analysis.

3.2.1.3. Rainfall

Rainfall on all rainy days was measured and expressed in mm. Monthly rainfall was found out for the purpose of statistical analysis.

3.3. DESCRIPTIVE STATISTICS

It is used to study the distributional properties of the variable under the study period such as extreme precipitation year etc. It is a method of analyzing data sets to summarize their main characteristics. Descriptive statistics are the arithmetic mean, range, standard deviation and Coefficient of Variation (CV %) etc. Graphs, tables, plots etc. are used for representing various descriptive statistical measures effectively. While expressing these measures using different tools, data quality, confidence and uncertainty are to be considered. Box-plots is a commonly used technique for data presentation due its capability for summarizing five categories viz., minimum, maximum values, upper and lower quartiles and median in a single picture. It is considered as a standard technique and a quick way to summarize the distribution of a dataset.

3.3.1. Arithmetic mean

It is the measure of central tendency as it locates a central value from the series of data of which all other values lie around. It can be calculated as the ratio between sums of all values to the total number of observations.

$$\bar{x} = \Sigma x \,/\, n \qquad 3.1$$

3.3.2. Range

It is simplest measures of dispersion and is calculated as the difference between largest and smallest values in a data set.

$$Range = \text{maximum value} - minimum\ value \qquad 3.2$$

3.3.3. Standard Deviation (SD)

It is a measure of dispersion as it indicates how the values in a series deviate from its common mean. It can be calculated as mean of square root of squared deviation from arithmetic mean.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \mu)^2}{N}} \qquad 3.3$$

Where $\sigma = Standard\ deviation, N = Size, \mu = mean$

3.3.4. Coefficient of variation (CV %)

It is a relative measure of dispersion as it indicates the reliability of data under consideration. The value of CV is high which means low reliability and vice versa. CV can be calculated as the ratio of SD to arithmetic mean expressed in percentage.

$$cv = (\ \sigma / \ \bar{x}\ )*100 \qquad 3.4$$

3.4. TREND ANALYSIS

A time series is an ordered sequence of values of a variable at equally spaced time intervals. Univariate time series is a sequence of measurements of the same variable collected over time. After getting data, the most important step in time series analysis is to plot observations against time. This graph should show up important features of a time series such as trend, seasonality, outliers and discontinuity. Mathematically time series can be expressed as a functional relationship between Y variable (observations) and time (t). Represented symbolically as Y = F (t). Time series analysis is very useful for detecting real behavior of the past and then predicting the future.

Trend measures long term fluctuations in time series rather than short term fluctuations. It delineates increasing, decreasing or stagnant fluctuations in the data.

Trend can be measured in many ways. In Statistical point of view trend denotes significant change over time which can be detected by parametric and non-parametric procedures while trend analysis aimed to detect the statistical significance and magnitude of trend. In the present study graphical method, Mann-Kendall and Sen's slope estimates are used for analyzing the trend in the time series data.

3.4.1. Graphical method

Graphical method is relatively less subjective and simpler as compared to all other methods. In this method, points (t_1, y_1), (t_2, y_2)… (t_n, y_n) were plotted taking time on abscissa and variate value along the ordinate with proper scale. Then a free hand straight line was drawn in between the points in such a way that the entire graph got divided into two parts thus half of the points will be above the line and half below it. Slope of the line gives an indication about the trend and the y coordinate of a point on the line at any points gives the trend value.

3.4.2. Mann-Kendall and Sen's slope estimates

Normality test for data set based on Shapiro Wilks criteria is performed which is the most common test for checking the normality of data set if sample size is less than 2000. Test statistics W in Shapiro Wilks test assumes that the sample data is taken from a normally distributed population.

Here H_0 : Data is normally distributed.

Shapiro – Wilks W statistics is calculated using the formula

$$W = \frac{(\sum_{i=1}^{n} a_i x_i)^2}{\sum_{i=1}^{n}(x_i - \overline{x})^2} \qquad 3.5$$

Where x_i are ordered samples values and a_i are constants generated from the mean, variances and covariance of order statistics of a sample of size n from a normal distribution (Pearson and Hartley, 1972).

If p – value is greater than critical value, usually 0.05 then null hypothesis is accepted which means that the data follows normal distribution. The range of W is from 0 to 1.

Mann- Kendall test is the most commonly used nonparametric test to analyze significance of trend and for determining magnitude of trend, non-parametric Sen's estimator method can be used. This is a statistical method which is mostly used to check the null hypothesis of no trend versus the alternative hypothesis of the existence of monotonic increasing or decreasing trend of time series data. The non-parametric Mann-Kendall test will be appropriate where monotonic nature of trend should be followed i.e. mathematically the trend consistently increasing and never decreasing or consistently decreasing and never increasing and no seasonal or other cycle is present. Two type of test statistics are used depending upon the number of data values i.e. S – statistics and Z – statistics, S- statistics are used if number of data values are less than 10 whereas Z- statistics used (normal approximation/distribution) if the data points are more than or equal to 10 (Salmi *et al.*, 2002).

In MK test the S – Statistics can be calculated by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(x\text{j} - x\text{i}) \qquad 3.6$$

Where x_i and x_j are annual values in year i and j, j > i respectively, n is the number of data points, and *sgn* ($x_j - x_i$) is calculated using the equation

$$sgn\left(x_j - x_i\right) = \begin{cases} 1\; if\; x_j - x_i > 0 \\ 0\; if\; x_j - x_i = 0 \\ -1\; if\; x_j - x_i < 0 \end{cases} \qquad 3.7$$

A positive or negative value of S indicates an upward (increasing) or downward (decreasing) trends when number of observations is 10 or more, the S statistics is approximately distributed as normal with the mean and variance given by

E(S) = 0

$$V(S) = \frac{n(n-1)(2n+1) - \sum_{i=1}^{n} t_i\,(t_i-1)(\,2t_i+5)}{18} \qquad 3.8$$

Where, n is the number of tied (zero difference between compared values) groups and t_i the number of data points in the ith tied group. Therefore the Z test statistic is defined as follows

$$z = \begin{cases} \frac{s-1}{\sqrt{var(s)}} & if\; s > 0 \\ 0 & if\; s = 0 \\ \frac{s+1}{\sqrt{var(s)}} & if\; s < 0 \end{cases} \qquad 3.9$$

Statistically the significance of trend is assessed by using the Z-value. A positive value of Z shows an upward (increasing) trend while the negative value indicates a downward (decreasing) trend.

The Sen's slope estimator provides a linear model for the trend analysis. The slope (Ti) of all data pairs is calculated using equation

$$T_i = \frac{x_j - x_i}{j - k} \tag{3.10}$$

where, x_i and x_j are data values at time k and j (j > k). The median of these n values of Ti is represented as the Sen's slope estimate for trend (true slope) using equation

$$Q_i = \begin{cases} T_{\frac{n+1}{2}} & for\ n\ is\ odd \\ \frac{1}{2}\left(T_{\frac{n}{2}} + T_{\frac{n+1}{2}}\right) & for\ n\ is\ even \end{cases} \tag{3.11}$$

Sen's estimator (Qi) is calculated using the equation depends upon the value of n as it is either odd or even and then (Qi) is computed using 100 (1 – α) % confidence interval using non-parametric test depending upon normal distribution. A positive value indicates increasing or upward trend while a negative value shows a downward or decreasing trend of a time series data.

3.5.MODEL FOR RAINFALL DATA

The time series approach used in this study is based on ARIMA - Box-Jenkins methodology. Exponential smoothing and ARIMA modelling are the most widely used time series approaches for forecasting purposes. Exponential smoothing uses trend and seasonality in the data set whereas ARIMA uses the autocorrelation relationship exists in the data set for model development and forecasting. For time series forecasting ARIMA models perform better as compared to exponential smoothening, so in this study ARIMA modeling technique was used for modelling rainfall data. Before selecting an appropriate ARIMA model for climatic data the stationarity of the data should be checked.

3.5.1. Stationarity and differencing

Stationary time series data is characterized by its unique nature of time independency of its various properties like mean, variance. A time series $\{x_t\}$ is said to be strictly stationary, if the joint probability distribution of observations (x_t, x_{t+1}, ..., x_{t+n}) is exactly same as the joint probability distribution of observations (x_{t+h+1}, x_{t+h+2}, ..., x_{t+h+n}) for every point ($t, t+1, \dots, t+n$) where h is the time space. The process $\{x_t\}$ is said to be weakly stationary, if it has a constant mean, finite variance and its auto-covariance function γ(t,s) depends only on the time lag |t−s|. There are many ways in which a time series fails to be stationary, and those are said to be non-stationary time series. Modelling of a non-stationary data will have no sense, so data should be stationary before fitting a model. By the method of differencing non-stationary data can be converted to stationary.

Differencing will stabilize the mean of the time series by eliminating or reducing trend and seasonality. Differenced series will be the change between consecutive observations. Ordinary differencing and seasonal differencing are the common ways to eliminate non-stationarity in the data.

First order differenced series:

$$y'_t = y_t - y_{t-1} \qquad 3.12$$

Second order differenced series:

$$y''_t = y'_t - y'_{t-1}$$

$$y''_t = y_t - 2\,y_{t-1} + y_{t-2} \qquad 3.13$$

Usually ordinary differencing upto two will be enough to make the data stationary. Sometimes seasonal differencing will also be found necessary to remove non-stationarity. This is nothing but difference between consecutive observations in the same season denoted as $y'_t = y_t - y_{t-m}$, where m is seasonal term.

3.5.1.1. *Unit root test*

The modern technique used to detect stationarity of the time series data is through unit root test. A number of unit roots tests are available such as Augmented Dickey Fuller test (ADF), Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test *etc.* In this study ADF test is used for detecting the stationarity.

The null hypothesis and the alternative hypothesis for ADF test is:

H_0: Presence of unit root indicating time series data is non stationary.

H_1: Absence of unit root indicating time series data is stationary.

The test statistic for ADF test is defined as follows:

$$\mathrm{DE_t} = \frac{\Upsilon}{SE\ (\Upsilon)} \qquad 3.14$$

DE_t is found greater than critical value or less than 0.05, then H_0 is rejected, otherwise we will accept H_0.

3.5.1.2. *Autocorrelation and Partial autocorrelation functions (ACF and PACF)*

Classical method used to determine whether data is stationary or not is by analyzing the nature of ACF and PACF plots. These plots graphically summarize the strength of association between observations in present time with its previous period.

Auto correlation is the correlation between observations of a variable taken at different time points. Auto Correlation Function (ACF**)** plots are widely for checking randomness in a data set. This randomness is ascertained by computing auto correlations for data values at varying time lags. Partial Auto Correlation Function (PACF) of $\{Z_t\}$ is a partial correlation coefficient between $\{Z_t\}$ and $\{Z_{t-k}\}$ by fixing the effect of others. PACF of order k is the correlation coefficient between $\{Z_t\}$ and a suitable linear combination of $Z_t, Z_{t-1}, \ldots,$ .ACF and PACF plots are drawn by considering correlation coefficients on the y-axis with number of lags in the x-axis. If the ACF and PACF plot shows a sudden decay then it indicates that the data is stationary or if a slow decay was observed which indicates non-stationarity.

3.5.2. Autoregressive model (AR Model)

In an autoregressive (AR) Model, each value in a series should be a linear function of the preceding value or values. In a first-order autoregressive process, only the single preceding value is used or in a second-order process, the two preceding values are used, and so on. These processes are commonly indicated by the notation AR(p) or ARIMA(p-0-0), where the number in parentheses indicates the order.

AR model of order p can be written as:

$$y_t = c + \phi_1 y_{t-1} + \phi_2 y_{t-2} + \cdots + \phi_p y_{t-p} + \varepsilon_t \qquad 3.15$$

3.5.3. Moving average model (MA Model)

In this model instead of considering past values of forecast variables past values of forecast errors are considered in the regression equation. In a moving-average process, each value is determined by the weighted average of the current disturbance and one or more previous disturbances. The order of the moving-average process specifies how many previous disturbances are averaged into the new value.

MA model of order q can be written as

$$y_t = c + \varepsilon_t + \theta_1 \varepsilon_{t-1} + \theta_2 \varepsilon_{t-2} + \cdots + \theta_q \varepsilon_{t-q} \qquad 3.16$$

3.5.4. Non seasonal ARIMA Model

Combination of AR and MA models along with order of integration or difference will form an Autoregressive Integrated Moving Average (ARIMA) model. The full model will be in the form:

$$y'_t = c + \phi_1 y'_{t-1} + \cdots + \phi_p y'_{t-p} + \theta_1 \varepsilon_{t-1} + \cdots + \theta_q \varepsilon_{t-q} + \varepsilon_t \qquad 3.17$$

Where y'_t the differenced series and right hand side contain predictors of lagged values of y_t and ε_t (residual term).

The form of ARIMA (p,d,q) can also be written as,

$$\phi(B)(1-B)^d Z_t = \theta(B)\varepsilon_t \qquad 3.18$$

Where ϕ – Coefficient of non-seasonal AR component

B – Backshift operator

θ - Coefficient of non-seasonal MA component

This can be notated simply as ARIMA (p, d, q)

Where p – Order of autoregressive part

d – Order of integration

q – Order of moving average part

3.5.5. Seasonal ARIMA (SARIMA) Model

The SARIMA model is formed by including a seasonal component to the ARIMA model. It can be represented as ARIMA (p, d, q) (P, D, Q) in which p and q are non-seasonal autoregressive and moving average parameters, P and Q are the seasonal autoregressive and moving average parameters, respectively. The two other parameters, d and D, are non-seasonal and seasonal differencing respectively, used to make the series stationary.

The form of ARIMA (p,d,q) × (P,D,Q) has the following form,

$$\phi_p\ (B)\ \Phi_P\ (B^S)\ \nabla^d\ \nabla_S^D\ Z_t = \ \theta_q\ (B)\ \Theta_Q\ (B^S)\ \varepsilon_t \qquad 3.19$$

Where Φ – Coefficient of seasonal AR component

Θ - Coefficient of seasonal MA component

To obtain the ARIMA model by the Box-Jenkins methodology, there are three steps that must be considered which are identification, parameter estimation, and diagnostic checking (goodness of fit test).

3.5.5.1. *Identification*

In this step, three integers p, d, and q and P, D, Q representing respectively the number of autoregressive orders, the number of differencing orders, and the number of moving-average orders of both non-seasonal and seasonal part of ARIMA model are determined. Stationarity check of the data set reveals the nature of order of integration included in the model. It can be done by using classical method involving autocorrelation functions (ACF) and partial autocorrelation functions (PACF) plots and modern method like Augmented Duckey Fuller test (ADF) test (Saha *et al*, 2016).

3.5.5.2. *Estimation of parameters*

After estimating order of the model next step is to determine the parameters such as c, $\phi_1, \dots, \phi_p, \theta_1, \dots, \theta_q$ etc. The parameters can be estimated using a function minimization algorithm, either minimize the sums of squared residuals or maximize the likelihood (probability) of the observed series. To compute the sums of squares (SS) of the residuals, the approximate maximum likelihood method (MLE) is chosen, as this method is the fastest and can be used for very large data sets. For ARIMA model MLE is similar to least square estimate which is based on minimizing the function $\sum_{t=1}^{T} \varepsilon_t^2$. Since the ARIMA model is much complicated to estimate the regression models, certain model selection criteria were used by most of the softwares including open source software Gretl, which is used in this study.

3.5.5.2.1. ***Information criteria***

Model selection was done based on Akaike's Information Criteria (AIC), Bayesian Information Criteria (BIC) and Hannan-Quinn Criteria (HQIC).

AIC is useful in selecting predictors for regression as well as determining order of an ARIMA model. It can be written as

$$\text{AIC} = -2\log(L) + 2\,(P + Q + K + 1) \qquad \textit{3.20}$$

Where L is the maximum likelihood function and last term represent the number of estimated parameters, in which K = 0 if c = 0 and K = 1 if c ≠ 0. (Akaike, 1974).

For ARIMA model, corrected AIC denoted as AIC_C can be written as:

$$\text{AIC}_\text{C} = \left(\frac{2n}{n-k-1}\right)K - 2ln[L] \text{ , Where n is the number of observations} \qquad \textit{3.21}$$

BIC or Schwarz information criteria (SIC)

$$\text{SIC} = \ln(n)K - 2ln(L) \text{ , (Schwartz, 1978)} \qquad \textit{3.22}$$

$$\text{HQIC} = 2\ln[ln(n)]K - 2ln[L] \text{ , (Hannan and Quin, 1979)} \qquad \textit{3.23}$$

3.5.5.3. ***Validation of the model***

Once the preferred model is identified, Standardized residuals should be analyzed. According to our model assumption, observations are normally distributed and thus, the standardized residuals should be standard normally distributed. Now, if a model was found to be not good enough, then errors will no longer remain uncorrelated and like a time series depends on its past values, the errors will remain uncorrelated as well. So model validation can be made by analyzing the nature of residuals in terms of autocorrelation and normality.

3.5.5.3.1. ***Residual Analysis***

When a model has been identified as best fit to a time series it is inevitable to check that the whether the selected model provides an adequate representation of the data. This is usually done by looking at the residuals. For a good model, residuals are stationary and uncorrelated and a model validation usually consists of plotting the residuals in various methods. Another way is by detecting whether residuals follow normal distribution, if so the model selected will be good.

3.5.5.3.1.1. *Ljung-Box Test*

The test is used to determine whether the autocorrelations for the errors or residuals are non-zero. (Modified Box-Pierce statistic), (Sallehuddin *et al.*, 2007; Kane and Yusof, 2013)

The null and alternate hypothesis of the test are given below,

H_0: The errors are uncorrelated

H_1: The errors are correlated.

The test statistic is:

$$Q_m = n\,(n+2)\sum_{k=1}^{m}\frac{\gamma_k^2}{n-k} \qquad 3.24$$

Where n is the number of observations, γ_k is the autocorrelation between residuals with lag k and m total number of lags. The statistic Q_m has a finite sample distribution that is much closer to that of χ2 (m−p−q). The procedure is to reject the null hypothesis of uncorrelated residuals, if the computed value of Q_m is larger than the chi-square table value for a specified significance level.

3.5.5.3.1.2. *Normality plot of residuals*

Graphical tool used for comparing data set with normal distribution. From the nature of histogram one can easily identify whether it is normally distributed or not.

3.6. IMPACT OF CLIMATE CHANGE ON YIELD OF PADDY AND CARDAMOM

Multiple linear regressions were performed to detect impact of climate change on yield of paddy and cardamom. Yield data of paddy from Kottayam district and cardamom from Idukki district were taken as dependent variable. Parameters will be estimated using **OLS**. In Kottayam paddy cultivation was practiced mainly in two season’s one as an additional crop (May-June to Aug-Sep) and another as Puncha crop (oct –nov to dec- jan). Separate regression was estimated for the two seasons by considering weather parameters as independent variables. In case of cardamom, production of cardamom from Idukki district is considered as dependent variable and quarterly weather parameters such as temperature and rainfall of the same district are considered as independent variables.

For paddy as additional crop the model defined will be:

$$\ln y_t = \ln M_{1t} + \ln M_{2t} + \ln M_{3t} + \ln N_{1t} + \ln N_{2t} + \ln N_{3t} + \ln R_{1t} + \ln R_{2t} + \ln R_{3t} + \varepsilon_t \qquad 3.25$$

Where,

y_t	=	Yield of paddy in t^{th} period
M_{1t}	=	Maximum temperature during June in t^{th} period
M_{2t}	=	Maximum temperature during July in t^{th} period
M_{3t}	=	Maximum temperature during August in t^{th} period
N_{1t}	=	Minimum temperature during June in t^{th} period
N_{2t}	=	Minimum temperature during July in t^{th} period
N_{3t}	=	Minimum temperature during August in t^{th} period
R_{1t}	=	Rainfall during June in t^{th} period
R_{2t}	=	Rainfall during July in t^{th} period
R_{3t}	=	Rainfall during August in t^{th} period
ε_t	=	Residual at t^{th} period

For paddy as Puncha crop the model defined will be:

$$\ln y_t = \ln M_{1t} + \ln M_{2t} + \ln M_{3t} + \ln N_{1t} + \ln N_{2t} + \ln N_{3t} + \ln R_{1t} + \ln R_{2t} + \ln R_{3t} + \varepsilon_t \qquad 3.26$$

Where,

y_t	=	Yield of paddy in t^{th} period
M_{1t}	=	Maximum temperature during October in t^{th} period
M_{2t}	=	Maximum temperature during November in t^{th} period
M_{3t}	=	Maximum temperature during December in t^{th} period

N_{1t} = Minimum temperature during October in t^{th} period

N_{2t} = Minimum temperature during November in t^{th} period

N_{3t} = Minimum temperature during December in t^{th} period

R_{1t} = Rainfall during October in t^{th} period

R_{2t} = Rainfall during November in t^{th} period

R_{3t} = Rainfall during December in t^{th} period

ε_t = Residual at t^{th} period

For Cardamom the model defined will be

$$\ln y_t = \ln M_{1t} + \ln M_{2t} + \ln M_{3t} + \ln N_{1t} + \ln N_{2t} + \ln N_{3t} + \ln R_{1t} + \ln R_{2t} + \ln R_{3t} + \varepsilon_t \qquad 3.27$$

Where,

y_t = Yield of Cardamom in t^{th} period

M_{1t} = Maximum temperature during January to March in t^{th} period

M_{2t} = Maximum temperature during April to June in t^{th} period

M_{3t} = Maximum temperature during July to September in t^{th} period

N_{1t} = Minimum temperature during January to March in t^{th} period

N_{2t} = Minimum temperature during April to June in t^{th} period

N_{3t} = Minimum temperature during July to September in t^{th} period

R_{1t} = Rainfall during January to March in t^{th} period

R_{2t} = Rainfall during April to June in t^{th} period

R_{3t} = Rainfall during July to September in t^{th} period

ε_t = Residual at t^{th} period

3.6.1. Detection of multicollinearity

The existence of a linear relationship between some or all independent variables in the regression model will create serious problems in estimation, prediction and inference and is referred to as multicollinearity. For detecting multicollinearity among independent variables, variance inflation factor (VIF) of each variable is worked out using the following formula.

The variance inflation factor for the i^{th} variable is calculated as

$$VIF = \frac{1}{1-R_i^2} \qquad 3.28$$

Where R_i^2 is the coefficient of multiple regression of X_i on the remaining independent variable.

If the VIF value is more than 10 for any independent variable, then there exists a serious multicollinearity between that particular independent variable to the remaining variables.

3.6.2. Detection of autocorrelation

Autocorrelation is defined as the correlation between successive terms in a series of observations which is ordered according to time or space. It relates to correlation between successive values of the same variable. The presence of autocorrelation may violate the assumption of ordinary regression and give rise to wrong interpretations. The common test used to detect Autocorrelation is Durbin – Watson test. The hypothesis usually used in DW- test is

$H_0: \rho = 0$ $\quad$ $H_1: \rho > 0$

The test statistics is

$$d = \frac{\sum_{i=2}^{n}(e_i - e_{i-1})^2}{\sum_{i=1}^{n} e_i^2} \qquad 3.29$$

Where,

ρ = Correlation coefficient of error terms.

d = Durbin – Watson value

e_i = i^{th} residual term

e_{i-1} = $i\text{-}1^{th}$ residual term

Upper and lower critical values, d_U and d_L have been tabulated for different values of k and n.

If d < dL reject $H_0: \rho = 0$

If d > dU do not reject H_0: $\rho = 0$

If dL < d < dU test is inconclusive.

Usually if the value of d = 2 then, the model is said to have no autocorrelation.

3.7.STATISTICAL PACKAGES USED IN THE STUDY

In the present study, Microsoft Excel and SPSS 16.0 package was used for performing descriptive statistics and fitting multiple regression models. R environment for statistical computing was used for trend analysis and open source software “Gretl” was used for ARIMA model fitting for rainfall data.

RESULTS AND DISCUSSIONS

4. RESULTS AND DISCUSSIONS

The data corresponds to the weather parameters such as maximum temperature, minimum temperature and rainfall collected from RARS, Vellayani, RARS, Kumarakom, CRS, Pampadumpara for a period from 1991 to 2019 and RRS, Moncompu from 1997 to 2018 were subjected to different statistical analysis. This chapter presents the result obtained from the study in line with the objective specified under the following headlines.

4.1. Change in monthly weather parameters over time

4.2. Trend analysis of weather parameters

4.3. Model fitting for rainfall

4.4. Impact of weather parameters on yield of paddy in Kottayam district

4.5. Impact of weather parameters on yield of cardamom in Idukki district

4.1. CHANGE IN MONTHLY WEATHER PARAMETERS OVER TIME

4.1.1. Descriptive statistics for maximum temperature, minimum temperature and rainfall data from Vellayani (1991-2019)

To study the climate change overtime, the changes in month wise data of maximum temperature, minimum temperature and rainfall for a period from 1991 to 2019 were analysed. Descriptive statistics are utilized to summarize the climate change of weather parameters and it includes measures of central tendency and measures of dispersion. The mean, range, and coefficient of variation (CV%) for monthly maximum temperature and minimum temperature and rainfall for a period of 29 years from Vellayani are given in Table 1.

The average monthly maximum temperature over the years varied from 30.01° C in July to 32.94° C in April which indicated not much variation in the maximum temperature from June to May in a year. During the month from February to May and in October the range in maximum temperature is very high as compared to other months and with also very low CV in all the months. For minimum temperature the highest value was found for the month April, May and lowest in January with very low CV. However, an entirely different pattern was noticed for rainfall. Usually monthly rainfall was high in June and lowest in January, February and March. In Vellayani maximum rainfall of 8098 mm was recorded in June followed by 7876 mm rainfall in October and November (6146 mm) over the study period. The CV of rainfall provides a different picture as compared to maximum and minimum temperature. High CV of more than 100 was recorded during the month December to March indicating that these months received no rain to some amount of rain over the years.

The distribution of maximum and minimum temperature and rainfall over the years when analysed indicated that the precipitation rate was almost constant and very low during January to March, after that it shows an increasing trend up to June and then decreases. The annual temperature showed an increasing pattern in the initial months up to May later on it decreased up to June, July and then shown an increase.

Monthly distribution of maximum temperature, minimum temperature and rainfall for 29 years was represented using box plot and they are shown in Fig: 1, Fig: 2 and Fig: 3 respectively. This type of graph not only provides the distribution but also gives the extreme values and outliers present in each of these variables. There are a lot of extremities or outliers present in temperature and rainfall. In the case of rainfall, a deviation from average was recorded during February 1999, March 2013, June 1991 and 1992 and August 2000, 2018 and 2019. Also, it is clear from the Figure 1 that heavy rainfall was recorded in August 2018 and 2019 which created severe floods in Kerala. For maximum temperature February (1996, 2019), April (2016, 2019), August (2000, 2016), September (2018), October (1997), November (2016), December (2016) were spotted as outliers. For minimum temperature many years showed deviation from normal temperature since almost all months have outliers except for February and September. The interpretation made from numerical descriptive statistical measures like SD, range and CV and that from these types of graphical representations are almost the same.

Table 1: Descriptive statistics of Month wise weather parameters for the period from 1991 to 2019 at Vellayani

	Maximum temperature (° C)			**Minimum temperature (° C)**			**Rainfall (mm)**		
Month	**Mean**	**Range**	**CV (%)**	**Mean**	**Range**	**CV (%)**	**Total**	**Range**	**CV (%)**
January	31.03	30.3-32.3	1.82	21.91	20.1-24.7	4.87	291.80	0-41.5	118.29
February	31.63	29.6-33.6	2.61	22.36	20.4-24.2	4.80	444.40	0-78.6	141.90
March	32.74	31.3-34.6	2.42	23.69	20.8-24.8	4.06	496.10	0-86	127.70
April	32.94	31.3-35.3	3.06	24.90	21.9-26.8	4.06	2495.80	14-182.8	61.83
May	32.04	30.3-34.1	3.11	24.92	21.9-26.3	3.80	5836.40	12-463.2	65.80
June	30.45	29-31.9	2.73	23.86	21.2-25.4	4.40	8098.90	72-667.3	51.12
July	30.01	29-31.8	2.69	23.42	20.3-24.9	4.66	5390.70	32.6-395	51.09
August	30.17	28.6-31.8	2.41	23.47	21.2-24.8	3.90	3703.50	32.8-368.3	62.24
September	30.62	29.2-32.4	2.42	23.67	22.2-24.5	2.83	4874.40	2.8-390.6	70.15
October	30.70	29-34.7	3.59	23.52	21.4-24.9	3.21	7876.60	22.2-594	50.00
November	30.59	29.2-32	2.21	23.22	21.6-24.5	2.96	6146.00	56-434.3	42.58
December	30.92	29.9-32.3	1.99	22.40	19.9-23.8	4.35	2060.60	0-259.3	101.31

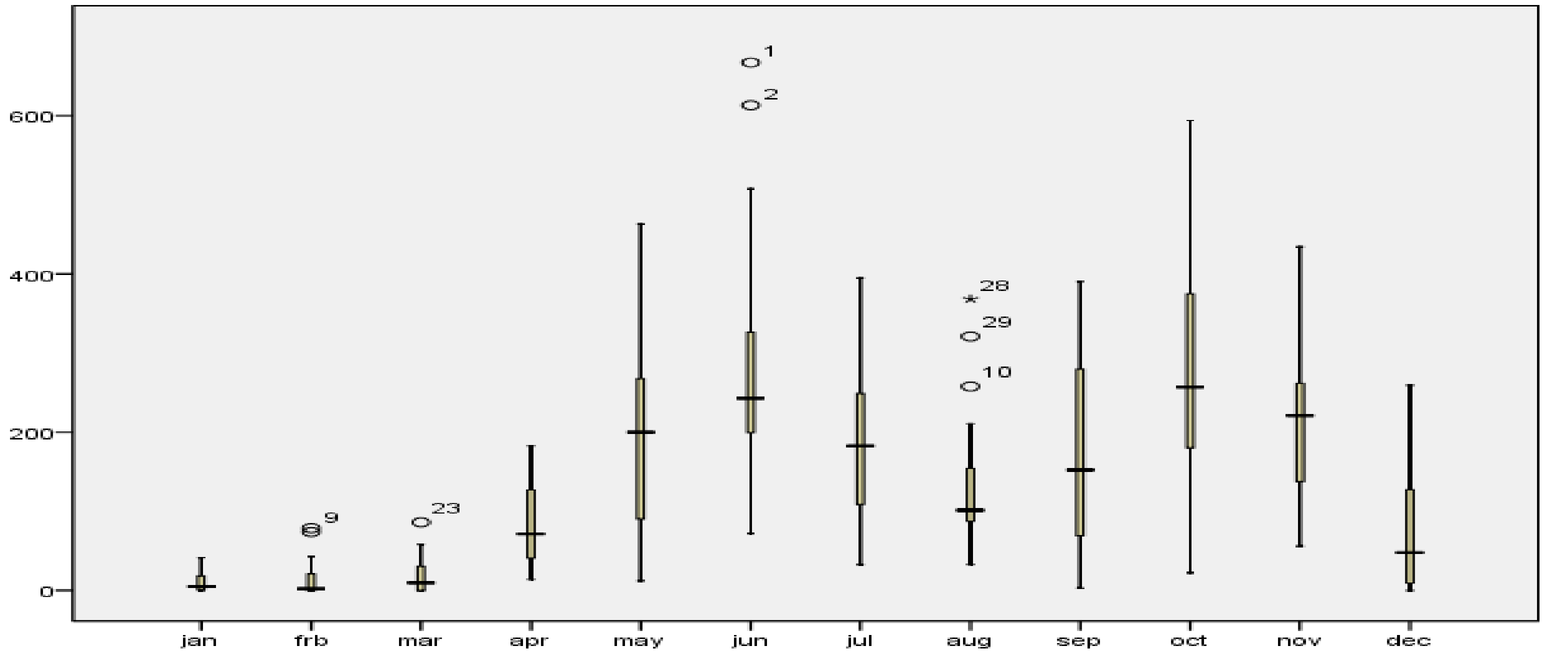

Fig. 1: Distribution graph of monthly Rainfall (mm) for the period from 1991 to 2019 at Vellayani

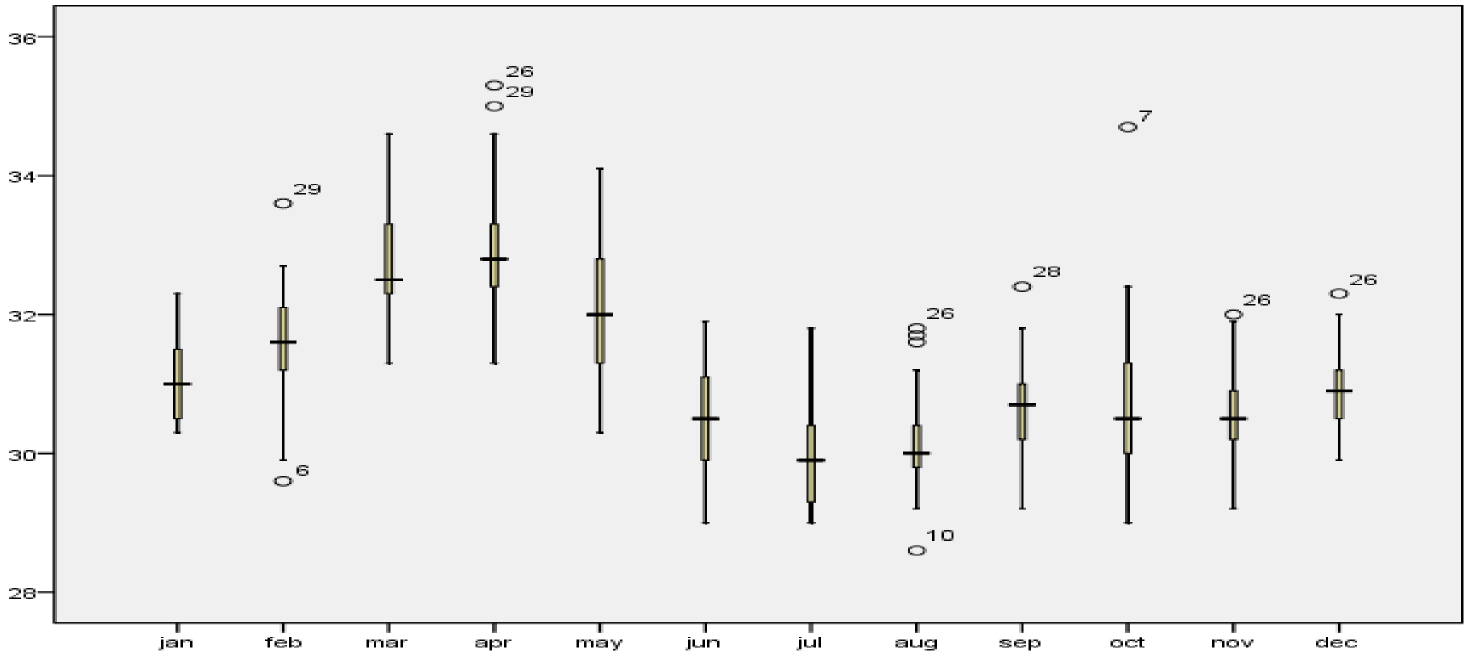

Fig. 2: Distribution graph of monthly maximum temperature (^{0} C) for the period from 1991 to 2019 at Vellayani

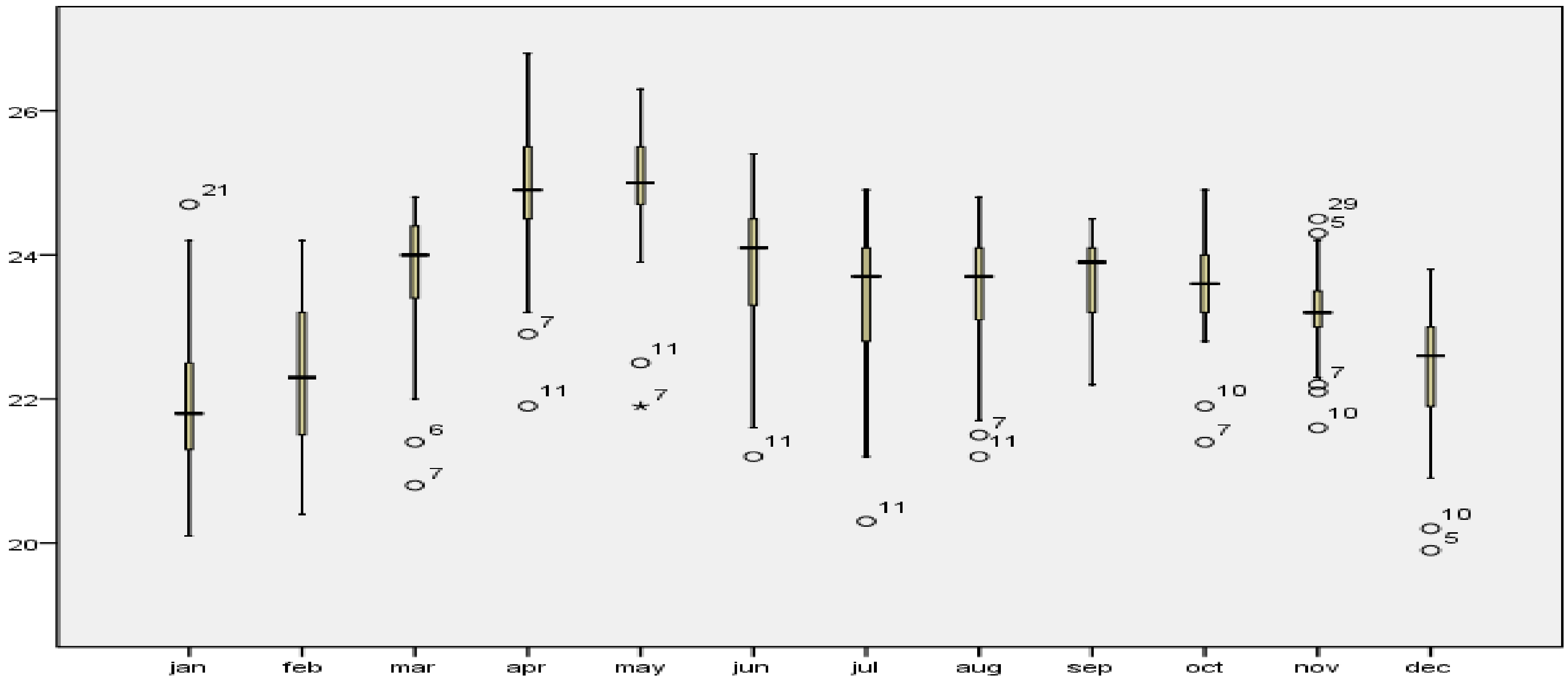

Fig. 3. Distribution graph of monthly minimum temperature (^{0} C) for the period from 1991 to 2019 at Vellayani

4.1.2. Descriptive statistics for maximum temperature, minimum temperature and rainfall data from Kumarakom (1991-2019)

To analyse climate change overtime, the changes in month wise data of maximum temperature, minimum temperature and rainfall for a period from 1991 to 2019 were analysed. Descriptive statistics are utilized to summarize the climate change of weather parameters and it includes measures of central tendency and measures of dispersion. The mean, range, standard deviation (SD) and coefficient of variation (CV %) for monthly maximum temperature and minimum temperature and rainfall for a period of 29 years from Kumarakom are given in Table 2.

The average monthly maximum temperature over the years varied from 30.27° C in July 34.34° C in April which indicated some sort of variation in the maximum temperature was observed from June to May in a year. The range in maximum temperature was high for March and low for January with very low CV in all the months. For minimum temperature the highest value was found for the month April, May and lowest for January with very low values for CV. However, an entirely different pattern was noticed for rainfall. Usually monthly rainfall was high in June and lowest in January, February and March. In Kumarakom maximum rainfall of 15685.8 mm was recorded in June followed by 14299.4 mm rainfall in July and least in January (318.4 mm) over the study period. The CV of rainfall provides a different picture as compared to maximum and minimum temperature. High CV of more than 100 was recorded during the month December to March indicating that these months received no rain to some amount of rain over the years.

Table 2: Descriptive statistics of Month wise weather parameters for the period from 1991 to 2019 at Kumarakom

	Maximum temperature (° C)			**Minimum temperature (° C)**			**Rainfall (mm)**		
Month	**Mean**	**Range**	**CV (%)**	**Mean**	**Range**	**CV (%)**	**Total**	**Range**	**CV (%)**
January	32.64	31.77-33.68	1.57	21.51	19.12-22.76	4.91	318.4	0-77.4	176.46
February	33.34	32.21-34.3	1.53	22.47	21.05-23.93	3.21	406	0-86	147.84
March	34.24	32.73-35.25	1.79	24.13	22.18-25.05	2.98	1558.7	0-230.7	112.26
April	34.34	32.57-35.5	1.96	24.59	23.43-25.73	2.22	3420.3	2.3-269.4	59.89
May	33.45	31.2-34.76	2.51	24.32	22.73-25.52	3.35	6664.4	30.8-631.4	66.45
June	31.00	29.45-32.45	2.29	23.3	21.94-24.62	2.78	15685.8	259.5-817.7	24.26
July	30.27	29.13-31.82	2.35	22.93	21.44-24.63	3.37	14299.4	190.2-832.1	34.1
August	30.82	29.85-31.97	1.88	23.17	21.82-24.68	3.23	9734.2	117.3-700.5	42.52
September	31.58	30.56-32.48	1.74	23.11	21.22-24.87	3.9	7894.1	18.9-639.6	56.06
October	31.68	30.68-33.12	2.01	22.78	20.59-24.04	3.91	9478.6	91.8-625.4	45.03
November	32.09	30.73-32.89	1.69	22.37	18.02-24.13	6.18	4302.2	0-343.8	60.62
December	32.36	30.98-33.42	1.74	21.63	18.38-23.42	5.04	1093.8	0-140.2	106.01

The distribution of maximum and minimum temperature and rainfall over the years when analysed it was clear that the precipitation rate was almost constant and low during January to March, after then it shows an increasing pattern upto June and then decreases and again moves up. Annual temperature showed an increasing pattern in the initial months up to April later on decreases up to June, July and a slight increase in pattern could be visible.

Monthly distribution of maximum temperature, minimum temperature and rainfall for 29 years was represented using box plot and they are shown in Figure 4, Figure 5 and Figure 6 respectively. There are a lot of extreme values and outliers present in temperature and rainfall. In the case of rainfall, a deviation from average was recorded during rainfall January (1998), February (1994, 2000), March (2008), May (2004), June (2013), July (2007), August (2014). The interquartile length for January, February, March and December were very small indicating lesser variation in the data set over the study period. All months except for September, October, November and December had outlier values gave an indication of deviation from normal rainfall. For maximum temperature March (2008), April (1994, 1999), May (1999), November (1993, 2010) and December (2010) showed deviation from normal temperature. Size of box plots were almost the same and the number of outliers were few indicating less variability in the data set. For minimum temperature February (2000), March (1992, 2008), June (1995, 2008), November (1995) and December (1999) are spotted as outliers.

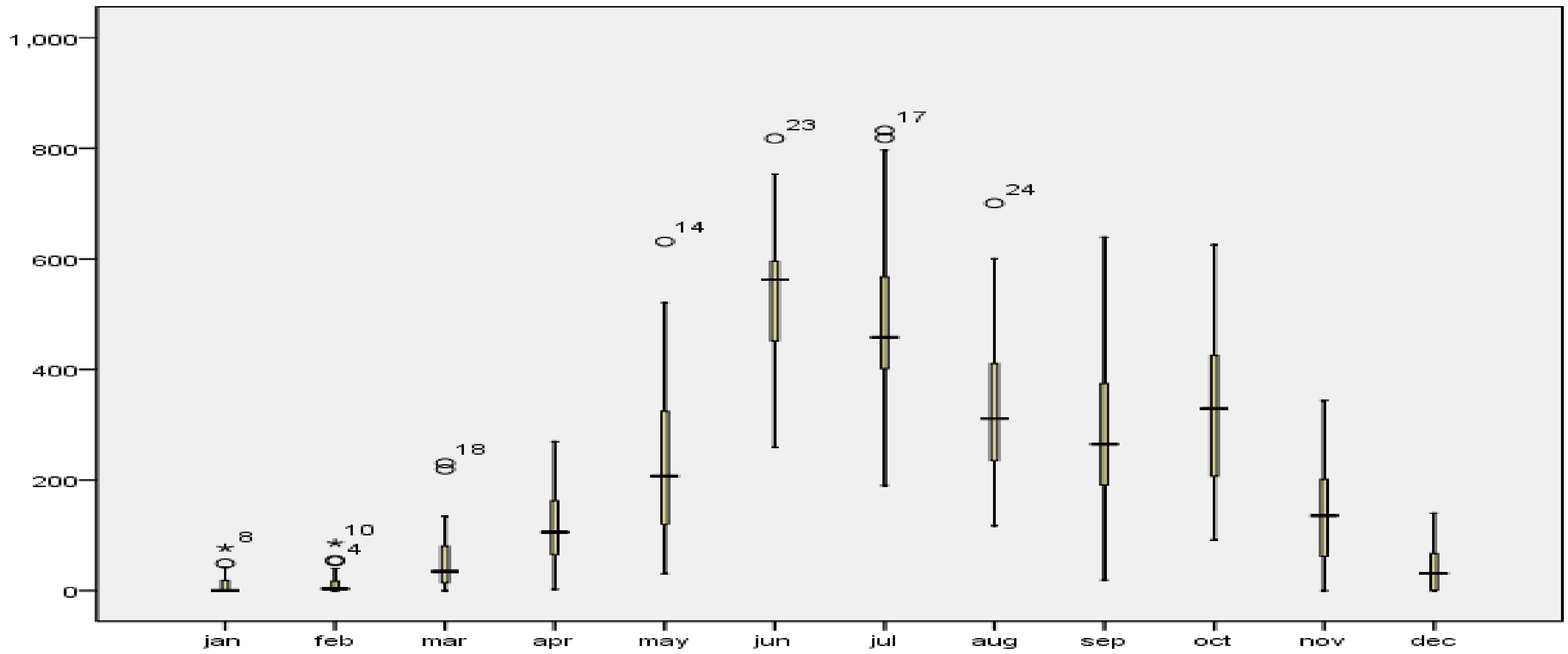

Fig. 4: Distribution graph of monthly Rainfall (mm) for the period from 1991 to 2019 at Kumarakom

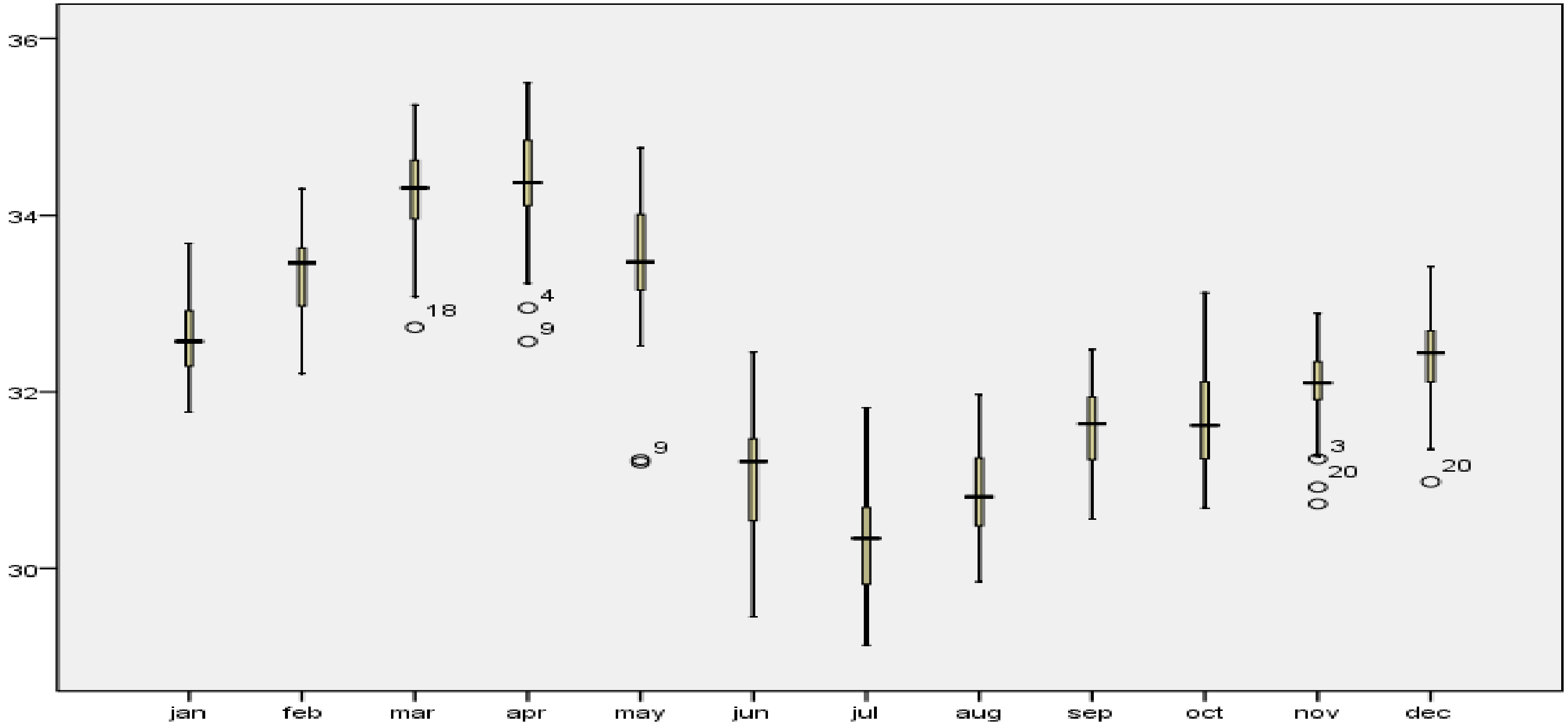

Fig. 5: Distribution graph of monthly maximum temperature (^{0} C) for the period from 1991 to 2019 at Kumarakom

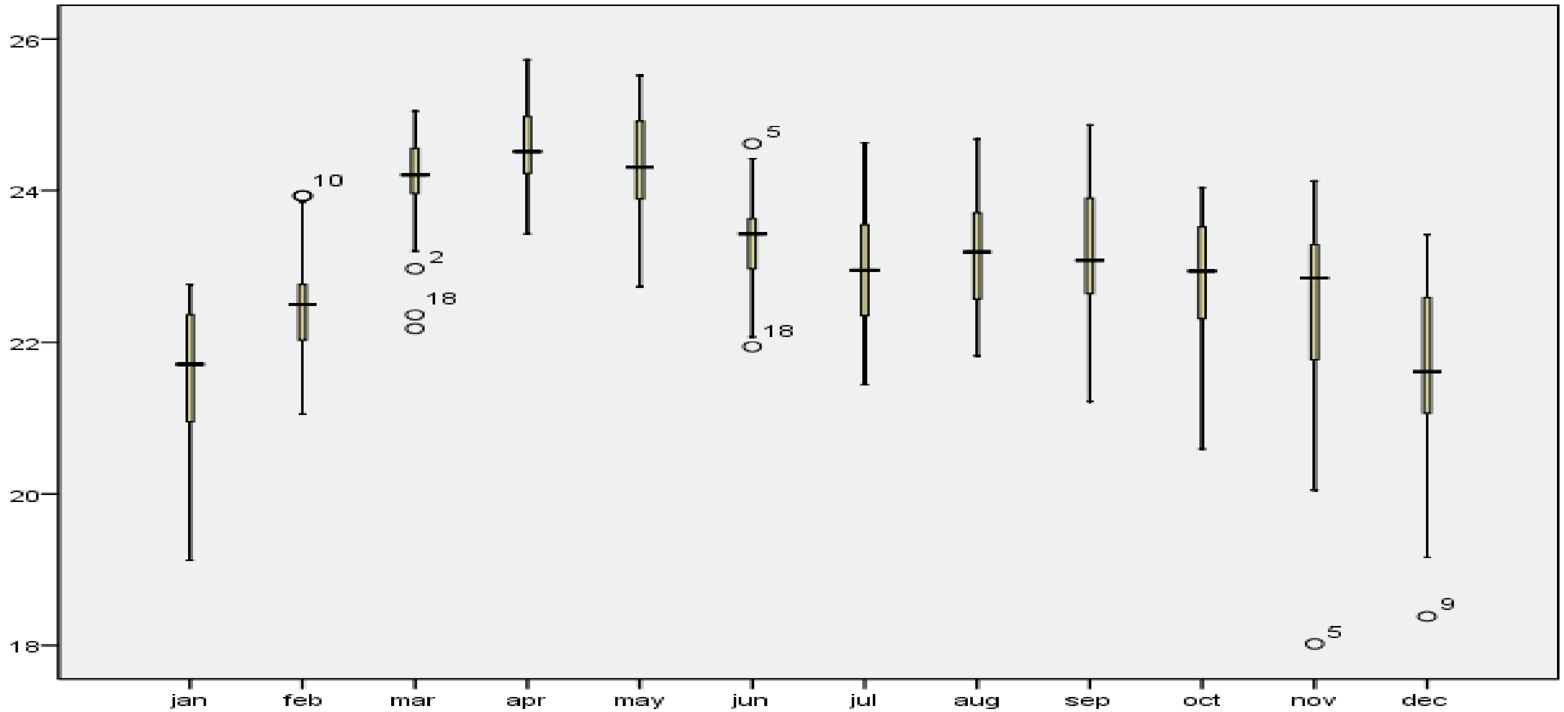

Fig. 6: Distribution graph of monthly minimum temperature (^{0} C) for the period from 1991 to 2019 at Kumarakom

4.1.3. Descriptive statistics for maximum temperature, minimum temperature and rainfall data from Moncompu (1997-2018)

To analyse the climate change overtime, the changes in month wise data of maximum temperature, minimum temperature and rainfall for a period from 1997 to 2018 were analysed. Descriptive statistics are utilized to summarize the climate change of weather parameters and it includes measures of central tendency and measures of dispersion. The mean, range, standard deviation (SD) and coefficient of variation (CV %) for monthly maximum temperature and minimum temperature and rainfall for a period of 22 years from Moncompu are given in Table 3.

The average monthly maximum temperature over the years varied from 20.97° C in July 33.72° C in March which indicated more variation in the maximum temperature was observed from June to April over the year. The range in maximum temperature was high for September and low for February with very low CV in all the months. For minimum temperature the highest value was received during the month of April, May and lowest during January with very low values for CV. However, rainfall data showed an entirely different pattern. Usually monthly rainfall was high in June and lowest in January, February and March. In Moncompu, maximum rainfall of 10904 mm was recorded in June followed by 9620.02 mm rainfall in July and a very poor rain appeared in January (294.7 mm) over the study period. The CV of rainfall provides a different picture as compared to maximum and minimum temperature. High CV of more than 100 was recorded during the month December to February indicating that these months received no rain to some amount of rain over the years.

Table 3: Descriptive statistics of Month wise weather parameters for the period from 1997 to 2018 at Moncompu

	Maximum temperature (° C)			**Minimum temperature (° C)**			**Rainfall (mm)**		
Month	**Mean**	**Range**	**CV (%)**	**Mean**	**Range**	**CV (%)**	**Total**	**Range**	**CV (%)**
January	32.61	31.22-33.65	1.74	22.45	21.7-23.3	1.81	294.7	0-81.7	158.29
February	33.04	32.1-33.85	1.52	22.98	22-24.1	2.72	550.45	0-180.6	172.68
March	33.72	32.55-34.85	1.95	24.52	23.6-25.7	2.04	1116.3	2.8-200.9	84.53
April	33.6	32.7-34.82	1.61	24.97	24.1-25.72	1.69	3204.9	6.8-335.8	60.26
May	32.87	31.15-34.99	2.87	25.51	24.13-26.6	2.53	6250.3	49-825.8	65.74
June	30.78	30.12-31.77	1.76	24.57	23.95-25.4	1.59	10904	17.8-943.6	48.32
July	29.97	28.38-31.44	2.62	24.04	23.4-25.5	2.15	9620.02	95.4-861.3	46.96
August	30.24	29.04-31.42	1.99	24.2	23.07-24.93	2.12	7603.4	165.4-633.1	41.54
September	30.72	28.39-33.05	3.43	24.49	23.53-25.4	1.92	6486.4	79.3-754	63.8
October	30.61	28.04-32.66	3.92	24.51	23.14-25.66	2.63	7272.3	122.2-690.5	49.74
November	31.86	30.58-32.8	1.6	24.24	23.02-25.38	2.52	3310.51	13.5-315.2	49.42
December	32.04	29.63-33.64	3.29	23.26	21.95-24.52	2.97	1155.8	0-198	114.06

The distribution of maximum and minimum temperature and rainfall over the years when analysed provided that the precipitation rate was almost constant and low during January to March, after then it shows an increasing pattern upto June and then decreases and again moves up. Annual temperature showed an increasing pattern in the initial months up to May later decreases up to June, July and then a slight increase was noticed.

Monthly distribution of maximum temperature, minimum temperature and rainfall for 22 years was represented using box plot and they are shown in Figure 7, Figure 8 and Figure 9 respectively. The number of outliers is high for rainfall as compared to temperature data. For rainfall a deviation from average was recorded during January (1995), February (2007), March (2002), May (1998), June (2003), September (1991, 1992) and November (1996). The interquartile range during January, February and March were very small indicating lesser variation in the data set over the study period. For maximum temperature January (1993) and December (1992, 2006) showed a deviation from normal temperature. The number of outliers were few indicating less variability in the data set. Also from the position of the second quartile it was clear that all the months was almost symmetric except for January, April, May, June which is negatively skewed. For minimum temperature during 1998 September outlier was reported.

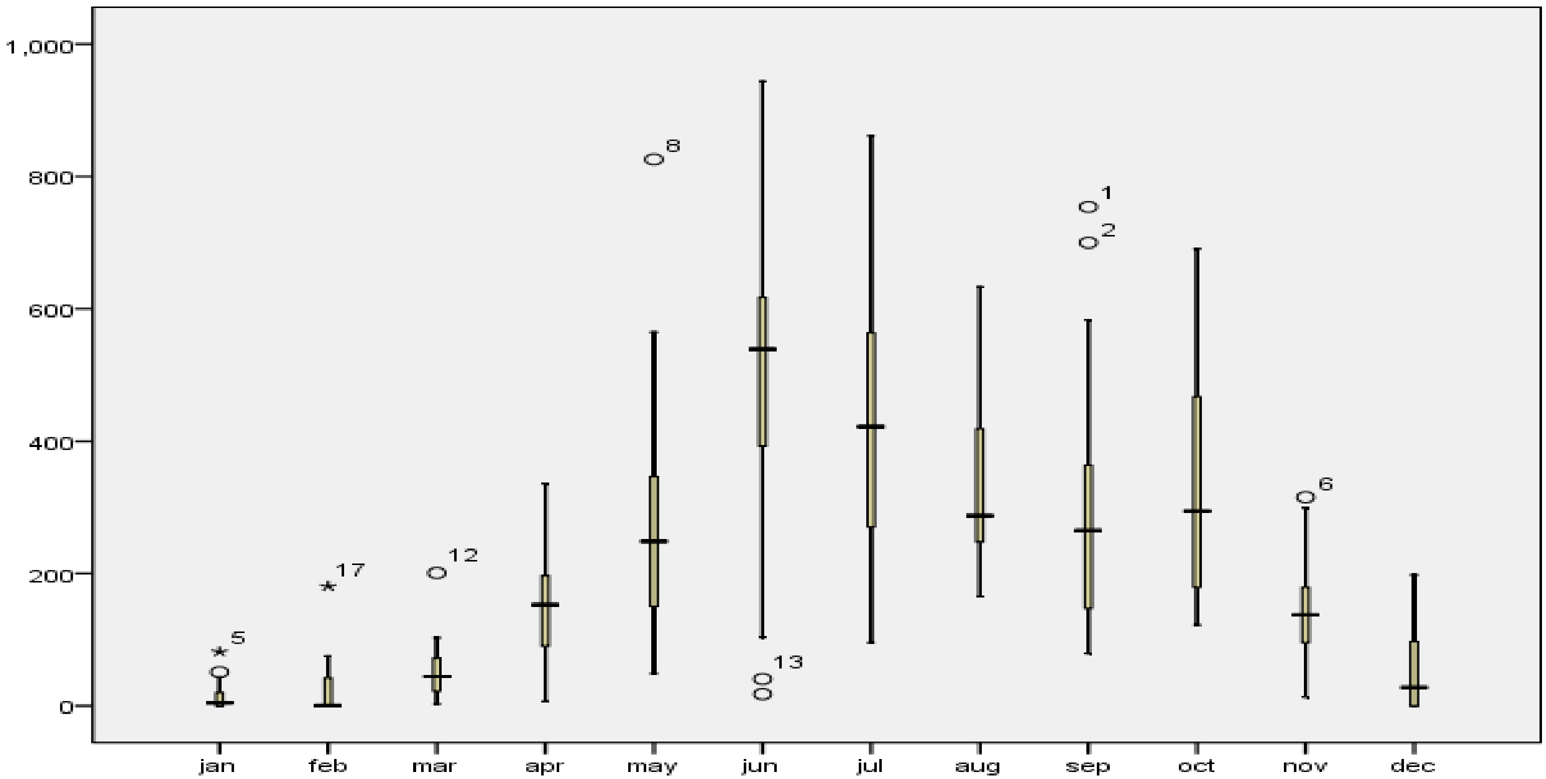

Fig. 7: Distribution graph of monthly Rainfall (mm) for the period from 1997 to 2018 at Moncompu

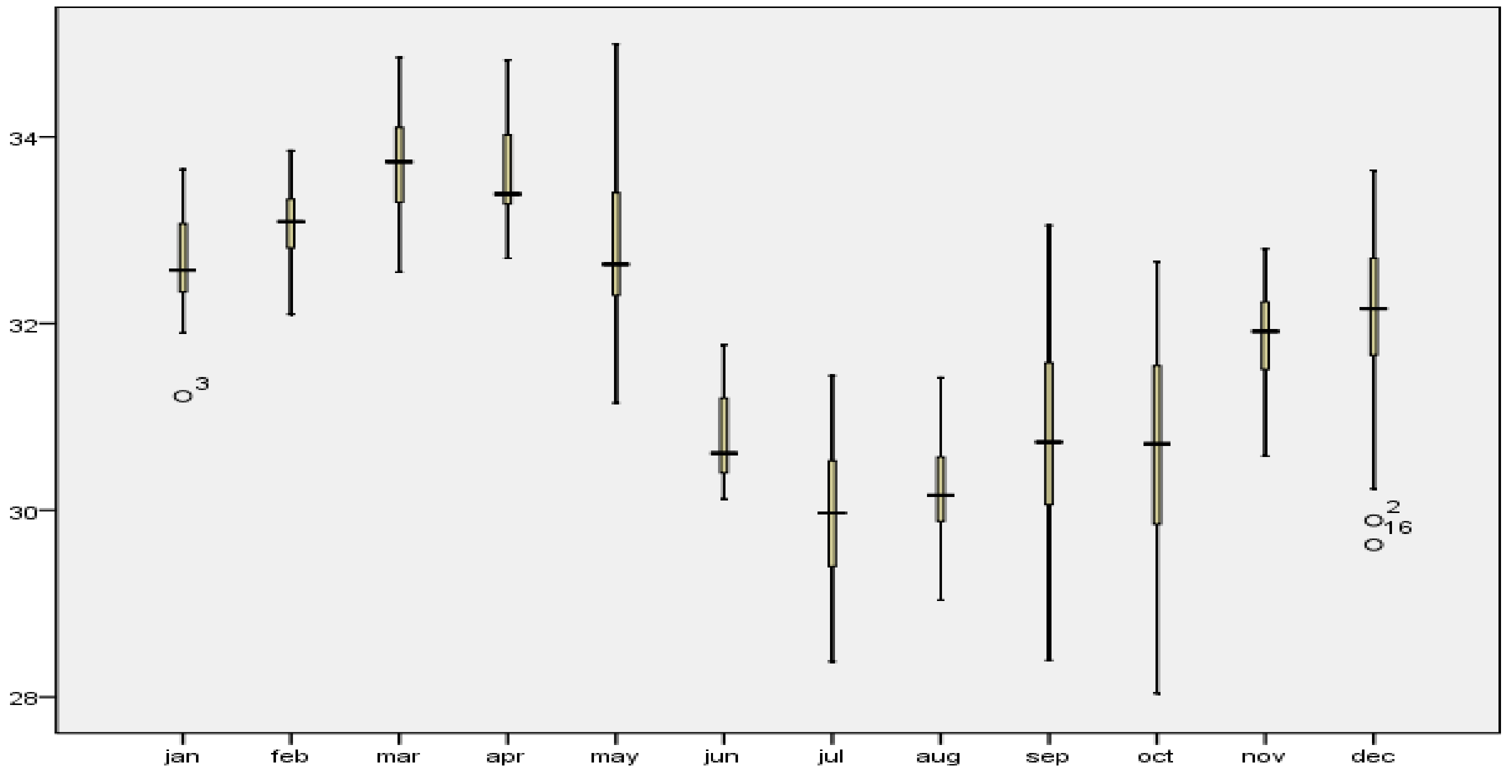

Fig. 8: Distribution graph of monthly Maximum temperature (^{0} C) for the period from 1997 to 2018 at Moncompu

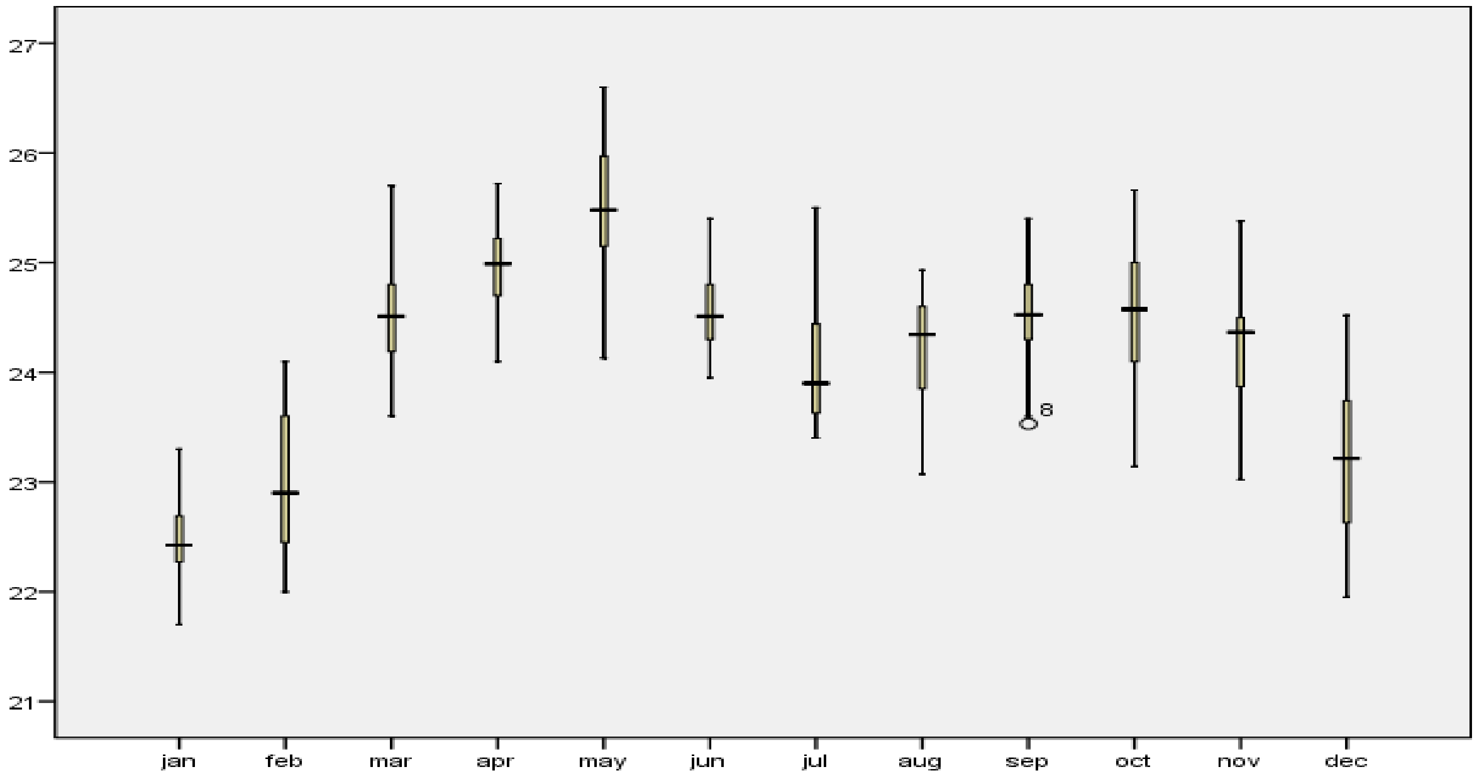

Fig. 9: Distribution graph of monthly Minimum temperature (^{0}C) for the period from 1997 to 2018 at Moncompu

4.1.4. Descriptive statistics for maximum temperature, minimum temperature and rainfall data from Pampadumpara(1991-2019)

To analyse the climate change overtime, the changes in month wise data of maximum temperature, minimum temperature and rainfall for a period from 1991 to 2019 were analysed. Descriptive statistics are utilized to summarize the climate change of weather parameters and it includes measures of central tendency and measures of dispersion. The mean, range, standard deviation (SD) and coefficient of variation (CV %) for monthly maximum temperature and minimum temperature and rainfall Pampadumpara for a period of 29 years are given in Table 4.

The average monthly maximum temperature over the years varied from 22.82° C in July to 28.87° C in April which indicated some sort of variations in the maximum temperature from June to May in a year. The range in maximum temperature was high for January and low in September with a low CV in all the months. The minimum temperature the highest value was found during the month of April and lowest for January with low CV. Rainfall data showed an entirely different pattern. Usually monthly rainfall was high in July and lowest in January, February. In Pampadumpara maximum rainfall of 10543.9 mm was recorded in July followed by 8251.5 mm rainfall in August and very low in February (519.9 mm) over the study period. The CV of rainfall provides a different picture as compared to maximum and minimum temperature. High CV of more than 100 was recorded during the month December to March indicating that these months received no rain to some amount of rain over the years.

Table 4: Descriptive statistics of Month wise weather parameters for the period from 1991 to 2019 at Pampadumpara

	Maximum temperature (°C)			**Minimum temperature (°C)**			**Rainfall (mm)**		
Month	**Mean**	**Range**	**CV (%)**	**Mean**	**Range**	**CV (%)**	**Total**	**Range**	**CV (%)**
January	24.31	20.05-29	8.88	15.15	13-17.77	8.65	611.6	0-99	139.34
February	26.02	21.37-29	8.14	15.85	13-19.29	10.47	519.9	10-96.8	150.53
March	28.42	23.45-32	8.75	17.61	14.5-21.82	11.17	1147.4	0.1-165.2	105.69
April	28.87	24.8-33	7.19	19.08	15.5-23.3	11.16	2825.65	18.5-263.2	76.6
May	27.38	23.61-32	6.9	19.01	15.98-22.08	8.27	2794.1	0.1-258.3	72.99
June	24.72	21.16-30	10.64	17.92	13.4-19.48	6.79	7620.55	47.45-496.1	41.47
July	22.82	20.07-27	6.81	16.89	11.83-19.06	9.26	10543.9	112.8-658	33.22
August	23.37	20.23-27	7.4	17.56	15.5-19.09	4.9	8251.5	106.2-770.5	50.04
September	24.72	21.68-28.5	7.57	17.91	16-21.7	7.73	4916.6	33.2-343	49.77
October	25.13	21.88-29	7.6	17.79	14.5-21.43	8.56	7490.16	68.9-458.6	36.72
November	24.32	20.85-28.68	8.57	17.28	14-21.15	8.6	4623.1	26.8-387	61.14
December	23.64	20.31-27	7.65	15.75	12.5-20.08	12.43	1686.2	0.1-203.8	106.88

The distribution of maximum and minimum temperature and rainfall over the years revealed that the precipitation rate was almost constant and low during January, February after then it shows an increasing pattern upto July and then decreases and again moves up. Annual temperature showed an increasing pattern in the initial months up to April and later it decreased up to June, July and then a slight increase was noticed.

Monthly distribution of maximum temperature, minimum temperature and rainfall for 29 years was represented using box plot and they are shown in Figure 10, Figure 11 and Figure 12 respectively. The number of outliers are high for both rainfall and temperature data. For rainfall a deviation from average was recorded during January (1996, 2010), February (2011), March (2008), April (2010), May (1995), August (2018), November (1997) and December (2005). For maximum temperature January (1995, 2017, 2019), February (2017, 2019), March (2018, 2019), May (1991, 1993, 2015, 2017, 2018) and July (1996) showed deviation from normal temperature. The number of outliers were high indicating more variability in the data set. For minimum temperature January (2018), April (2017), May (2017), June (2019), July (2019), September (2017, 2019), October (1996, 2019) and November (2012) were spotted as outliers.

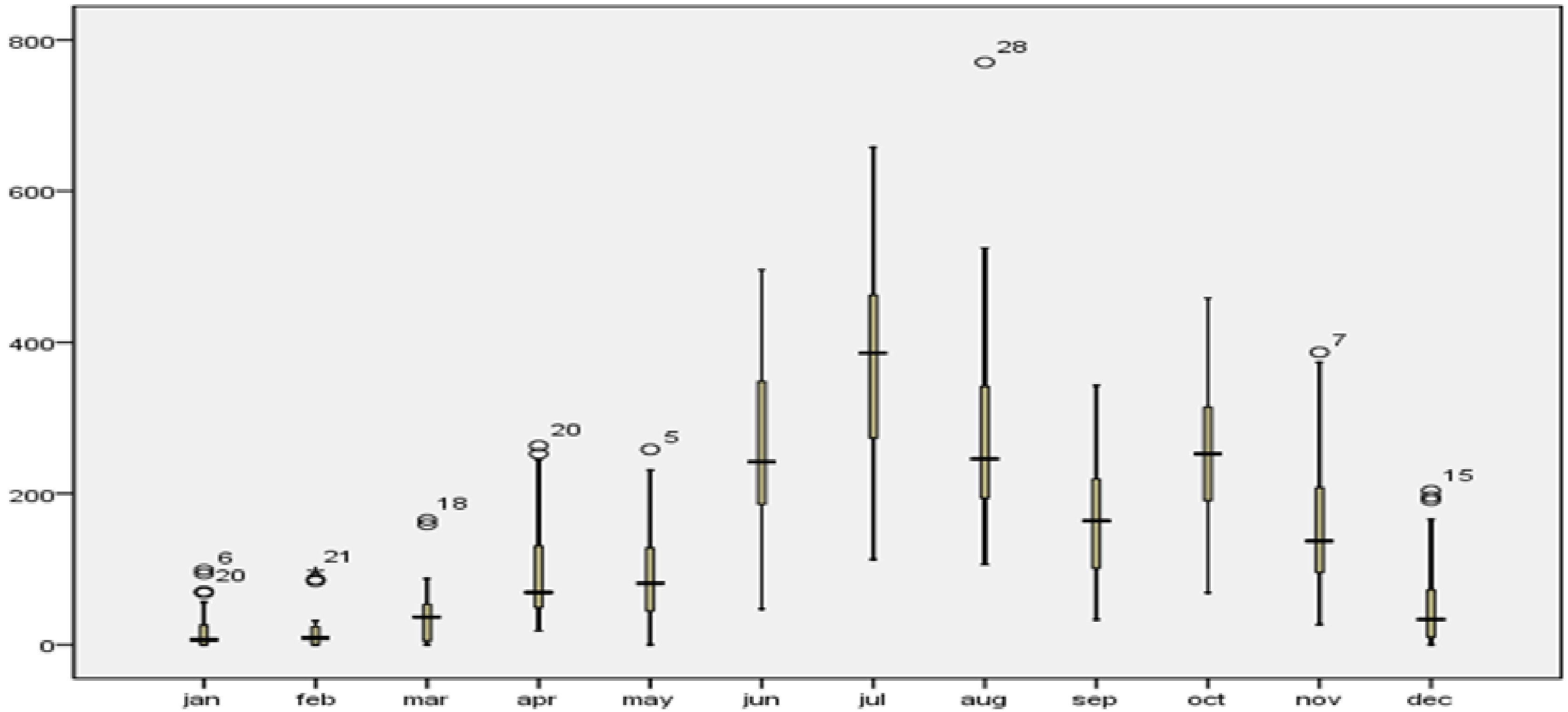

Fig. 10: Distribution graph of monthly Rainfall (mm) for the period from 1991 to 2019 at Pampadumpara

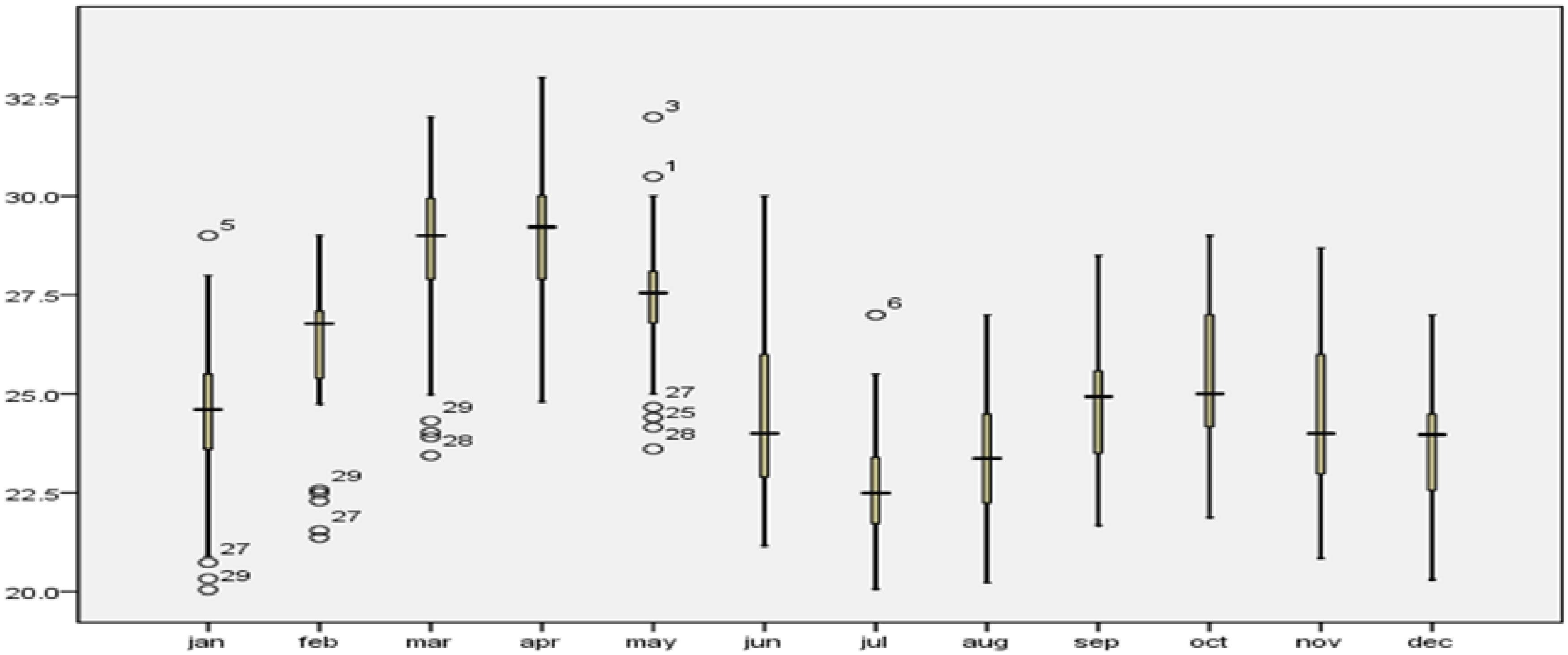

Fig. 11: Distribution graph of monthly Maximum temperature (^{0} C) for the period from 1991 to 2019 at Pampadumpara

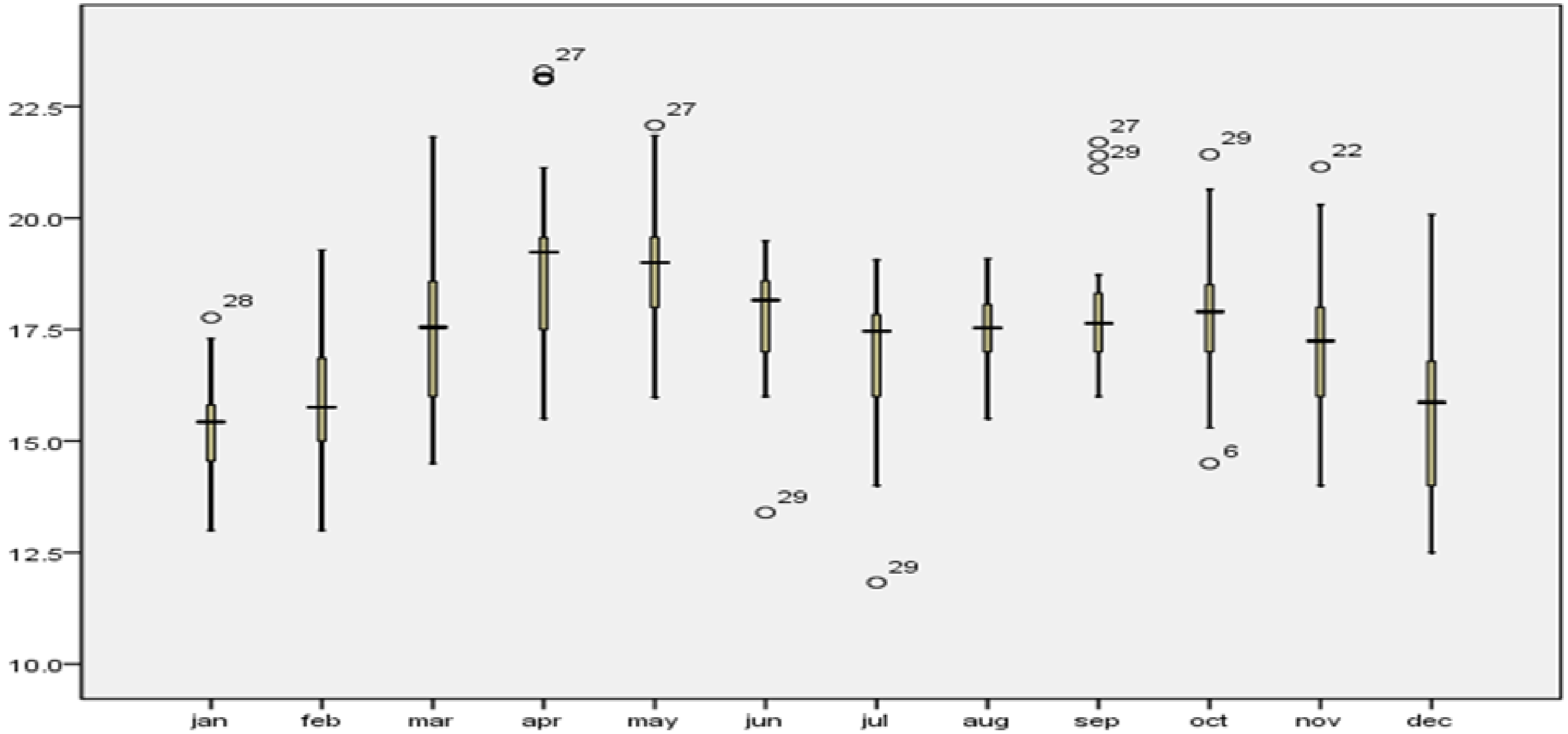

Fig. 12: Distribution graph of monthly Minimum temperature (^{0} C) for the period from 1991 to 2019 at Pampadumpara

4.2. TREND ANALYSIS OF WEATHER PARAMETERS

4.2.1. Trend analysis of weather parameters of Vellayani

4.2.1.1. ***Graphical method for analyzing nature of trend***

Descriptive statistics including mean, standard deviation and coefficient of variation (CV %) are utilized to summarize the annual maximum temperature, minimum temperature and rainfall included in the study during the period from 1991 to 2019. Mean of maximum and minimum temperature and total rainfall was found out annually by taking the month wise data for the period from 1991 to 2019 from the four research stations under KAU. The table 5 shows the various descriptive statistics of the weather parameters at Vellayani.

The range of annual average maximum temperature lies between 30.47° C and 32.61° C with a coefficient of variation (CV) less than 6 and a highest standard deviation of 1.63° C was recorded during the year 1997 and 1998. Similarly, annual minimum temperature varies from 21.60° C to 24.41° C with a CV less than 6 and a highest standard deviation was found to be 1.36° C for the year 1992. However, the range of total rainfall was very high (878.95mm to 2335.60mm) with a very high and fluctuating CV and a highest standard deviation of 233.02mm was noticed for the year 1999. Coefficient of variation (CV) is capable of categorizing the degree of variability of data as less when $CV<20$, moderate when $20<CV<30$ and high when $CV>30$ (Hare, 2003). For maximum temperature CV range was 1.75 to 5.24, for minimum temperature it was 2.93 to 5.91 but for rainfall it was 73.48 to 161.24, which shows that there was low CV for maximum and minimum temperature and a high CV for total rainfall. Also, from table it was clear that the highest maximum temperature was obtained in 2016 (32.6° C) and lowest was in 1999 (30.47° C) with a standard deviation of 0.568 (° C). For minimum temperature the highest value was obtained in 2017, 2019 (24.40° C) and lowest in 1997 (21.6° C) with a standard deviation of 0.715 (° C). The highest amount of rainfall was received in 2015 (2335.6mm) and lowest amount of rainfall of 879 mm was recorded in 2012 with a high standard deviation of 360.05mm. Due to high CV we can interpret that there was high fluctuation in annual rainfall distribution over the years

A plot of annual mean maximum temperature, minimum temperature and total rainfall are given in Figure 13, Figure 14 and Figure 15. These graphs clearly give the pattern of temperature and rainfall throughout the study period. Annual rainfall was highest during 2015 and lowest for the year 2012. Highest maximum temperature was noticed in the year 2016. From 2014 onwards the temperature showed a sudden increase upto 2016 and later it decreased during 2017 and again moved up. In the case of minimum temperature an increasing pattern in temperature could be observed over the 29 years

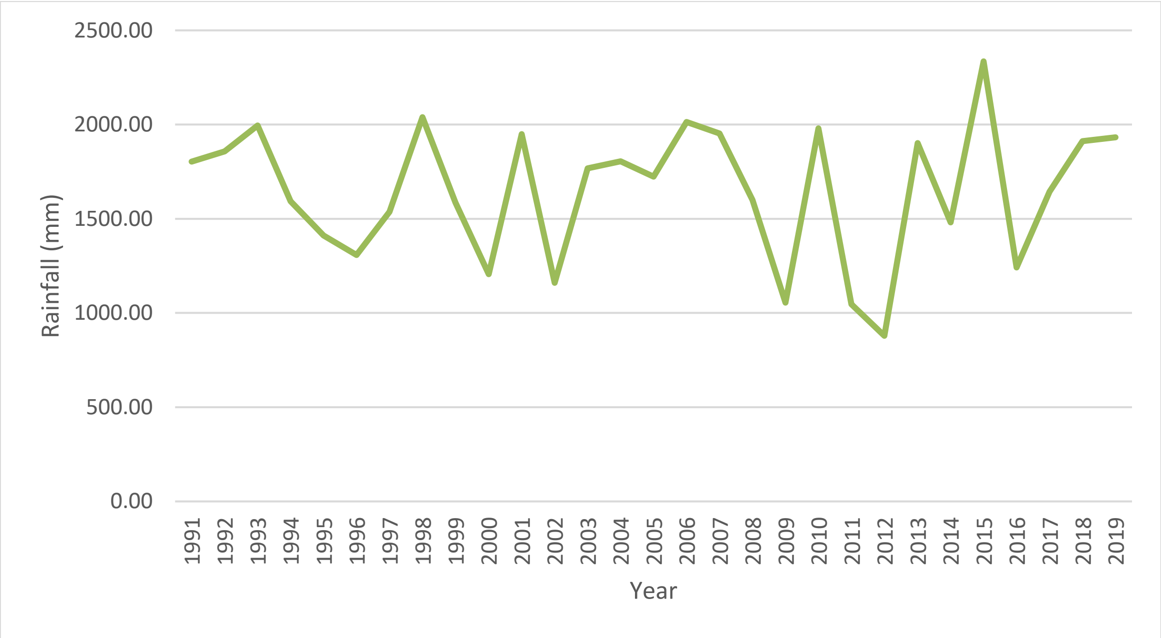

Fig. 13: Trends in annual rainfall (mm) at Vellayani

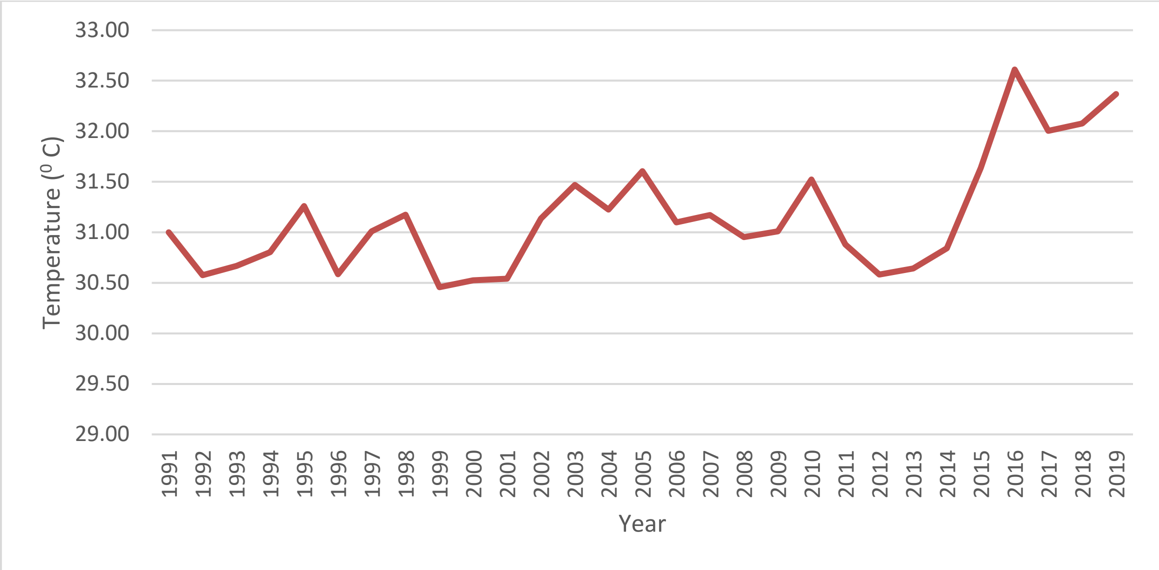

Fig.14: Trends in annual maximum temperature(° C) at Vellayani

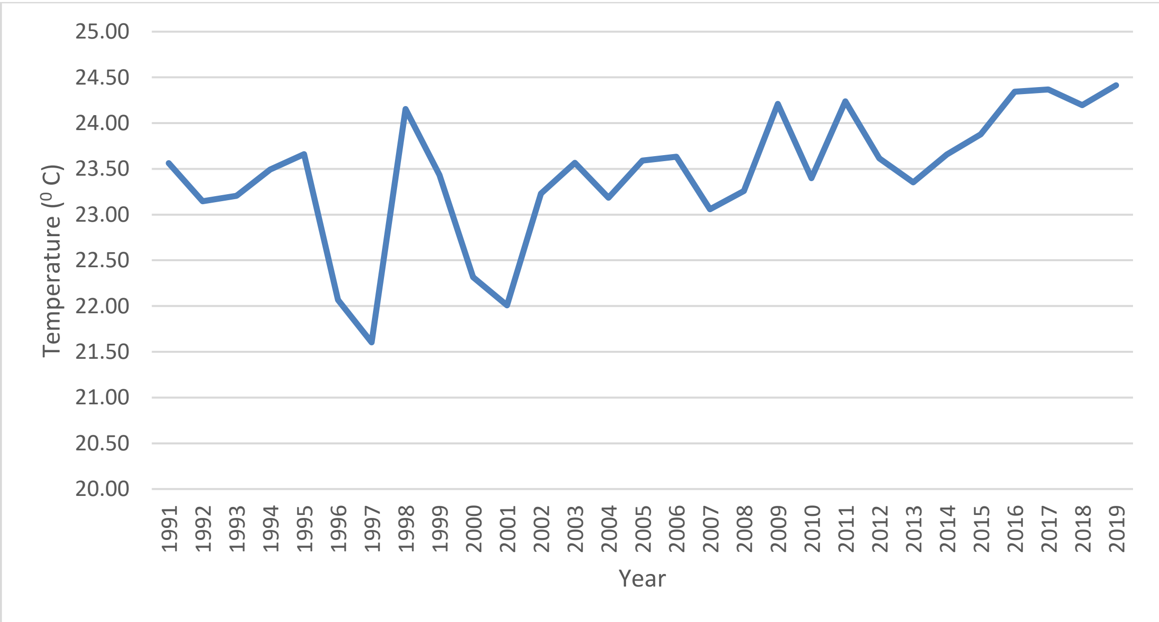

Fig. 15:Trends in annual minimum temperature (° C) at Vellayani

.

Table 5. Descriptive statistics for the weather parameters from Vellayani (1991-2019)

	Maximum temperature (° C)			**Minimum temperature (° C)**			**Rainfall (mm)**		
Year	**Mean**	**SD**	**CV (%)**	**Mean**	**SD**	**CV (%)**	**Total**	**SD**	**CV (%)**
1991	31.00	1.27	4.10	23.56	1.30	5.52	1802.80	187.89	125.07
1992	30.58	1.10	3.60	23.14	1.36	5.89	1858.50	195.08	125.95
1993	30.67	1.11	3.61	23.20	1.25	5.41	1995.10	170.80	102.73
1994	30.81	0.83	2.70	23.49	0.87	3.72	1593.70	119.86	90.25
1995	31.25	0.97	3.11	23.65	1.35	5.69	1410.80	118.21	100.54
1996	30.58	1.08	3.52	22.06	1.11	5.02	1307.10	92.81	85.21
1997	31.01	1.63	5.24	21.60	0.75	3.48	1536.50	117.09	91.45
1998	31.18	1.63	5.23	24.16	1.04	4.32	2038.90	145.63	85.71
1999	30.47	1.09	3.58	23.44	0.93	3.95	2311.80	233.02	120.95
2000	30.52	1.14	3.74	22.32	1.32	5.91	1205.80	87.92	87.50
2001	30.53	0.91	3.00	22.00	1.27	5.78	2161.70	160.67	89.19
2002	31.13	1.08	3.45	23.23	1.05	4.50	1160.00	120.53	124.69
2003	31.48	0.83	2.65	23.58	1.18	5.00	1767.80	139.07	94.40
2004	31.22	1.18	3.79	23.20	1.07	4.60	1804.40	141.46	94.07
2005	31.61	1.02	3.22	23.61	1.06	4.49	1724.00	120.43	83.82

2006	31.10	1.03	3.32	23.64	1.19	5.03	2013.10	179.60	107.06
2007	31.17	0.94	3.00	23.06	0.98	4.26	1953.60	126.52	77.71
2008	30.93	0.91	2.93	23.26	0.98	4.20	1881.40	115.34	73.57
2009	31.01	1.42	4.57	24.23	1.14	4.69	1216.70	128.94	127.17
2010	31.52	1.55	4.92	23.40	1.06	4.55	1980.20	148.12	89.76
2011	30.88	1.10	3.57	24.25	0.71	2.93	1046.40	64.62	74.11
2012	30.59	0.82	2.69	23.63	1.28	5.44	878.95	54.54	74.45
2013	30.66	1.38	4.49	23.36	1.12	4.80	1902.40	137.43	86.69
2014	30.84	0.95	3.07	23.65	1.05	4.45	1926.30	144.37	89.94
2015	31.63	0.55	1.75	23.88	1.05	4.41	2335.60	151.21	77.69
2016	32.61	1.25	3.83	24.33	0.95	3.91	1240.80	166.72	161.24
2017	32.00	1.17	3.66	24.37	1.10	4.52	1761.10	107.85	73.48
2018	32.08	1.01	3.14	24.20	1.04	4.31	1912.80	138.25	86.73
2019	32.38	1.54	4.76	24.41	1.31	5.39	1933.10	144.97	89.99

4.2.1.2. *Detection and estimation of trends in weather parameters at Vellayani*

In general, the trends in time series data was estimated using simple linear regression by taking time as the independent variable and using OLS. But if the time series data do not follow normal distribution, OLS parameter estimates may not be correct. So, the normality assumption of any time series has to be verified before applying OLS and it was done with the help of Shapiro Wilk's criteria. The null hypothesis of this test was that the data follows normal distribution versus data does not follow normal as the alternate hypothesis. Table 6 shows the result of a normality test performed for weather parameters at Vellayani.

Table 6: Result of normality test for weather data from Vellayani

Weather Parameter	**Shapiro-Wilk Test (W)**	**p value**
Rainfall (mm)	0.89	4.71e-015***
Maximum Temperature(℃)	0.97	4.79e-006***
Minimum temperature (℃)	0.99	0.01***

From table 6 it is clear that Shapiro - Wilks 'W' value for rainfall, maximum temperature, minimum temperature were significant indicated that all the three weather parameters didn't follow normal distribution. Mann-Kendal test (Mann, 1945; Kendall, 1975) was a non-parametric test usually used for detecting the presence of trend when the data do not follow normal distribution and the magnitude of trend was estimated using Sen's slope estimator (Sen, 1968). Sonali and Kumar (2013) studied the spatial and temporal trend analysis of annual, monthly and seasonal maximum and minimum temperatures using Mann-Kendall test and Sens slope estimation. Chakraborty *et al*. (2013) studied Trend and variability analysis of rainfall series at Seonath River Basin, Chhattisgarh (India) using both parametric and non-parametric methods. As a non-parametric method Mann-Kendall (MK) was used to detect trend and Sen's slope estimation for detecting magnitude of trend.

4.2.1.2.1. *Mann-Kendal (MK) test and Sen's slope estimator*

To ascertain statistical significance of the trends, annual data on rainfall, maximum temperature and minimum temperature was considered. MK test was also performed to annual deseasonalized data of all the weather parameters. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the presence of increasing or decreasing trend. It was also used to identify the trends in four seasons viz., summer (March-May), North West monsoon (October- November), South East monsoon (June – September) and winter (December – February). The results of MK test and Sen's slope estimates correspond to weather parameters in Vellayani are shown in table 7, table 8 and table 9 respectively.

In the MK test both the Z and P values gave an indication of the absence or the presence of a significant trend in a time series data. In the case of rainfall, the observed Z values for annual, deseasonalized annual and for four seasons were less than the critical value of 1.96 revealed no significant trend in annual as well as seasonal rainfall. Even though there was no significant trend in rainfall, Sen's slope estimates for annual, north-east and south-west monsoon was negative revealed a decline in annual and these two seasons rainfall. However, Sen's slope estimates for summer and winter suggested an increase in rainfall during this season but it was not significant.

Table 7: Results of MK test and Sen's slope estimator for rainfall at Vellayani

Season	Z- Value	P- Value	S	tau	Sen's slope
Annual	-0.02	0.98	-2	-0.004	-0.87
Deseasonalized Annual	0.43	0.67	24	0.005	3.14
Summer	1.31	0.19	71	0.17	4.42
North east monsoon	-0.84	0.40	-46	-0.11	-3.60
South west monsoon	-0.92	0.36	-50	0.28	-0.12
Winter	1.07	0.28	58	0.14	1.79

The observed Z values for annual maximum temperature (2.68), annual deseasonalized (2.72), summer (2.18), southwest monsoon (2.33), north east monsoon (2.81), and winter (2.53) were greater than 1.96 and P values were also less than 0.05 implies the presence of significant trend in annual as well as seasonal maximum temperature overtime. The Sen's slope estimates values are all positive which further projecting a significant increasing trend in annual maximum temperature and in different seasons.

Table 8: Results of MK test and Sen's slope estimator for Maximum temperature at Vellayani

Season	Z- Value	P- Value	S	tau	Sen's slope
Annual	2.68	0.007***	144	0.35	0.04
Deseasonalized Annual	2.72	0.006***	145	0.35	0.039
Summer	2.18	0.03**	117	0.29	0.042
North east monsoon	2.81	0.004***	151	0.37	0.043
South west monsoon	2.33	0.02**	125	0.31	0.037
Winter	2.53	0.01**	136	0.33	0.036

For minimum temperature Z values and P values are found to lie in the significant range for all the six categories, giving an indication of a significant trend. Since the Sen's slope estimates are positive and it lies between 0.035 and 0.047 suggested a significant increase in maximum temperature at Vellayani. The trend analysis on weather parameters indicates a significant increase in maximum and minimum temperature with a non-significant decline in annual, south west monsoon and north east monsoon rainfall at Vellayani.

Table 9: Results of MK test and Sen's slope estimator for Minimum temperature at Vellayani

Season	Z- Value	P- Value	S	tau	Sen's slope
Annual	3.47	0.0005***	186	0.458	0.039
Deseasonalized Annual	3.51	0.0004***	188	0.463	0.039
Summer	2.93	0.003***	157	0.387	0.037
North east monsoon	2.21	0.026**	119	0.293	0.035
South west monsoon	3.00	0.002***	161	0.397	0.042
Winter	2.53	0.011**	136	0.334	0.047

4.2.2. Trend analysis of weather parameters in Kumarakom

4.2.2.1. ***Graphical method for analyzing nature of trend***

Mean of the annual maximum and minimum temperature and rainfall was found by using the monthly data collected for the period from 1991 to 2019 at Kumarakom are shown in table 10. The range of average maximum temperature lies between 31.88° C to 32.96° C with a CV less than 7. The annual minimum temperature varied from 21.89° C to 23.80° C with a CV less than 9. However, the range of rainfall was very high and it varied from 1478.2mm to 3208.8mm with a high and fluctuating CV and the highest standard deviation of 296.54mm was observed in the year 2018. In the case of maximum temperature CV ranges from 2.54 to 6.38, for minimum temperature it was from 3.02 to 8.74 but for rainfall it was from 76.23 to 124.52, which shows that there was less CV for maximum and minimum temperature and a high CV for rainfall.

Figure 16, Figure 17 and Figure 18 are the plot of annual mean maximum temperature, minimum temperature and total rainfall. These graphs give a thought regarding the pattern of rainfall and temperature throughout the study period. Annual rainfall was highest during 1994 and lowest for the year 2016. The plot shows a slight alternating nature with decline in trend. Highest maximum temperature was noticed in the year 2016. Over the study period maximum temperature shows an overall decline in trend. For minimum temperature 2002 had the highest value and lowest in 2008.

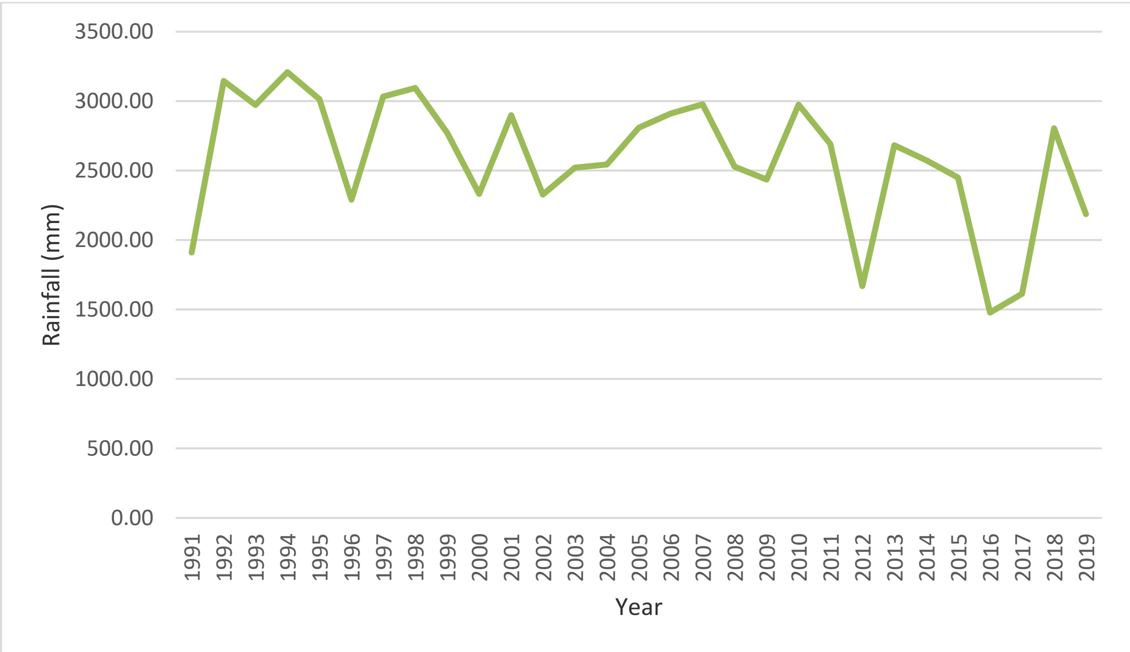

Fig. 16: Trends in annual rainfall (mm) at Kumarakom

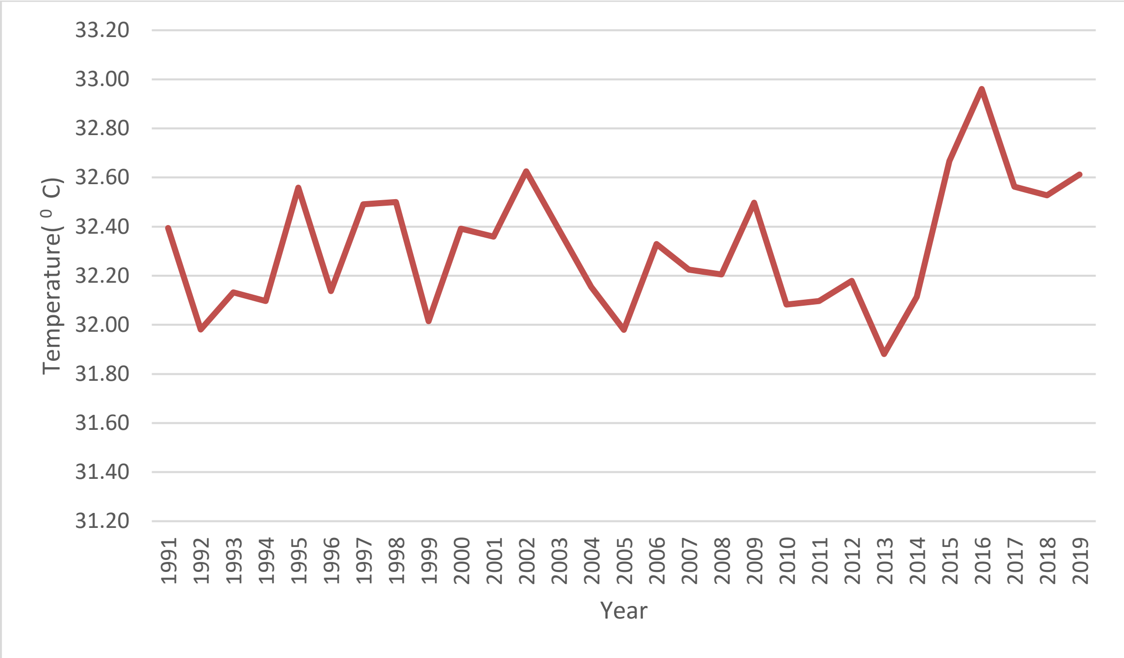

Fig. 17: Trends in annual maximum temperature (° C) at Kumarakom

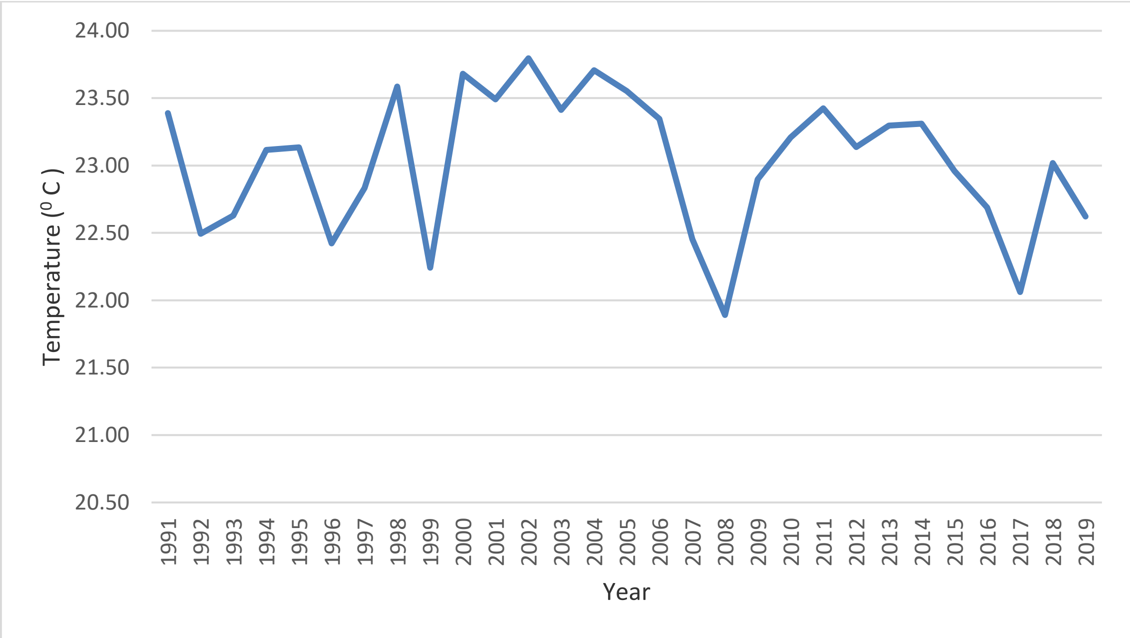

Fig. 18: Trends in annual minimum temperature (° C) at Kumarakom

Table 10. Descriptive statistics for the weather parameters from Kumarakom (1991-2019)

	Maximum temperature (° C)			**Minimum temperature (° C)**			**Rainfall (mm)**		
Year	**Mean**	**SD**	**CV (%)**	**Mean**	**SD**	**CV (%)**	**Total**	**SD**	**CV (%)**
1991	32.39	2.07	6.38	23.39	1.36	5.82	1910.30	198.22	124.52
1992	31.98	1.89	5.91	22.49	1.60	7.11	3146.40	280.04	106.80
1993	32.13	1.59	4.95	22.63	1.34	5.91	2972.80	273.74	110.50
1994	32.10	1.19	3.70	23.12	1.18	5.11	3208.80	219.59	82.12
1995	32.56	1.36	4.19	23.14	2.02	8.74	3014.60	218.16	86.84
1996	32.14	1.64	5.11	22.42	1.95	8.71	2289.80	181.97	95.36
1997	32.49	1.42	4.36	22.83	1.42	6.23	3032.20	212.30	84.02
1998	32.50	1.86	5.73	23.59	1.00	4.24	3094.10	241.13	93.52
1999	32.01	1.31	4.10	22.24	1.52	6.83	2771.90	233.71	101.18
2000	32.39	1.47	4.55	23.68	0.90	3.80	2333.20	204.76	105.32
2001	32.36	1.19	3.66	23.49	0.89	3.78	2899.70	211.82	87.66
2002	32.63	1.64	5.03	23.80	0.86	3.62	2328.20	176.74	91.09
2003	32.39	1.33	4.11	23.41	0.88	3.76	2521.60	225.13	107.14
2004	32.15	1.58	4.91	23.71	0.86	3.63	2545.00	207.24	97.72

2005	31.98	1.78	5.56	23.55	0.71	3.02	2808.50	203.36	86.89
2006	32.33	1.21	3.75	23.35	0.93	3.97	2909.90	212.28	87.54
2007	32.23	1.51	4.68	22.45	1.21	5.39	2978.30	262.44	105.74
2008	32.21	0.95	2.93	21.89	1.04	4.76	2527.90	160.91	76.38
2009	32.50	1.13	3.48	22.90	1.13	4.94	2436.40	200.79	98.90
2010	32.08	1.61	5.02	23.21	1.22	5.28	2976.10	194.01	78.23
2011	32.10	1.02	3.17	23.43	0.72	3.09	2691.60	214.07	95.44
2012	32.18	0.82	2.54	23.14	0.97	4.19	1668.70	108.56	78.07
2013	31.88	1.57	4.91	23.30	1.17	5.03	2682.90	241.49	108.01
2014	32.11	1.26	3.92	23.31	0.88	3.79	2573.60	217.76	101.53
2015	32.67	1.01	3.09	22.96	0.71	3.11	2450.50	165.92	81.25
2016	32.96	1.32	4.00	22.69	1.66	7.31	1478.20	145.25	117.92
2017	32.56	1.09	3.34	22.06	1.23	5.58	1614.30	109.96	81.74
2018	32.53	1.73	5.32	23.02	1.17	5.07	2804.40	296.54	126.89
2019	32.61	1.63	4.99	22.62	1.56	6.92	2186.00	225.10	123.57

4.2.2.2. *Detection and estimation of trends in weather parameters at Kumarakom*

Similar to as mentioned in the earlier section, the normality assumption of any time series has to be verified before applying OLS which can be done with the help of Shapiro Wilk's test. The null hypothesis of this test was that the data follows normal distribution against the data does not follow normal as the alternate hypothesis. The result of normality test performed for weather parameters data from Kumarakom is given in table 11

Table 11: Result of normality test for weather data from Kumarakom

Weather Parameter	**Shapiro-Wilk Test (W)**	**p value**
Rainfall (mm)	0.89	2.48e-015***
Maximum Temperature (℃)	0.99	0.003***
Minimum temperature (℃)	0.97	1.32e-005***

From table 11 it is clear that the calculated Shapiro - Wilks 'W' value for rainfall, maximum temperature, minimum temperature were significant indicated that the three weather parameters didn't follow normal distribution. Thus the non-parametric Mann-Kendall test (Mann, 1945; Kendall, 1975) is used for identifying the presence of trend and Sen's slope estimator (Sen, 1968) to find the magnitude of trend in such situations

4.2.2.2.1. *Mann-Kendal test and Sen's slope estimator*

To determine statistical significance of the trends in annual weather parameters and for different seasons, the non-parametric Mann-Kendall (MK) test was used. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the presence of increasing or decreasing trend. MK test was also used to identify the trends in four seasons viz., summer (March-May), North West monsoon (October- November), South East monsoon (June – September) and winter (December – February). The results of MK test and Sen's slope estimates correspond to weather parameters in Kumarakom data are shown in table 12, table 13 and table 14.

In the MK test both Z and P values gave an indication of the absence or the presence of a significant trend. In the case of annual rainfall, deseasonalized annual and for north east monsoon season P value is less than 0.1 revealed the presence of a significant trend at 10 percent level of significance. Even though there was no significant trend for summer, winter and monsoon seasons rainfall the Sen's slope estimate for all the categories except for winter were negative revealed a decline in annual, deseasonalized annual and four season's rainfall excluding the winter. However, Sen's slope estimate for winter suggested an increase in rainfall during this season but it was not significant.

Table 12: Results of MK test and Sen's slope estimator for rainfall at Kumarakom

Season	**Z- Value**	**P- Value**	**S**	**Tau**	**Sen's slope**
Annual	-2.42	0.02*	-130	-0.32	-23.12
Deseasonalized Annual	-1.71	0.09*	-92	-0.23	-20.78
Summer	-1.41	0.16	-76	-0.19	-3.87
North east monsoon	-2.31	0.02*	-121	-0.30	-10.42
South west monsoon	-1.18	0.24	-64	-0.16	-0.03
Winter	0.28	0.78	16	0.003	0.50

The observed Z values of annual maximum temperature, annual deseasonalized, summer, southwest monsoon, north east monsoon, and winter were respectively 1.03, 1.26, -0.09, 2.42, 2.01and -2.23 respectively. Among these north east monsoon, south west monsoon and winter had Z values greater than 1.96 and P values were also less than 0.05 implies the presence of significant trend overtime. Moreover, all the Sen's slope estimates are all positive except for summer and winter seasons which further means an increasing trend in annual maximum temperature and in monsoon seasons.

Table 13: Results of MK test and Sen's slope estimator for Maximum temperature at Kumarakom

Season	**Z- Value**	**P- Value**	**S**	**Tau**	**Sen's slope**
Annual	1.03	0.30	56	0.14	0.005
Deseasonalized Annual	1.26	0.21	68	0.17	0.006
Summer	-0.09	0.92	-6	-0.01	-0.001
North east monsoon	2.01	0.04**	108	0.27	0.03
South west monsoon	2.42	0.02**	130	0.32	0.03
Winter	-2.23	0.03**	-120	-0.30	-0.02

For minimum temperature Z values and P values are found to lie in the significant range only for south west monsoon and for the remaining five categories Z values are less than the critical value which gives an indication of a non-significant trend. Since the Sen's slope estimates are negative for annual, deseasonalized annual, north east and south west monsoon, and it lies between 0.001 and 0.01 suggested a decrease in minimum temperature at Kumarakom but an increase in temperature was noted for summer and winter season. The trend analysis on weather parameters at Kumarakom indicates a non-significant increase in annual maximum temperature and a decreasing in annual minimum temperature with a significant decline in annual rainfall.

Table 14: Results of MK test and Sen's slope estimator for Minimum temperature at Kumarakom

Season	Z- Value	P- Value	S	Tau	Sen's slope
Annual	-0.81	0.42	-44	-0.11	-0.01
Deseasonalized Annual	-0.84	0.40	-46	-0.11	-0.01
Summer	0.02	0.98	2	0.004	0.0001
North east monsoon	-0.02	0.98	-2	-0.004	-0.001
South west monsoon	-2.06	0.04**	111	-0.27	-0.03
Winter	0.45	0.65	25	0.006	0.006

4.2.3. Trend analysis of weather parameters for Moncompu

4.2.3.1. *Graphical method for analyzing nature of trend*

Descriptive statistics including mean, standard deviation and coefficient of variation (CV) are utilized to summarize the annual maximum temperature, minimum temperature and rainfall included in the study. Mean of annual maximum and minimum temperature and rainfall was found using the monthly data collected for the period from 1997 to 2018 from RRS, Moncompu and the estimated values are shown in table 15.

The range of average maximum temperature lies between 31.28° C and 32.54° C with a CV less than 8 and highest standard deviation was observed as 2.47° C for the year 1998. Minimum temperature varies from 23.72° C to 24.69° C with a CV less than 6. However, the range of rainfall was very high from 1598 mm to 3595.6 mm with very high and fluctuating CV. For maximum temperature the CV was 2.42-7.87, for minimum temperature it was 2.44-5.20 but for rainfall it was 69.32-121.41, which shows that there was less CV for maximum and minimum temperature and a high CV for rainfall. It is also evident from the table 15 that the highest maximum temperature was obtained in 2000 (32.54° C) and lowest was in 2011 (31.28° C) with a standard deviation of 0.327° C. For minimum temperature the highest value was obtained in 2017(24.69° C) and lowest in 1998 (23.72° C) with a standard deviation of 0.226 (^{0}C). In case of rainfall in the year 1997(3595.6mm) received the highest amount of precipitation and lowest amount of rainfall(1598mm) was received in 2012 with a high standard deviation of 576.07mm. Due to the high value of CV we can conclude that there is a high variation in rainfall distribution over the years.

A plot of annual mean maximum temperature, minimum temperature and rainfall are given in Figure 19, Figure 20 and Figure 21. These graphs clearly give the indication of pattern of change in temperature and rainfall throughout the study period. Annual rainfall was highest during 1997 and lowest for the year 2003 and 2012. The plot shows an increase in trend in the initial years and then a decrease in trends. Highest maximum temperature was noticed in the year 2000. From 2011 onwards the temperature showed a sudden increase up to 2018. For minimum temperature an increasing pattern of temperature could be observed over the entire study period.

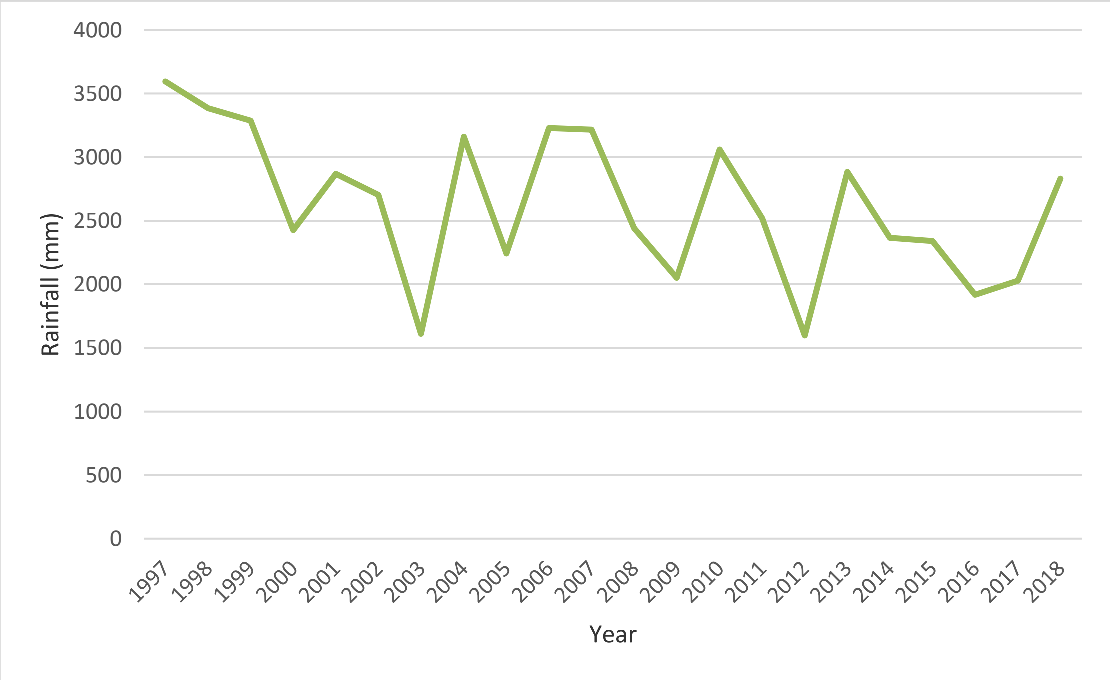

Fig. 19: Trends in annual rainfall (mm) at Moncompu

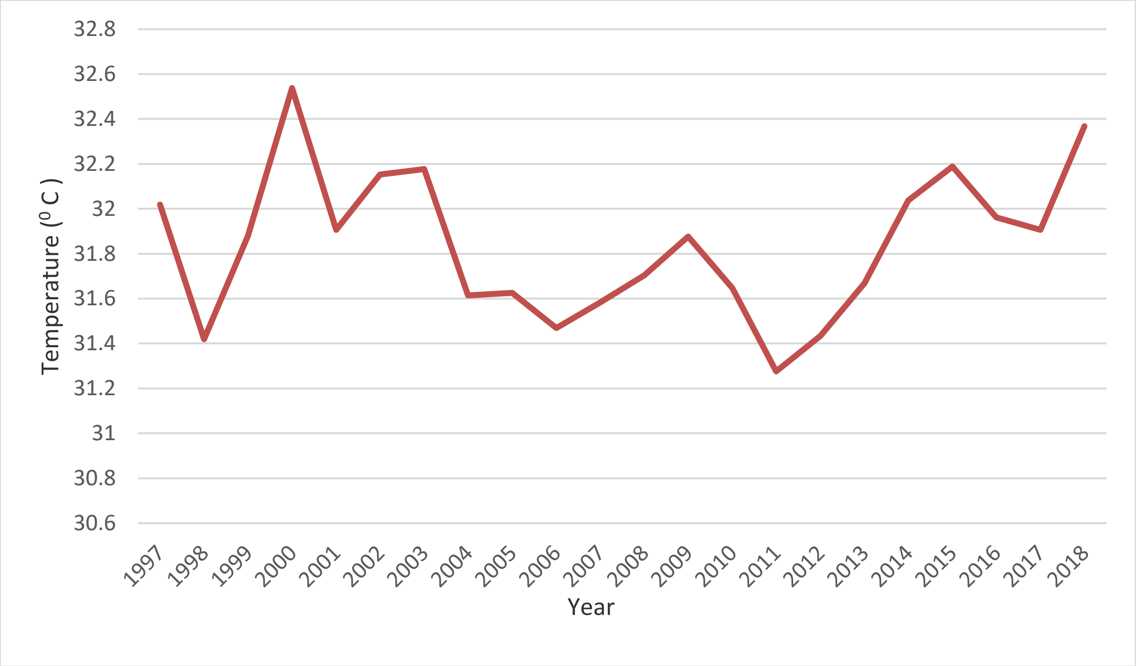

Fig. 20: Trends in annual maximum temperature (° C) at Moncompu

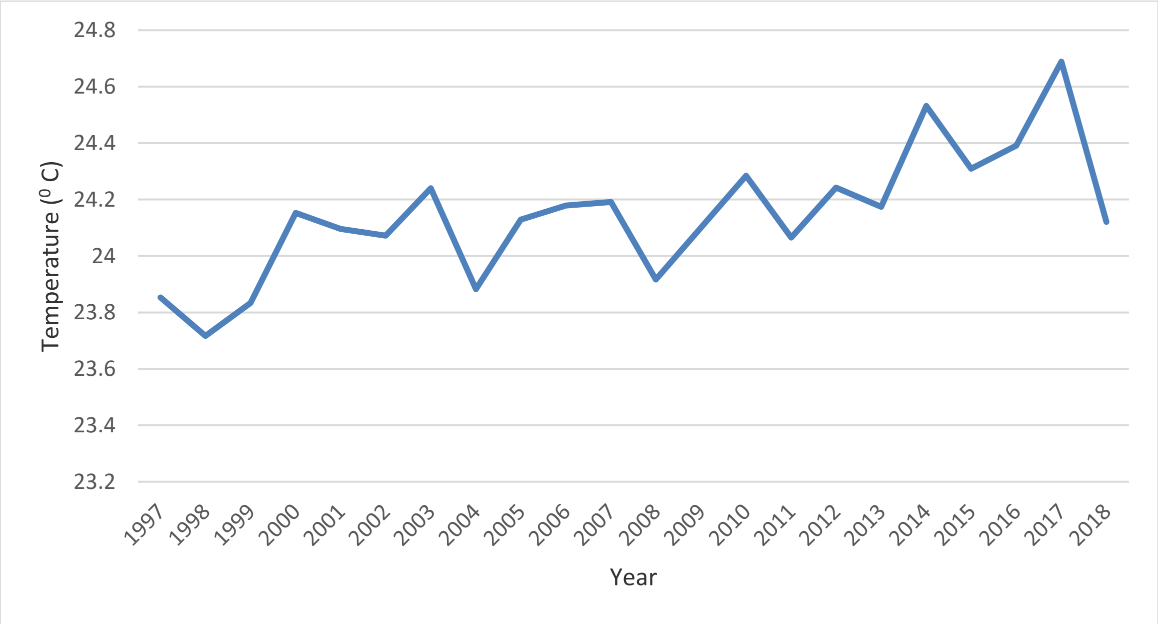

Fig. 21: Trends in annual minimum temperature (° C) at Moncompu

Table 15: Descriptive statistics for the weather parameters from Moncompu (1997-2018)

	Maximum temperature (^{0}C)			**Maximum temperature (^{0}C)**			**Rainfall (mm)**		
Year	Mean	SD	CV (%)	Mean	SD	CV (%)	Total	SD	CV (%)
1997	32.02	2.08	6.48	23.85	0.87	3.64	3595.6	284.2	94.85
1998	31.42	2.47	7.87	23.72	0.81	3.4	3386.4	286.23	101.43
1999	31.88	1.55	4.88	23.83	0.94	3.95	3288	271.14	98.96
2000	32.54	1.53	4.71	24.15	1.15	4.76	2427.65	198.37	98.06
2001	31.91	1.25	3.93	24.1	1.01	4.18	2870.1	198.22	82.87
2002	32.15	1.21	3.75	24.07	0.85	3.52	2702.6	222.01	98.58
2003	32.18	1.22	3.79	24.24	1.11	4.57	1611.5	144.75	107.79
2004	31.61	1.38	4.36	23.88	1.08	4.51	3160.21	254.06	96.47
2005	31.63	2.08	6.57	24.13	0.76	3.15	2242.2	177.15	94.81
2006	31.47	1.72	5.47	24.18	0.83	3.44	3228.3	247.77	92.1
2007	31.58	1.6	5.08	24.19	1.26	5.2	3215.7	269.7	100.64
2008	31.7	1.05	3.3	23.92	1.02	4.26	2441.6	188.27	92.53
2009	31.88	1.43	4.5	24.1	1.2	4.97	2051.9	160.12	93.65
2010	31.65	1.75	5.52	24.28	0.76	3.12	3059.9	194.51	76.28

2011	31.28	1.39	4.45	24.06	1.07	4.44	2520	145.58	69.32
2012	31.43	1.23	3.92	24.24	1.22	5.02	1598	108.94	81.81
2013	31.67	1.55	4.91	24.17	1.12	4.64	2884.3	291.83	121.41
2014	32.04	1.3	4.05	24.53	1.03	4.18	2366.7	190.48	96.58
2015	32.19	0.88	2.72	24.31	0.98	4.02	2341	153.03	78.44
2016	31.96	1.62	5.07	24.39	0.87	3.56	1917.7	176.91	110.7
2017	31.91	0.77	2.42	24.69	1.16	4.7	2028.82	176.57	104.44
2018	32.37	1.4	4.34	24.12	0.59	2.44	2830.9	255.24	108.19

4.2.3.2. ***Detection and estimation of trends in weather parameters at Moncompu***

The trends in time series data was estimated using simple linear regression by taking time as the independent variable and using OLS. But if the time series data do not follow normal distribution, OLS parameter estimates may not be giving a reliable result. So, the normality assumption of any time series has to be verified before applying OLS and it was done with the help of Shapiro Wilk's criteria. The null hypothesis of this test was that the data follows normal distribution versus data does not follow normal as the alternate hypothesis. Table 16 shows the result of normality test performed for weather parameters data from Moncompu

Table 16: Result of normality test for weather data from Moncompu

Weather Parameter	**Shapiro-Wilk Test (W)**	**p value**
Rainfall (mm)	0.88	1.93e-013***
Maximum Temperature (℃)	0.97	0.00***
Minimum Temperature (℃)	0.98	0.002***

From table 16 it is clear that Shapiro - Wilks 'W' value for rainfall, maximum temperature, minimum temperature were significant indicated that the three weather parameters didn't follow normal distribution. As discussed in earlier sections Mann-Kendal test was a non-parametric test usually used for detecting the presence of trend in such situations and the magnitude of trend was estimated using Sen's slope estimator.

4.2.3.2.1. ***Mann-Kendal test and Sen's slope estimator***

To ascertain statistical significance of the trends, annual data on rainfall, maximum temperature and minimum temperature was considered and MK test was performed to annual data of weather parameters. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the presence of an increasing or decreasing trend. MK test was also used to identify the trends in four seasons viz., summer (March-May), North West monsoon (October- November), South East monsoon (June – September) and winter (December – February). The results of MK test and Sen's slope estimates correspond to weather parameters in Moncompu data are shown in table 17, table 18 and table 19.

In the Mk test both Z and P values gave an indication of the absence or the presence of a significant trend. In the case of rainfall, the observed Z values for annual, deseasonalized annual and north east monsoon had Z value greater than the critical value of 1.96 revealed that there is significant trend in annual as well as deseasonalized annual and north east monsoon rainfall over the years. Even though there was no significant trend in rainfall for most of the seasons the Sen's slope estimate for all the six categories were negative indicating a decline in rainfall annual and in all the seasons.

Table 17: Results of MK test and Sen's slope estimator for rainfall at Moncompu

Season	**Z- Value**	**P- Value**	**S**	**tau**	**Sen's slope**
Annual	-2.59	0.01***	-93	-0.40	-43.5
Deseasonalized Annual	-2.03	0.04***	-73	-0.31	-36.42
Summer	-0.62	0.53	-23	-0.09	-4.59
North east monsoon	-2.42	0.02**	-87	-0.37	-15.2
South west monsoon	-1.24	0.21	-45	-0.19	-20.9
Winter	-0.17	0.86	-7	-0.03	-0.22

The observed Z values for maximum temperature for annual, deseasonalized annual and all seasons were less than 1.96 and P values were greater than 0.05 implies the presence of non-significant trend overtime. However, all the Sen's slope estimates were positive except for winter and summer which further gave an indication of an increasing trend in maximum temperature annually and in different seasons. But the

Sen's slope estimate for summer and winter suggests a non-significant declining trend in these seasons.

Table 18: Results of MK test and Sen's slope estimator for Maximum temperature at Moncompu

Season	Z- Value	P- Value	S	tau	Sen's slope
Annual	0.39	0.69	15	0.01	0.004
Deseasonalized Annual	0.39	0.69	15	0.01	0.004
Summer	-1.75	0.08	-63	-0.27	-0.042
North east monsoon	1.02	0.31	37	0.16	0.03
South west monsoon	1.30	0.20	47	0.20	0.03
Winter	-0.73	0.46	-27	-116	-0.02

Table 19: Results of MK test and Sen's slope estimator for Minimum temperature at Moncompu

Season	Z- Value	P- Value	S	tau	Sen's slope
Annual	3.44	0.00***	123	0.53	0.02
Deseasonalized Annual	3.27	0.001***	117	0.51	0.02
Summer	0.79	0.43	29	0.13	0.02
North east monsoon	3.95	7.89e-05***	141	0.61	0.07
South west monsoon	1.72	0.08	62	0.27	0.01
Winter	1.18	0.24	43	0.19	0.02

For minimum temperature the Z values and P values are found to lie in significant range for annual, deseasinalised annual and north east monsoon gave an indication of a significant trend at 1% level of significance. Since the Sen's slope estimates are positive for all the six categories and the estimates lie between 0.01 and 0.07 suggested an increase in minimum temperature at RRS, Moncompu over the years. The trend analysis on weather parameters at Moncompu indicates an increase in maximum temperature for annual and in all the seasons except for summer and winter and an increase in minimum temperature during the entire period with a decline in annual and seasonal rainfall at Moncompu.

4.2.4. Trend analysis of weather parameters for Pampadumpara

4.2.4.1. Graphical method for analyzing nature of trend

Mean of annual maximum and minimum temperature and rainfall was found from the monthly data for the period from 1991 to 2019 from Pampadumpara and the descriptive statistics for various weather parameters is presented in table 20. The range of average annual maximum temperature lies between 21.96° C to 27.79° C with a CV of less than 12 and the highest standard deviation was observed as 3.03° C for the year 1992. The minimum temperature varied from 13.34° C to 20.29° C with CV less than 17 and a highest standard deviation of 3.10 ° C was observed for the year 2017. However, the range of rainfall was very high (1163.5 to 2717.3mm) with very high and fluctuating CV and a highest standard deviation of 250.64mm was observed for the year 2018. For maximum temperature CV ranges was 6.20 to 11.37, for minimum temperature it was from 6.26 to 16.63 but for rainfall it was from 64.30 to 131.05, which shows that there was not much variation in maximum and minimum temperature and a high variability in annual rainfall.

A plot of annual mean maximum temperature, minimum temperature and total rainfall are given in Figure 22, Figure 23 and Figure 24. These graphs clearly give the pattern of temperature and rainfall throughout the study period. Annual rainfall was highest during 2018 and lowest for the year 2016. The plot shows a downward trend. The highest maximum temperature was noticed in the year 1997. From 1998 onwards the temperature showed a sudden decrease up to 2000 and later it moves almost constantly and again decreased during 2014 and again moved up. For minimum temperature an increasing pattern of temperature could be observed over a period of 29 years

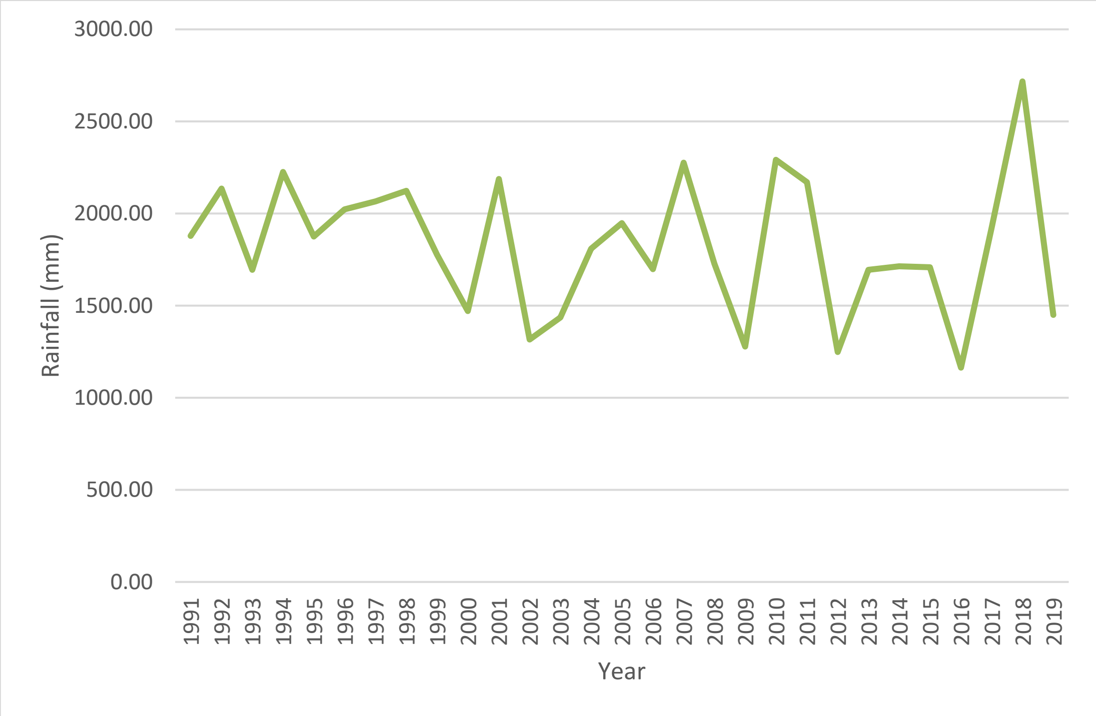

Fig. 22: Trends in annual rainfall (mm) at Pampadumpara

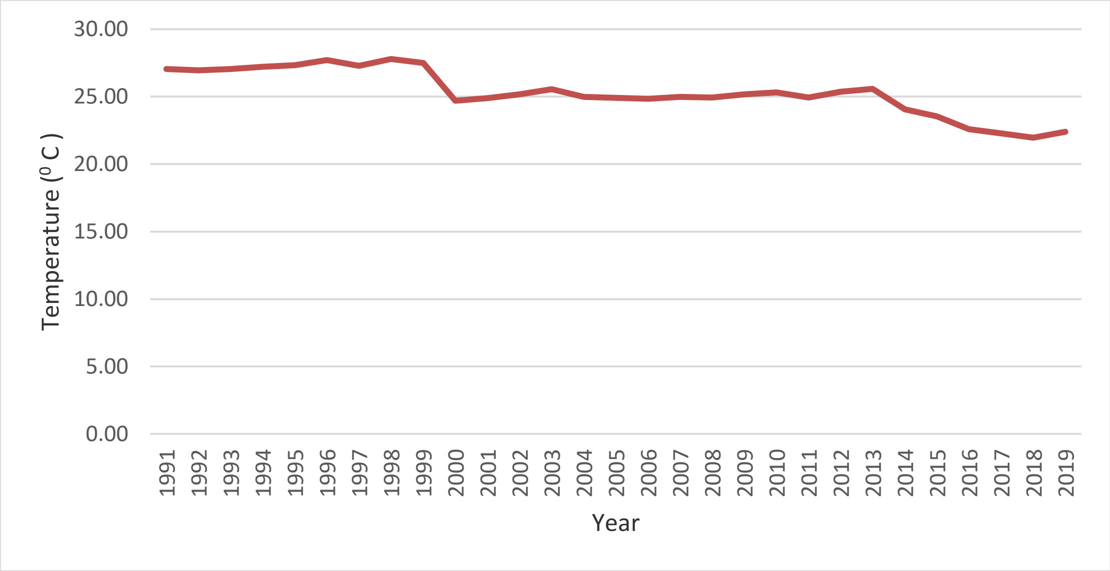

Fig.23: Trends in annual Maximum temperature (° C) at Pampadumpara

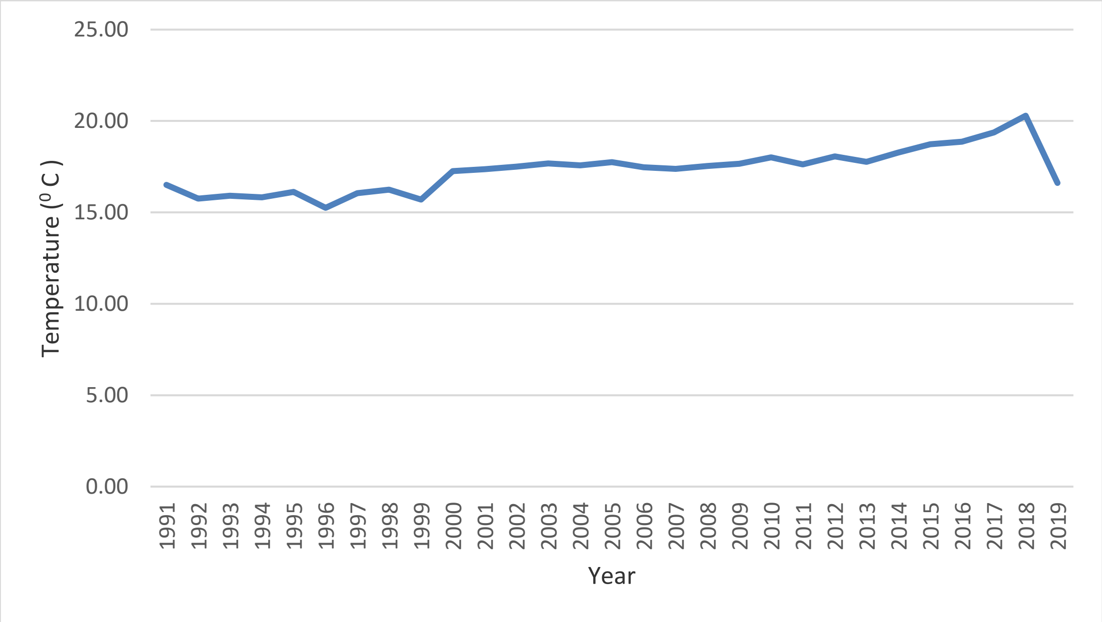

Fig. 24: Trends in annual Minimum temperature (° C) at Pampadumpara

Table 20. Descriptive statistics for the weather parameters from Pampadumpara (1991-2019)

	Maximum temperature (° C)			**Minimum temperature (° C)**			**Rainfall (mm)**		
Year	Mean	SD	CV (%)	Mean	SD	CV (%)	Total	SD	CV (%)
1991	27.04	2.72	10.05	16.50	1.73	10.50	1878.40	168.83	107.85
1992	26.96	3.03	11.23	15.75	1.66	10.53	2134.90	148.00	83.19
1993	27.04	2.93	10.82	15.92	1.38	8.66	1695.50	121.29	85.84
1994	27.21	2.39	8.78	15.83	1.74	10.97	2226.00	166.75	89.89
1995	27.33	1.72	6.30	16.13	1.30	8.06	1874.70	123.07	78.78
1996	27.71	2.40	8.65	15.25	1.56	10.23	2023.60	152.80	90.61
1997	27.29	2.45	8.99	16.06	1.59	9.91	2065.50	157.34	91.41
1998	27.79	2.17	7.80	16.25	1.53	9.42	2124.00	142.11	80.29
1999	27.50	1.71	6.20	15.71	1.74	11.06	1776.10	150.31	101.56
2000	24.71	2.35	9.52	17.26	1.20	6.94	1471.50	98.95	80.69
2001	24.89	2.33	9.35	17.36	1.12	6.43	2187.70	136.72	75.00
2002	25.17	2.11	8.37	17.89	1.50	8.37	1316.20	113.93	103.88
2003	25.54	2.06	8.07	17.67	1.26	7.14	1436.00	122.17	102.09
2004	24.99	2.62	10.49	17.57	1.16	6.60	1809.50	127.90	84.82
2005	24.92	2.16	8.68	17.75	1.11	6.26	1947.96	139.51	85.94

2006	24.84	2.29	9.22	17.47	1.30	7.45	1698.50	120.26	84.97
2007	24.98	2.73	10.94	17.38	1.39	8.02	2276.00	164.00	86.47
2008	24.94	1.61	6.46	17.93	1.85	10.33	1728.10	131.80	91.52
2009	25.16	2.36	9.36	17.67	1.37	7.75	1277.10	113.80	106.93
2010	25.31	2.56	10.12	18.01	1.38	7.69	2291.36	151.81	79.51
2011	24.95	2.03	8.13	17.63	1.14	6.49	2170.00	116.28	64.30
2012	25.36	2.37	9.36	18.07	1.72	9.51	1248.30	90.46	86.96
2013	25.59	2.60	10.18	17.77	2.04	11.48	1695.05	167.55	118.62
2014	24.05	2.73	11.37	18.27	2.17	11.88	1714.60	183.51	128.43
2015	23.53	2.29	9.74	18.72	1.38	7.38	1707.69	108.68	76.37
2016	22.59	1.95	8.64	18.88	2.09	11.05	1163.50	100.37	103.52
2017	22.28	1.63	7.30	18.63	3.10	16.63	1926.40	118.69	73.93
2018	21.96	1.46	6.64	20.29	1.55	7.66	2717.30	250.64	110.69
2019	22.41	1.95	8.72	13.34	1.94	14.51	1449.20	158.27	131.05

4.2.4.2. *Detection and estimation of trends in weather parameters at Pampadumpara*

In general, the trends in time series data was estimated using simple linear regression by taking time as the independent variable and the parameters was estimated using OLS. But if the time series data do not follow a normal distribution, OLS parameter estimates may not be provides a valid conclusion. So, the normality assumption of any time series has to be verified before applying OLS and it was done with the help of Shapiro Wilk's criteria. The null hypothesis of this test was that the data follows normal distribution versus data does not follow normal as the alternate hypothesis. Table 21 shows the result of the normality test performed for weather parameters from Pampadumpara.

Table 21: Result of normality test for weather data from Pampadumpara

Weather Parameter	**Shapiro-Wilk Test (W)**	**P value**
Rainfall (mm)	0.89	1.59e-014***
Maximum Temperature (℃)	0.98	2.99e-005***
Minimum Temperature (℃)	0.98	0.00***

From table 21 it is clear that Shapiro - Wilks 'W' value for rainfall, maximum temperature, minimum temperature was significant indicated that the three weather parameters didn't follow normal distribution. In such situation the non-parametric Mann-Kendal test (Mann, 1945; Kendall, 1975) was suggested and to identify the presence of trend and the magnitude of trend was estimated using Sen's slope estimator (Sen, 1968).

4.2.4.2.1. Mann-Kendal test and Sen's slope estimator

The presence of trends in annual data on rainfall, maximum temperature and minimum temperature was analyzed using MK test and the nature of trend was diagnosed using Sen's slope estimator. MK test was also performed to annual deseasonalized data of weather parameters. The MK test checks the null hypothesis of no trend versus the alternative hypothesis of the presence of increasing or decreasing trend. MK test was also used to identify the trends in four seasons viz., summer (March-May), North West monsoon (October- November), South East monsoon (June – September) and winter (December – February). The results of MK test and Sen's slope estimates corresponding to the weather parameters in Pampadumpara are shown in table 22, table 23 and table 24.

In the MK test both Z and P values gave an indication of the absence or the presence of a significant trend. In the case of rainfall the observed Z values for annual and all the seasonal data were less than the critical value of 1.96 revealed no significant trend in rainfall over the years. It was found that no significant trend in rainfall but the Sen's slope estimate was negative which indicated a non-significant decline in rainfall at Pampadumpara over the study period.

Table 22: Results of MK test and Sen's slope estimator for rainfall at Pampadumpara

Season	Z- Value	P- Value	S	tau	Sen's slope
Annual	-1.22	0.223	-66	-0.162	-9.481
Deseasonalized annual	-1.67	0.095	-90	-0.221	-23.5
Summer	-1.71	0.087	-92	-0.226	-3.79
North east monsoon	-1.67	0.095	-90	-0.221	-6.316
South west monsoon	-0.51	0.612	-28	-0.068	-2.862
Winter	-0.018	0.985	-2	-0.004	-0.23

For maximum temperature both Z values and p values correspond to annual, deseasonalized and seasonal data were found to lie in significant range, so it indicated the presence of a significant trend. The Sen's slope estimates values are all negative which further emphasize a significant decreasing trend in maximum temperature annually and in different seasons.

Table 23: Results of MK test and Sen's slope estimator for maximum temperature at Pampadumpara

Season	**Z-Value**	**P- Value**	**S**	**tau**	**Sen's slope**
Annual	-3.98	$6.967*10^{-5}$***	-213	-0.525	-0.165
Deseasonalized annual	-3.96	7.56e-05 ***	-212	-0.522	-0.162
Summer	-4.72	$2.27*10^{-6}$***	-253	-0.623	-0.187
North east monsoon	-3.21	0.001***	-172	-0.425	-0.145
South west monsoon	-4.76	1.88e-06***	-255	-0.628	-0.171
Winter	-4.37	$1.23*10^{-5}$***	-234	-0.577	-0.155

For minimum temperature Z values and P values are found to lie in the significant range for all the six categories, giving an indication of a significant trend. Since the Sen's slope estimates are positive and lie between 0.074 and 0.171 suggested an increase in minimum temperature at Pampadumpara. In general, the trend analysis on weather parameters at Pampadumpara indicates a significant decrease in maximum temperature and an increase in minimum temperature with a non-significant decline in annual, deseasonalized annual and seasonal rainfall over the years.

Table 24: Results of MK test and Sen's slope estimator for minimum temperature at Pampadumpara

Season	**Z- Value**	**P- Value**	**S**	**tau**	**Sen's slope**
Annual	5.35	8.99e-08***	286	0.704	0.121
Deseasonalized annual	5.27	1.36e-07***	282	0.69	0.121
Summer	4.59	$4.41*10^{-6}$***	245	0.61	0.171
North east monsoon	4.92	8.75e-07***	263	0.65	0.107

South west monsoon	4.43	9.23e-06***	237	0.59	0.074
Winter	4.29	1.73e-05***	230	0.57	0.123

4.2.5. Inter-regional variation in weather parameters in Southern Kerala

A comparative analysis in trends in weather parameters of four regions was carried out in this section to get an idea about the change in these parameters over the years. Trends in annual and seasonal rainfall at Vellayani, Kumarakom, Moncompu and Pampadumpara are depicted in Fig 25, Fig 26, Fig 27 and Fig 28. It is evident from Fig.25 that there was a decline in rainfall at Vellayani over the years and it ranged within the limits of 1000 mm to below 2000 mm. However, the annual as well as all seasons rainfall showing a decline trend except for the years 2018 and 2019 at Kumarakom (Fig: 26) but this region is receiving an annual rainfall in the range of 2000mm to 3000 mm. A similar pattern of decline was evident at Moncompu (Fig 27) with highest amount of annual rainfall of 2000 mm to more than 3000 mm. While in Pampadumpara the annual rainfall ranged from 1500 mm to 2000 mm and there was no increase in annual and the southwest rainfall but a decline was noticed in other seasons (Fig: 28). In general, a reduction in rainfall was recorded in the four regions over the study period except during the floods in 2018 and 2019. So, in general we can come in the conclusion of a decline in rainfall in Southern Kerala over the study period. It is also evident from the trend analysis that the highest rate of reduction in amount of precipitation overtime was observed at Moncompu followed by Kumarakom and Pampadumpara and Vellayani. Even if there is a decline in rainfall in all the regions highest amount of rain was reported at Moncompu followed by Kumarakom, Pampadumpara and Vellayani.

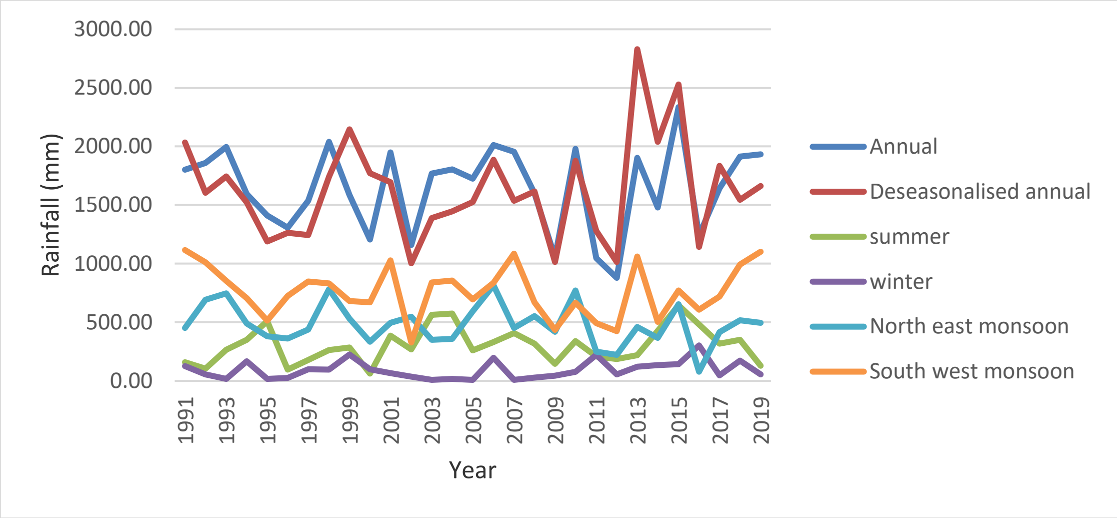

Fig. 25: Trends in annual and seasonal rainfall over the years at Vellayani

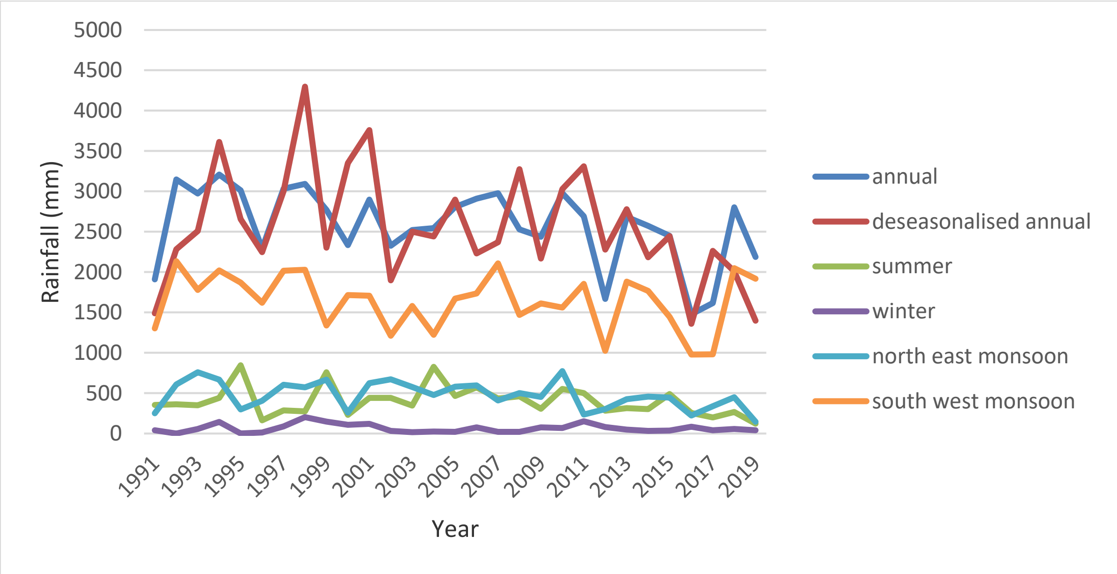

Fig. 26: Trends in annual and seasonal rainfall over the years at Kumarakom

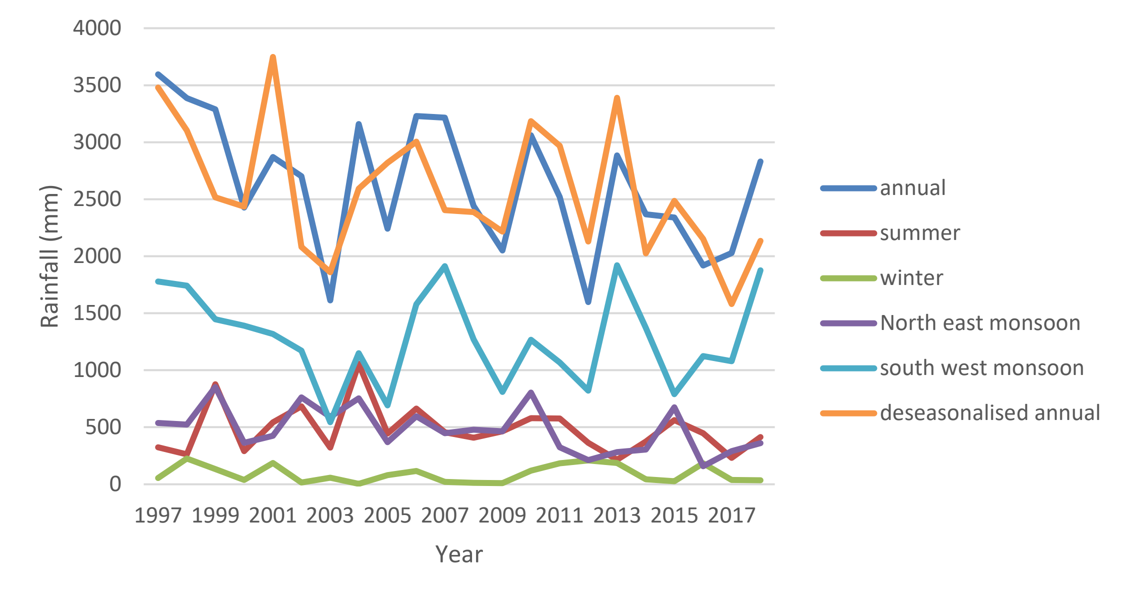

Fig. 27: Trends in annual and seasonal rainfall over the years at Moncompu

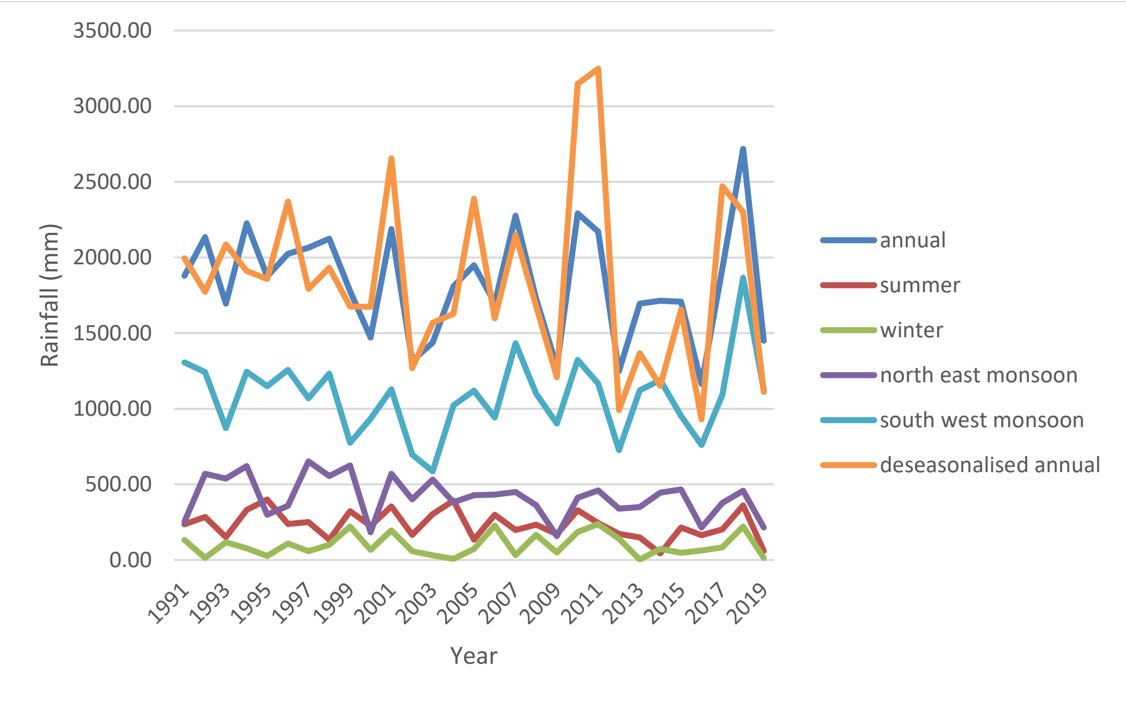

Fig. 28: Trends in annual and seasonal rainfall over the years at Pampadumpara

Figure 29 to Figure 32 represents the trend plot of maximum temperature of Vellayani, Kumarakom, Moncompu and Pampadumpara respectively. In case of maximum temperature all the regions except Pampadumpara has shown an increasing trend. The rate of increase in maximum temperature was found to be highest at Vellayani followed by Kumarakom and Moncompu. The summer maximum temperature was increasing at at faster rate in Vellayani as compared to other regions.

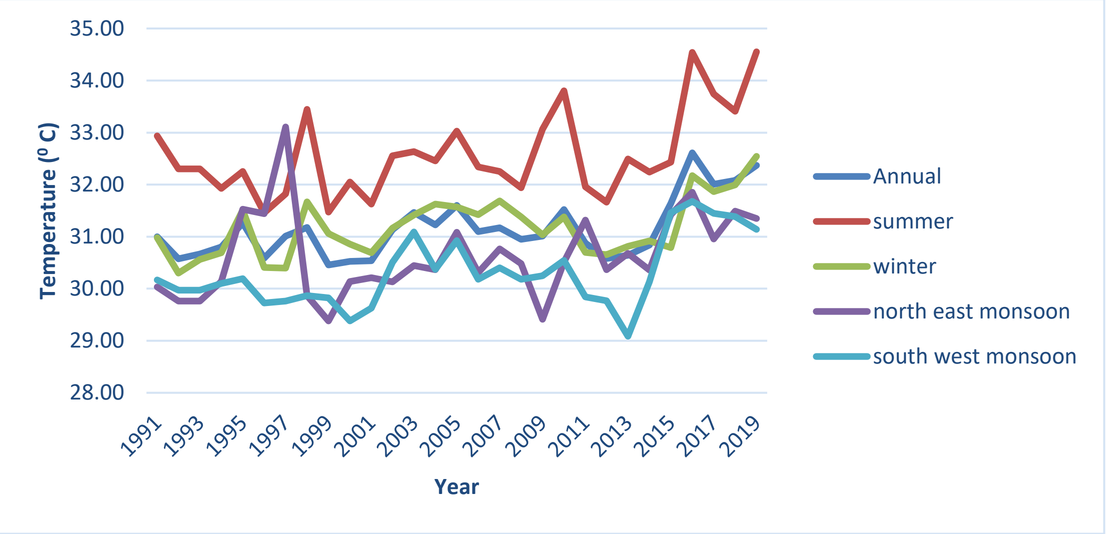

Fig. 29: Trends in annual and seasonal maximum temperature over the years at Vellayani

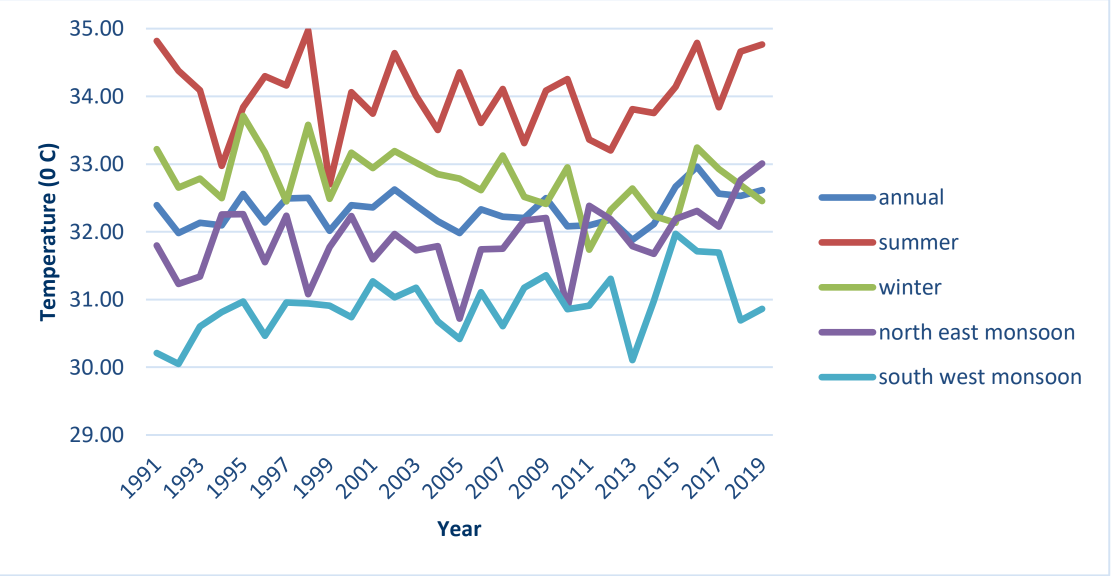

Fig. 30: Trends in annual and seasonal maximum temperature over the years at Kumarakom

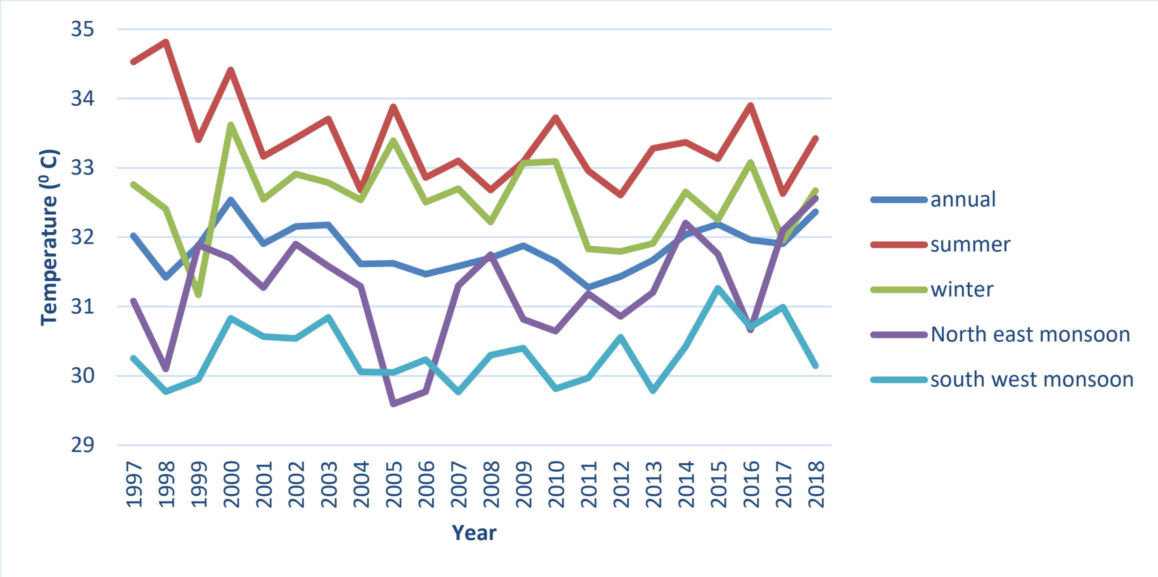

Fig. 31: Trends in annual and seasonal maximum temperature over the years at Moncompu

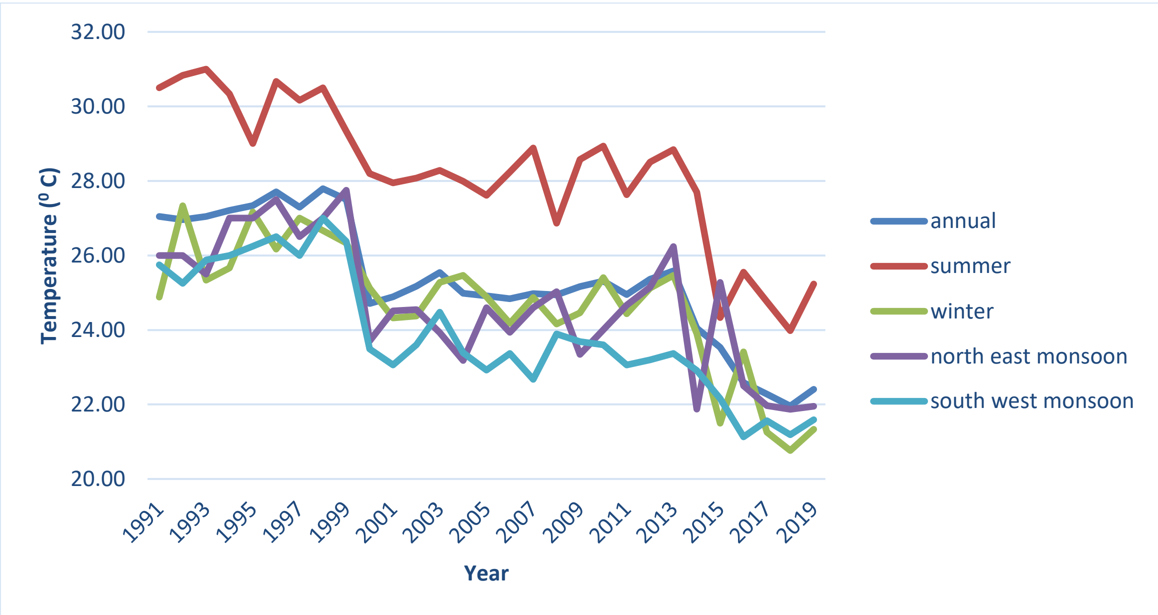

Fig. 32: Trends in annual and seasonal maximum temperature over the years at Pampadumpara

Figure 33 to 36 represent the trend plot for minimum temperature with regards to annual, and various seasons for the four stations. Vellayani has shown an increase in trend which is same as that of maximum temperature. While at Kumarakom an increase in trend can be noticed for minimum temperature during summer and winter but others show a decline in trend. Similarly, an increase in trend can be observed for annual and all seasons at Moncompu and Pampadumpara. For minimum temperature also all stations except Kumarakom showed an increase in trend in which the rate of increase was highest for Pampadumpara followed by Vellayani. Overall analysis of temperature trend revealed that in Southern Kerala there was an increase in temperature throughout.

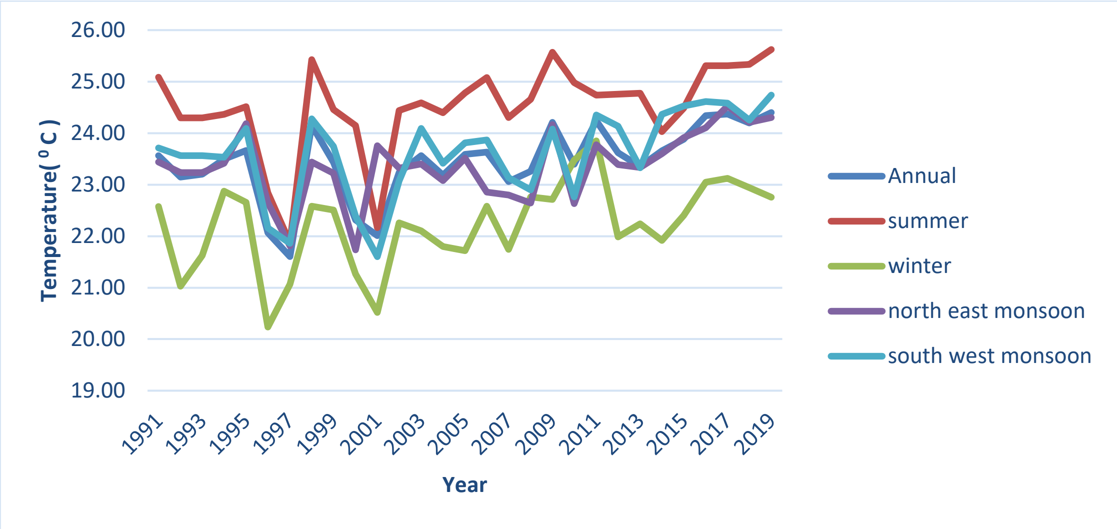

Fig. 33: Trends in annual and seasonal minimum temperature over the years at Vellayani

Fig. 34: Trends in annual and seasonal minimum temperature over the years at RARS, Kumarakom

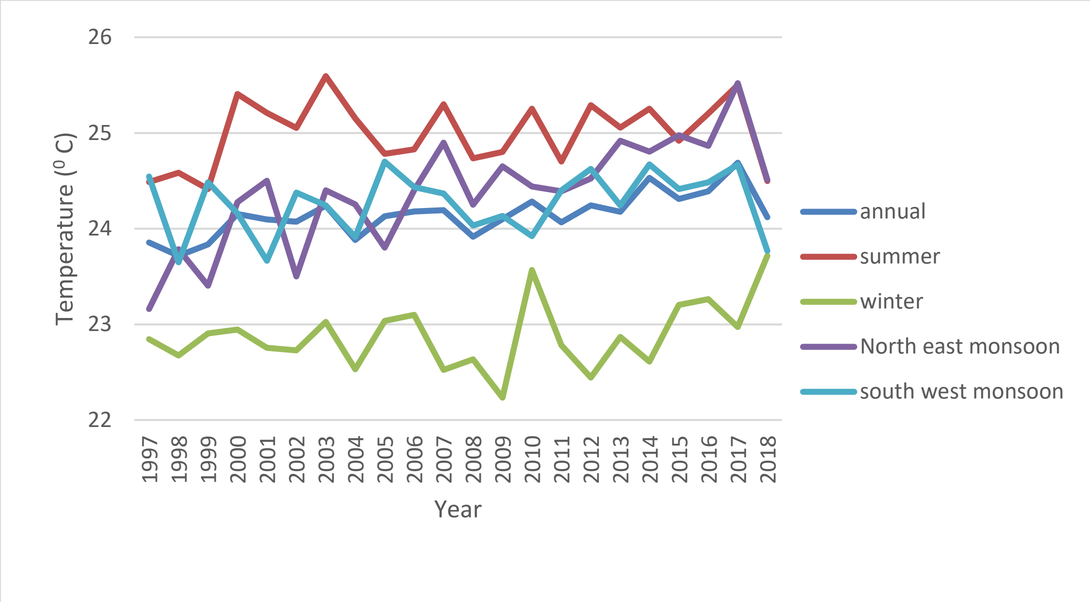

Fig. 35: Trends in annual and seasonal minimum temperature over the years at RRS, Moncompu

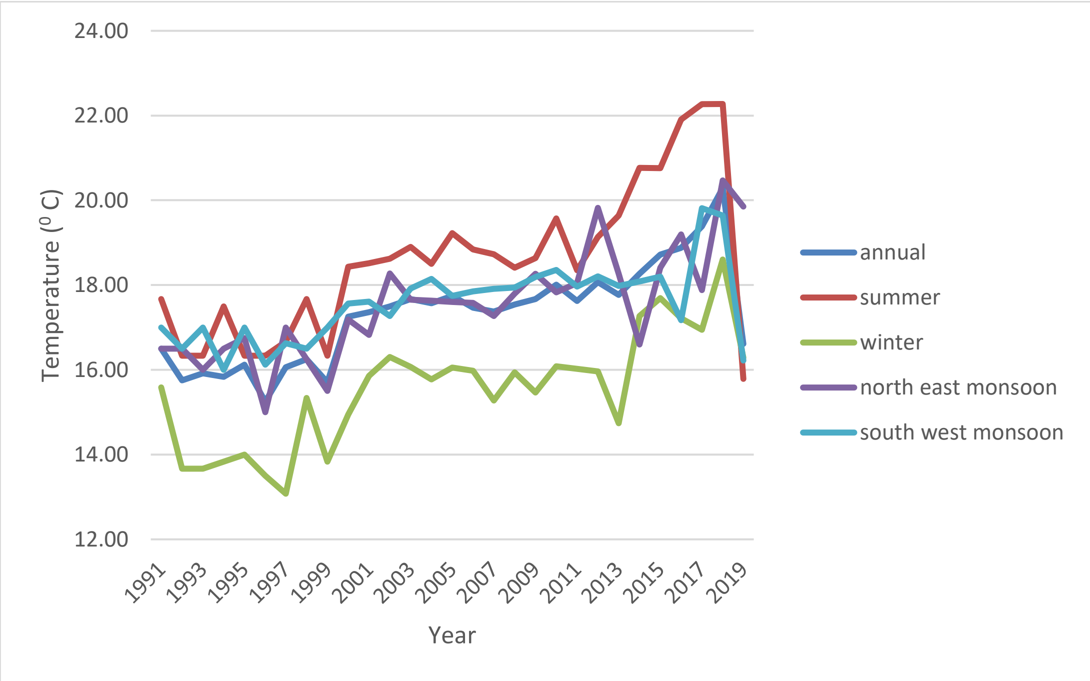

Fig.36: Trends in annual and seasonal minimum temperature over the years at CRS, Pampadumpara

4.3. MODEL FITTING FOR RAINFALL

4.3.1. Model fitting for Rainfall data from Vellayani

In order to determine the most appropriate seasonal ARIMA model for to study the change in rainfall, Box - Jenkins (1970) methodology was applied which includes identification of the model, estimation of the model parameters and validation of the model (Hipel *et al*., 1977).

The time series data should be stationary which means that it should have a constant mean, variance, and covariance which dependent only on time before fitting ARIMA models. The most used method to transform non-stationary data to stationary is differencing the data points, which replaces each value in the series by the difference between two consecutive values as t^{th} and t-1 th periods for a first order differenced series.

4.3.1.1. *Identification of the model*

Stationarity of the data was checked by using unit root test and examining the autocorrelation function (ACF) and partial autocorrelation function (PACF) to identify the potential models. Initially unit root test was performed to detect stationary of monthly rainfall data. Null hypothesis for the ADF test was the presence of unit root indicating non stationary and the alternate hypothesis as no unit root indicating a stationary time series. ADF test was used to check the rainfall data in Vellayani as stationary and the critical value for the ADF test was found to be -9.89, which indicated that the null hypothesis is rejected. It means that rainfall data in the level form was stationary or the order of integration is zero. Based on the significant value of the ADF test the order for integration for both non seasonal and seasonal component was detected and it is shown in Table 25.

Table 25: Order of integration based on unit root test result of rainfall data from Vellayani

Weather parameter	**Regular difference order**	**Seasonal difference order**
Rainfall	0	1

Classical methods based on ACF and PACF were also performed to identify AR and MA components for both non seasonal and seasonal part. Figure 37 shows the correlogram corresponds to the rainfall data with lag length of 25 in X-axis and autocorrelation values in the Y-axis. The seasonal autocorrelation relationship was observed and quite prominent from ACF and PACF and the fast decay was observed in the plot means that the data was stationary. Based on the nature of the correlogram and the result of the unit root test we can choose a temporary model for rainfall and the model could be ARIMA (p, 0, q) (P, 1, Q).

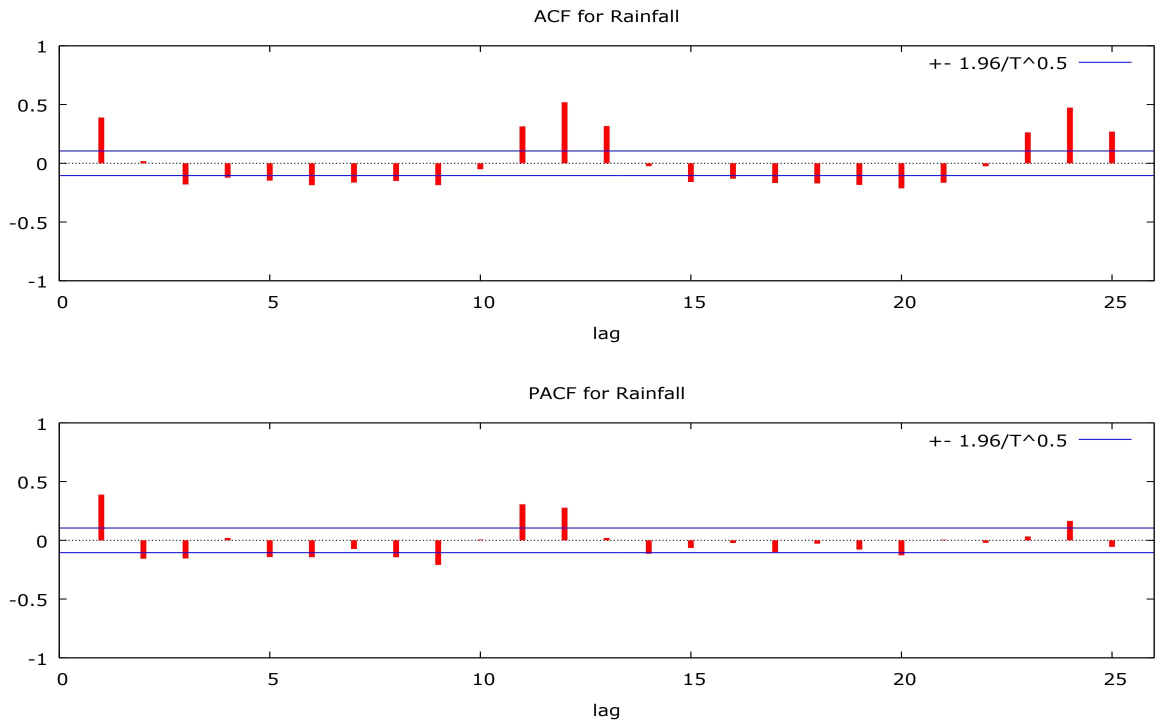

Fig. 37: ACF and PACF plot for rainfall at Vellayani

4.3.1.2. *Estimation of Parameters of the model*

Even though the order of integration was identified the parameters and the best ARIMA model was identified by trial and error method based on the value of AIC, BIC and Hannan Quinn criteria. The different models estimated with different criteria using the open source software Gretl are shown in Table 26.

Table 26: ARIMA models for Rainfall at Vellayani

ARIMA Model		Coefficient	P-value	AIC	BIC	Hannan Quinn
(001)(111)	Phi-1 theta-1 Theta-1	0.07 0.12 −0.89	0.33 0.02 ** 3.39e-052 ***	4037.84	4060.74	4046.97
(001)(112)	Phi-1 theta-1 Theta-1 Theta-2	−0.95 0.14 0.14 −0.77	6.89e-037 *** 0.01 *** 0.45 1.28e-014 ***	4037.81	4064.53	4048.47
(003)(111)	Phi- theta -1 theta -2 theta-3 Theta-1	0.06 0.14 0.08 −0.08 −0.88	0.43 0.01 *** 0.14 0.16 2.13e-049 ***	4037.69	4068.22	4049.86
(003)(010)	theta-1 theta-2 theta-3	0.12 0.12 −0.03	0.02 ** 0.02 ** 0.53	4185.58	4208.49	4194.71
(202)(111)	phi-1 phi-2 Phi-1 theta-1 theta-2	−0.44 −0.70 0.06 0.56 0.803460	0.003 *** 0.0007 *** 0.43 2.49e-06 *** 1.44e-05 ***	4037.90	4072.25	4051.60

	Theta-1	−0.893021	1.37e-05***			
(100)(011)	phi-1 Theta-1	0.14 −0.85	0.009 *** 7.15e-06***	4035.98	4055.07	4043.59
(103)(011)	phi-1 theta-1 theta-2 theta-3 Theta-1	−0.16 0.31 0.11 −0.06 −0.85	0.71 0.49 0.22 0.37 5.00e-06***	4038.15	4068.69	4050.32
(101)(011)	phi-1 theta-1 Theta-1	0.31 −0.17 −0.85	0.27 0.55 1.23e-06***	4037.61	4046.74	4060.51

From table 26 it is clear that the model having p=1, d=0, q=0, P=0, D=1, Q=1 has lower values for AIC, BIC and Hanann Quinn criterion which revealed the best model for rainfall as ARIMA (1, 0, 0) (0, 1, 1)$_{12}$. All the coefficients of the estimated model are highly significant since p-values were less than 0.05. A similar type of analysis was also performed using open source software Gretl which also provides an opportunity for automatically detecting the best model using X-12 ARIMA package. The software also detected the same model ARIMA (1, 0, 0) (0, 1, 1)$_{12}$ as the best one for rainfall data at Vellayani. Figure-38 shows the plot for actual and fitted values based on the best selected model, where the red line represents the actual values and blue line represents the fitted values and from the graph it is obvious that fitted values are very much closer to the actual values.

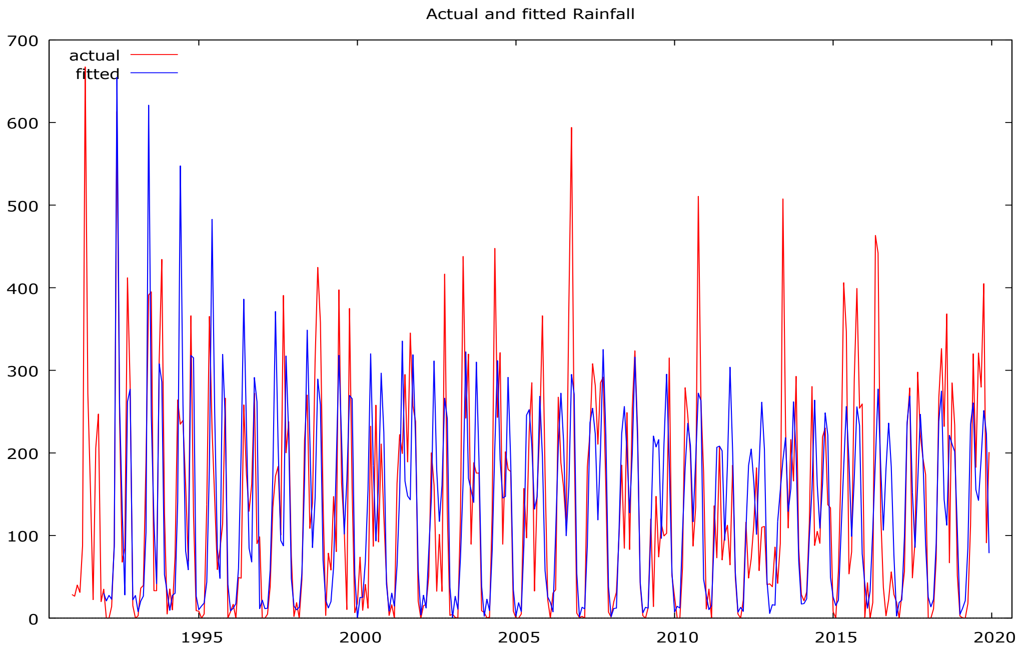

Fig. 38: Actual versus fitted plot for rainfall in Vellayani

4.3.1.3. ***Model validation***

The best fitted model for rainfall was found to be ARIMA (1, 0, 0) (0, 1, 1)$_{12}$.

The functional form of the model is

$$y_t - y_{t-12} = \phi_1 y_{t-1} - \phi_1 y_{t-13} + \Theta_1 e_{t-12} + e_t \qquad 4.1$$

Let $y_t - y_{t-12} = Z_t$ then,

$$Z_t = \phi_1 Z_{t-1} + \Theta_1 e_{t-12} + e_t \qquad 4.2$$

Here ϕ_1 = 0.14 and Θ_1 = -0.85

$$Z_t = 0.14\, Z_{t-1} - 0.85\, e_{t-12} + e_t \qquad 4.3$$

It is important to perform diagnostic checks to test the adequacy of the selected model as the best or not. One way to accomplish this is through the analysis of residuals. The standardised residuals are estimated from the model should be a white noise so that it follows IID (Independent and identically distributed) with zero mean and constant variance. Two methods are commonly used; one for checking the autocorrelation of the residuals using Ljung-Box Q test (Box *et al*, 1991) and second for checking the normality of the residuals. It has been found to measure the overall adequacy of the chosen model by examining a quantity Q known as Ljung-Box statistic, (Yurekli et. al.; 2005, Sallehuddin et. al.; 2007) which is a function of autocorrelations of residuals and its approximate distribution was Chi-square. If Ljung-Box statistic value is found non-significant it indicates that residuals are uncorrelated and hence we can conclude that the model was good enough for the prediction. The estimated Ljung-box test statistic of rainfall at Vellayani was 8.08 with a P value of 0.62 indicating that the residuals are not correlated. Figure 39 displays the normality plot of residuals for rainfall and it clearly shows that residuals are normally distributed.

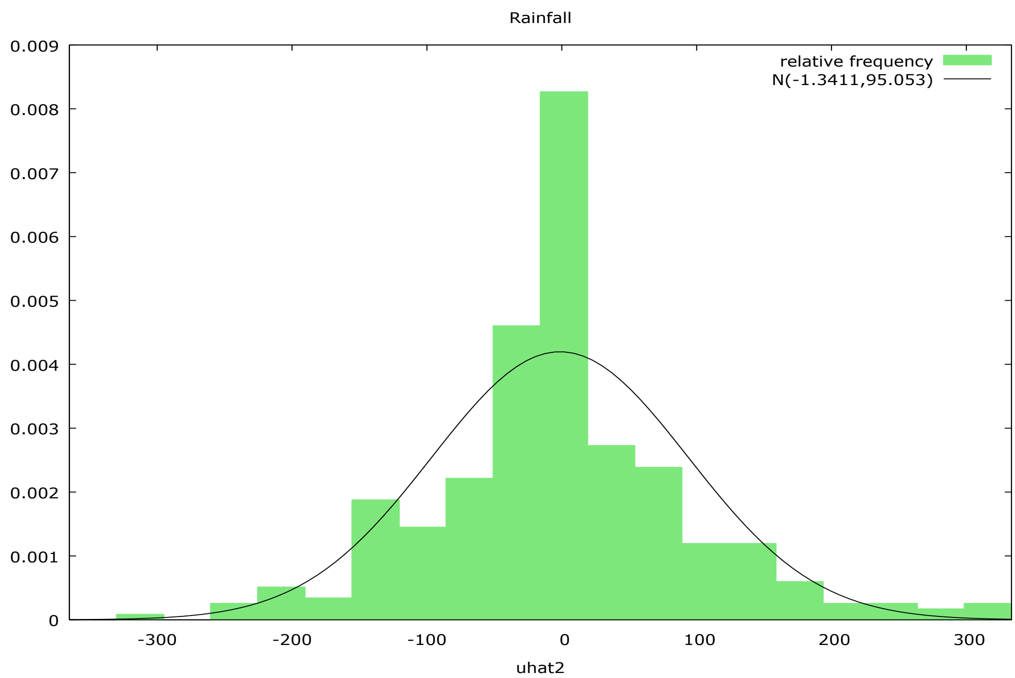

Fig. 39: Normality plot of Residuals for Rainfall

4.3.2. Models for Rainfall at Kumarakom

A similar type of analysis as explained in section 4.3.1 was used to model the rainfall pattern in Kumarakom using Box - Jenkins (1970) methodology.

4.3.2.1. *Identification of the model*

ADF test was applied and the critical value for the ADF test was found to be -13.63, which suggested rejection of the null hypothesis. It means that rainfall data in the level form was stationary or the order of integration is zero. Based on the significance value of the ADF test the order for integration for both non seasonal and seasonal component was detected and it is shown in Table 27.

Table 27: Order of integration based on unit root test result of rainfall data from Kumarakom

Weather parameter	**Regular difference order**	**Seasonal difference order**
Rainfall	0	1

The ACF and PACF graphs were drawn to identify the AR and the MA components for both non seasonal and seasonal and they are given in Figure 40. It displays the autocorrelation of rainfall data by taking lag period in the X-axis and autocorrelation values in the Y-axis. ACF and PACF showed a prominent seasonal autocorrelation component. The plot showed a rapid decay, indicating the data set was stationary. We may select a temporary model for rainfall based on the nature of the correlogram and the result of unit root test, and the model selected be ARIMA (p, 0, q) (P, 1, Q).

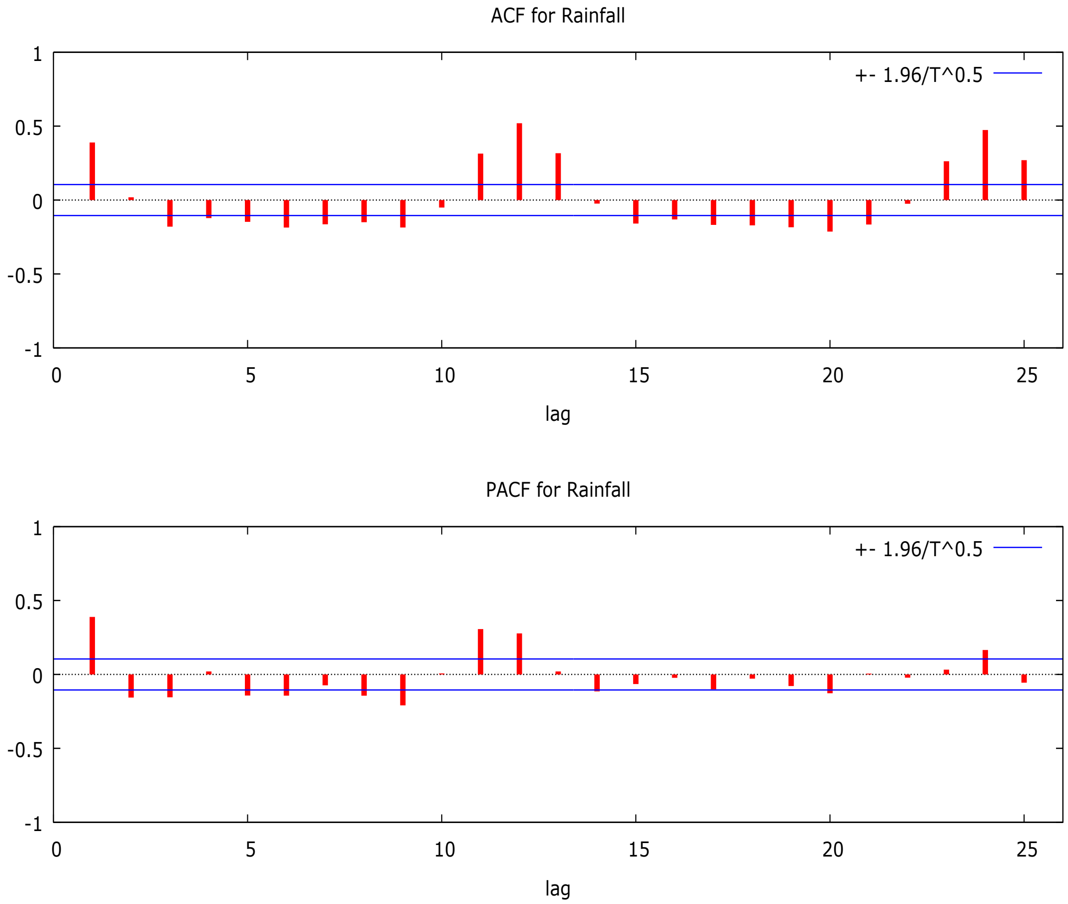

Fig. 40: ACF and PACF plot for rainfall in Kumarakom

4.3.2.2. *Estimation of Parameters*

While the parameters are defined in the order of integration the best ARIMA model was identified by a trial and error methods based on the value of AIC (Akike, 1974), BIC and Hannan Quinn criteria. The different model parameters estimated with different criteria using the open source software Gretl are shown in Table 28.

Table 28: ARIMA models for Rainfall at Kumarakom

ARIMA Model		Coefficient	P-value	AIC	BIC	Hannan Quinn
(000)(112)	Theta - 1 Theta-2	−1.01 0.01	0.0009 *** 0.81	4172.91	4191.99	4180.52
(100)(111)	phi-1 Phi-1 Theta-1	0.07 −0.02 −0.99	0.19 0.77 0.003 ***	4173.18	4196.08	4182.31
(101)(111)	phi-1 Phi-1 theta -1 Theta-1	−0.66 −0.005 0.74 −1.00	0.0004 *** 0.93 7.75e-06 *** 5.66e-09 ***	4173.22	4199.95	4183.88
(302)(111)	phi-1 phi-2 phi-3 Phi-1 theta-1 theta-2 Theta-1	1.74 −1.09 0.09 −0.01 −1.69 0.99 −0.94	1.05e-217 *** 2.56e-033 *** 0.09 * 0.85 0.00 *** 5.71e-207 *** 2.00e-044 ***	4175.61	4213.79	4190.83
(100((110)	phi-1 Phi-1	0.12 −0.55	0.02 ** 1.20e-32 ***	4250.59	4269.68	4258.19
(201)(110)	phi-1 phi-2 Phi-1 theta-1	−0.85 0.09 −0.54 1.00	2.05e-054 *** 0.08 * 4.55e-030 *** 0.00 ***	4248.31	4275.02	4258.96
(000)(011)	Theta-1	-1	$2.14 * 10^{-12}$	4170.97	4186.23	4177.05
(103)(110)	phi-1 Phi-1 theta-1	0.79 −0.55 −0.66	1.24e-07 *** 1.18e-032 *** 2.66e-05 ***	4252.64	4283.18	4264.81

	theta-2 theta-3	−0.15 0.10	0.03 ** 0.08 *			

It is evident from table 28 that the model having p=0, d=0, q=0, P=0, D=1, Q=1 has lower values for AIC, BIC and Hanann Quinn criterion which revealed that the best model for rainfall was ARIMA (0, 0, 0) (0, 1, 1)$_{12}$. All the coefficients of the estimated model are highly significant since p-values were less than 0.05. The same analysis was also carried out using open source software Gretl which also offers an opportunity to automatically identify the best model using X-12 ARIMA package. The use of the software also detected the same model ARIMA (0, 0, 0) (0, 1, 1)$_{12}$ as the best one for rainfall data at Kumarakom.

Figure 41 shows the plot for actual and fitted values based on the best selected model, where the red line represents the actual values and blue line represents the fitted values and it is clear from the graph that fitted values are very similar to the actual values.

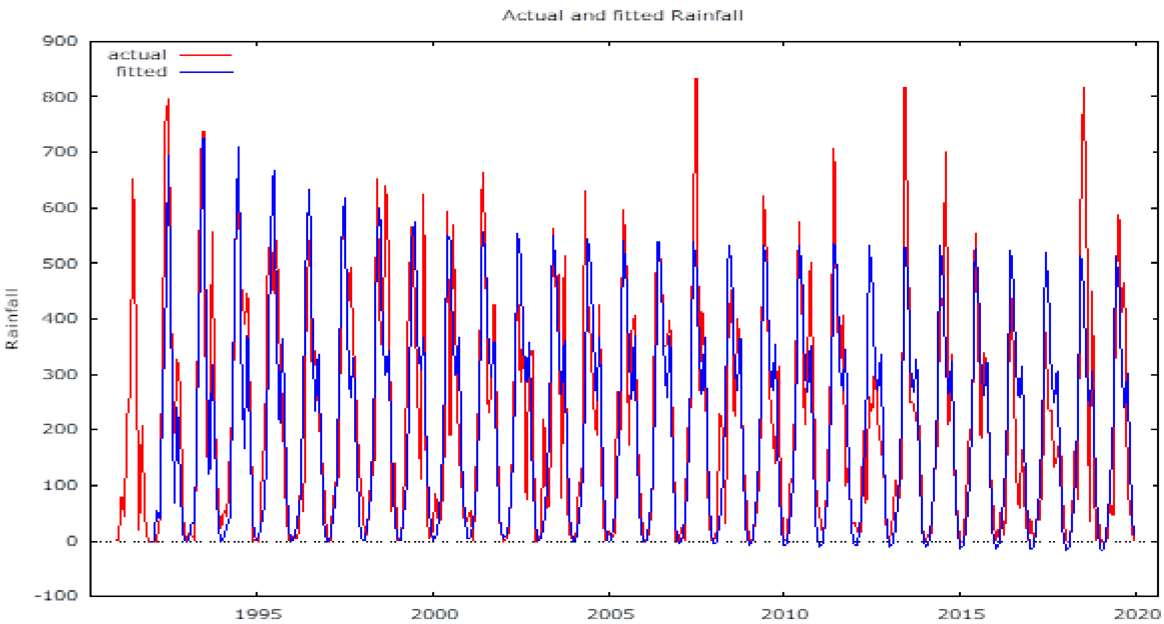

Fig. 41: Actual versus fitted plot for rainfall in Kumarakom

4.3.2.3. ***Model validation***

The best fitted model for rainfall was found to be a seasonal ARIMA (0, 0, 0) (0, 1, 1)$_{12}$. Therefore, the functional form of the model is

$$y_t - y_{t-12} = \Theta_1 e_{t-12} + e_t \qquad 4.4$$

Let $y_t - y_{t-12} = Z_t$ then,

$$Z_t = \Theta_1 e_{t-12} + e_t \qquad 4.5$$

Here Θ_1 = - 1

$$Z_t = -e_{t-12} + e_t \qquad 4.6$$

Diagnostic checking is necessary in order to assess the suitability of the selected model. The Standardised residuals are estimated from the model should be a white noise so that it follows IID (Independent and identically distributed) with zero mean and constant variance. The existence of autocorrelation in the residuals is tested using the Ljung-Box Q test (Box *et al*, 1991) and the normality using histogram. When the statistical significance of Ljung-Box statistic is to be non-significant, it shows that residuals are uncorrelated and conclude that model was good enough for prediction. The estimated Ljung-box test statistic was 7.57 with a p value 0.757 indicating that the residuals are uncorrelated. The normality plot of residuals (Figure 42) indicating that the residuals of the fitted model are normally distributed.

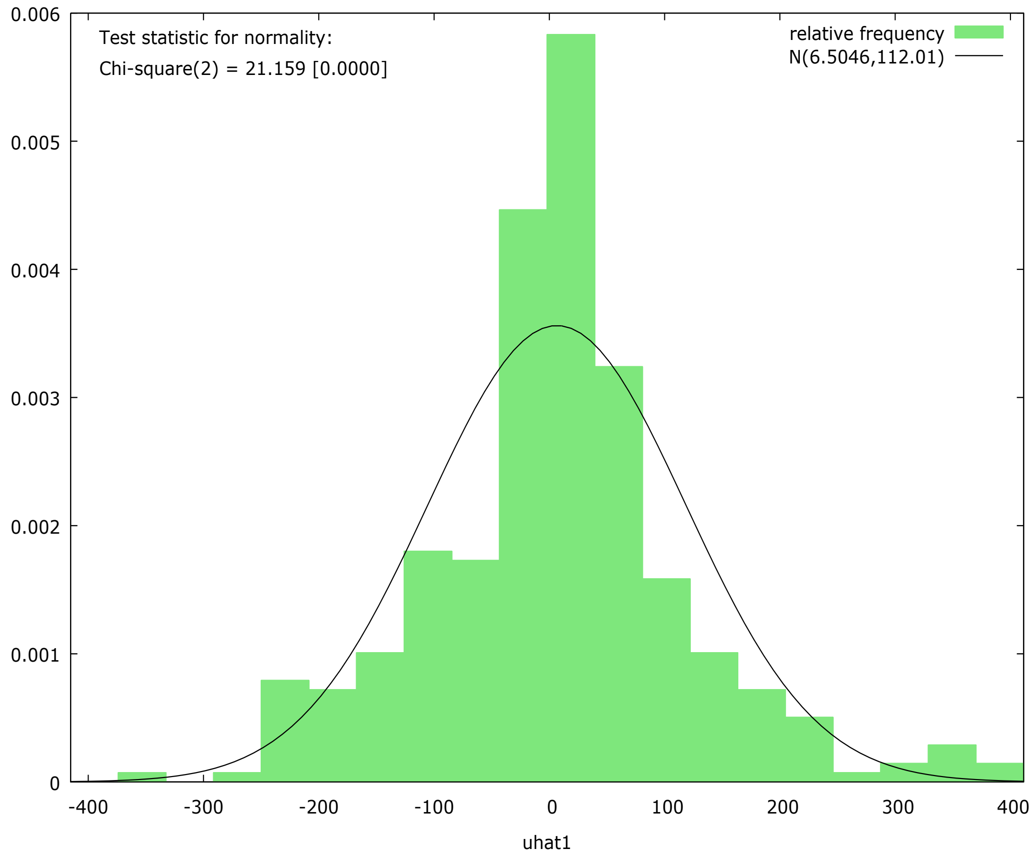

Fig. 42: Normality plot of Residuals for Rainfall

4.3.3. Models for Rainfall at Pampadumpara

Until fitting an ARIMA model, the time series data should be stationary which means that it should have a constant mean, variance, and the covariance between t th t+s th period depends only on time. The most popular method to transform non stationary data to stationary is differencing the data points, which replaces each value in the series by the difference between two ie., tth and t-1 th period values.

4.3.3.1. *Identification of model*

Stationarity of the data was tested by using unit root test and by examining the autocorrelation function (ACF) and the partial autocorrelation function (PACF) the potential model was identified. It was found that the critical value for the ADF test -13.28, which indicated that the null hypothesis is rejected. It means that rainfall in the level form was stationary or the order of integration is zero. Based on the significance value of the ADF test the order for integration for both non seasonal and seasonal component was detected and it is shown in Table 29.

Table 29: Order of integration based on unit root test result of rainfall data from Pampadumpara

Weather parameter	**Regular difference order**	**Seasonal difference order**
Rainfall	0	1

Figure 43 indicates the correlogram corresponds to the rainfall data with lag length 25 in the X-axis and autocorrelation values in the Y-axis. The seasonal autocorrelation relationship was quite prominent from ACF and PACF. Fast decay has been observed in the plot which means that the data set was stationary. Based on the nature of correlogram and the result of unit root test a temporary model for rainfall was selected and the model be ARIMA (p, 0, q) (P, 1, Q).

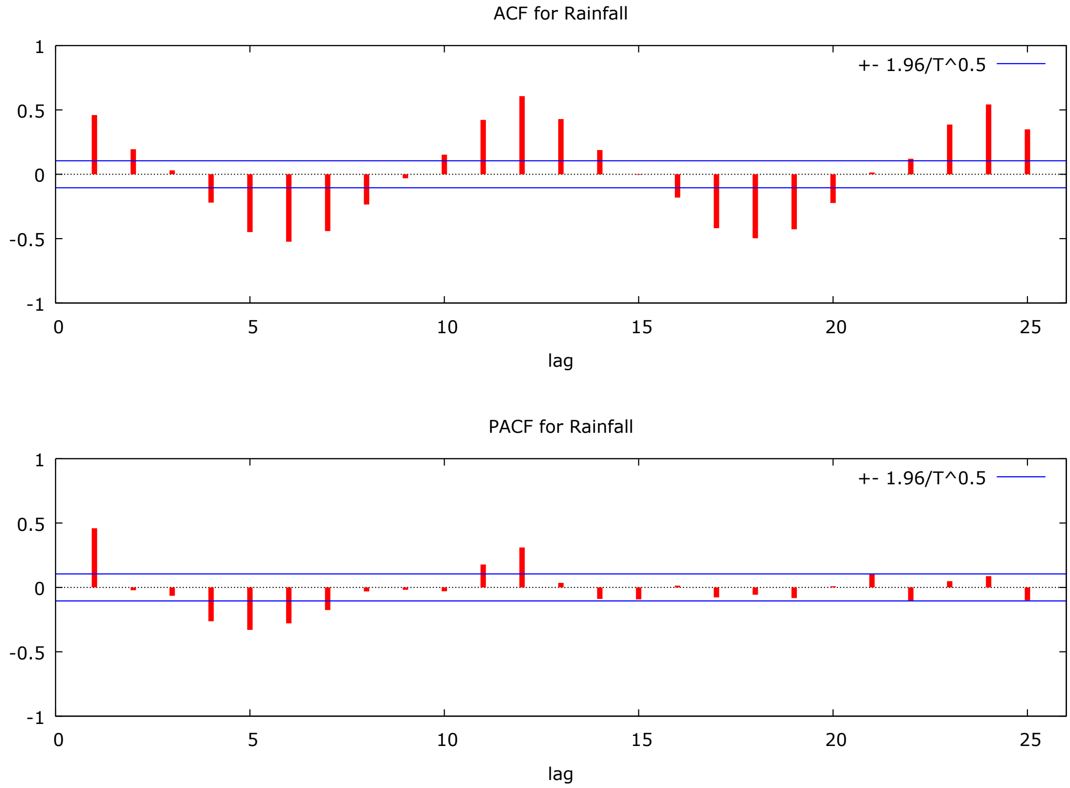

Fig. 43: ACF and PACF plot for rainfall in Pampadumpara

4.3.3.2. *Estimation of Parameters*

Since the parameters for order of integration was identified best ARIMA model was identified using trial and error method based on the value of AIC (Akike, 1974), BIC and Hannan Quinn criteria. The estimated parameters of the various models with different criteria using the open source software Gretl are shown in Table 30.

Table 30: ARIMA Models for Rainfall in Pampadumpara

ARIMA Model		**Coefficient**	**P-value**	**AIC**	**BIC**	**Hannan Quinn**
(000)(111)	Phi-1 Theta-1	−0.027 −0.879	0.6664 5.06e-114 ***	3994.908	4013.993	4002.516

(001)(112)	Phi-1 theta-1 Theta-1 Theta-2	0.708 0.046 −1.66 0.711	0.0002 *** 0.3788 5.76e-022 *** 1.82e-06 ***	3994.501	4021.221	4005.152
(101)(012)	phi-1 theta - 1 Theta-1 Theta-2	0.669 −0.608 −0.907 0.029	0.0084 *** 0.0239 ** 4.61e-048 *** 0.6301	3996.582	4023.302	4007.233
(100)(110)	phi-1 Phi-2	0.080 −0.499	0.1404 1.93e-024 ***	4088.251	4107.336	4095.859
(000)(011)	Theta- 1	0.88	1.46*10-144 ***	3993.09	3999.17	4008.36
(101)(211)	phi-1 Phi-1 Phi-2 theta-1 Theta-1	0.681 −0.056 −0.098 −0.629 −0.848	0.0117 ** 0.3944 0.1389 0.0270 ** 2.20e-079 ***	3996.478	4027.015	4008.651
(201)(111)	phi-1 phi-2 Phi-1 theta-1 Theta-1	0.563 0.029 −0.027 −0.514 −0.873	0.1304 0.6460 0.6677 0.1634 2.84e-111 ***	3998.427	4028.964	4010.600
(101)(011)	phi-1 theta-1 Theta-1	−0.962 1.00 −0.879	0.0000 *** 2.12e-107 *** 6.25e-135 ***	3994.020	4016.922	4003.149

It is clear from table 30 that the model having p=0, d=0, q=0, P=0, D=1, Q=1 has lower values for AIC, BIC and Hanann Quinn criterion which revealed that the best model for rainfall was ARIMA (0, 0, 0) $(0, 1, 1)_{12}$. All the coefficients of the estimated model are highly significant since p-values were less than 0.05. A same analysis was also performed using open source software Gretl which also provides an opportunity for automatically detecting the best model using X-12 ARIMA package. The software also detected the same model ARIMA (0, 0, 0) $(0, 1, 1)_{12}$ as the best one for rainfall data in Pampadumpara.

Figure 44 shows the plot for actual and fitted values based on the best selected model, where the red line represents the actual values and blue line represents the fitted values and from the graph it is clear that fitted values are closely related to the actual values.

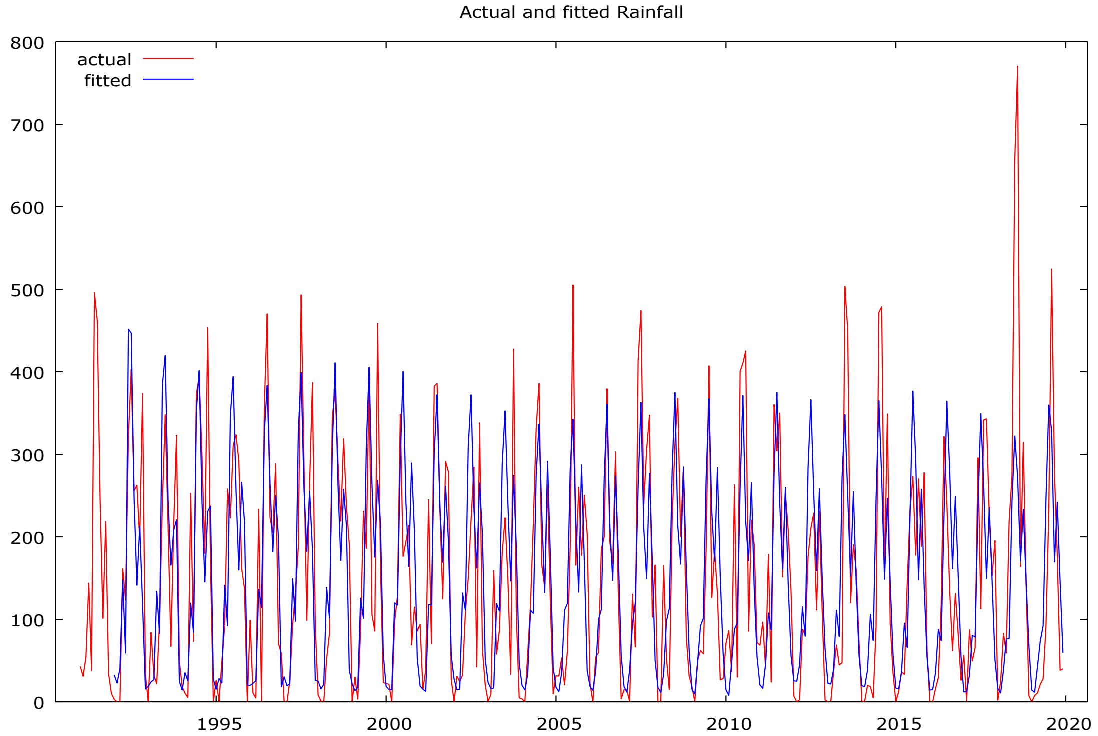

Fig. 44: Actual versus fitted plot for rainfall in Pampadumpara

4.3.3.3. *Model validation*

The best fitted model for rainfall was found to be ARIMA (0, 0, 0) $(0, 1, 1)_{12}$.

The functional form of the model is

$$y_t - y_{t-12} = \Theta_1 e_{t-12} + e_t \qquad 4.7$$

Let $y_t - y_{t-12} = Z_t$ then,

$$Z_t = \Theta_1 e_{t-12} + e_t \qquad 4.8$$

Here $\Theta_1 = 0.88$

$$Z_t = 0.88 e_{t-12} + e_t \qquad 4.9$$

It is important to perform diagnostic checks to assess the adequacy of the model chosen as the best or not. The estimated Ljung-box test statistic was 9.74 with a p value 0.55 indicating that the residuals are not correlated and from Figure 45 we can conclude that residuals are normally distributed.

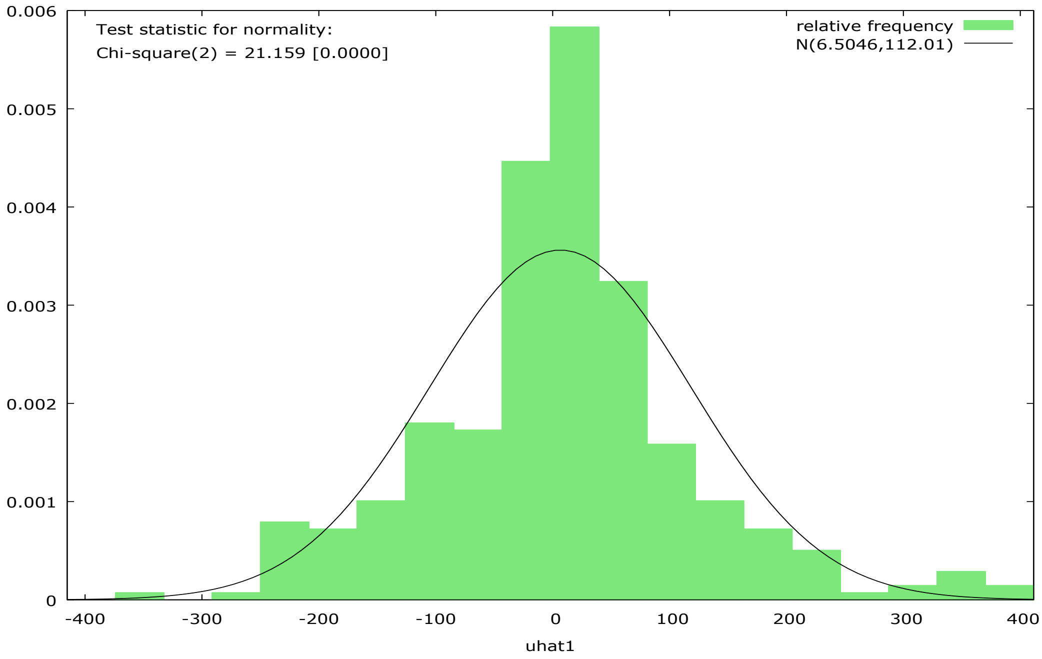

Fig. 45: Normality plot of Residuals for Rainfall

4.4. IMPACT OF WEATHER PARAMETERS ON YIELD OF PADDY IN KOTTAYAM DISTRICT

Even though a declining trend has been recorded in area and production of Paddy in most of the districts in Kerala over the years, an increasing trend in area and production was noticed in Kottayam and Alappuzha during the last decade (2000 to 2012-13). Kuttanad region is the one of the major rice growing tracts in Kerala which spreads in three districts namely Kottayam, Alappuzha and Pathanamthitta. In Kuttanad, 80 percent of the paddy fields are sown during the *puncha* season which begins from October–November and 40 percent of the paddy lands are cultivated in *virippu* season starting from May- June. Several studies have reported that weather parameters including temperature and rainfall have significant influence at various stages during flowering, panicle initiation etc which in turn affect the paddy production. In order to analyse the impact of weather parameters on the production of paddy in Kottayam district, area and production of Paddy in two seasons viz; one as additional crop (virippu) during the period May-June to Aug-September and puncha crop season from October- November to December-January for a period from 1995-96 to 2018-19 were collected and used in the analysis. In addition to this monthly data on weather parameters such as rainfall, maximum temperature and minimum temperature for the same the period from 1995-1996 to 2018-2019 were also used. The details regarding the variables used in the regression analysis are presented in Table 31.

Table 31: Trends in rainfall, maximum temperature and minimum temperature of Kottayam district (1995-2018) - Additional crop

year	Average maximum temperature (°C)			Average minimum temperature (°C)			Rainfall (mm)		
	June	July	August	June	July	August	June	July	August
1995	31.35	30.42	30.81	24.62	23.69	24.08	541	443.4	540.2
2000	30.05	31.03	30.13	23.63	23.81	23.35	594.8	190.2	569.8
2005	29.55	29.7	31.48	23.77	23.55	23.35	595.1	529.1	172.4
2010	32.45	31.16	31.97	23.51	22.35	22.38	574.8	447.8	209
2015	31.56	30.6	30.14	23.46	22.94	23.19	554.5	370.9	182.7
2018	30.49	29.82	29.99	23.5	22.95	22.54	595.7	818.7	600.4

4.4.1. Impact of weather parameters on paddy production in *virippu* crop season

Multiple linear regression equation was fitted with production of paddy as the dependent variable and the maximum temperature, minimum temperature and rainfall during June, July and August as the independent variables. The dependent and independent variables are transformed using logarithm before model fitting and the parameters are estimated using OLS. A number of regressions were estimated performed by taking logarithm of both or either dependent or independent and the best model was selected using R^2 and other model selection criteria. The estimated parameters of the best selected model along with VIF and Durbin-Watson statistics are presented in Table 32.

The best estimated model was *4.10*

$$ln\, y_t = -75.620 + 7.131 \ln M_1 - 1.642 \ln M_2 + 15.923 \ln M_3 + 13.410 \ln N_1 - 16.501 \ln N_2 + 8.630 \ln N_3 - 0.005 \ln R_1 - 1.061 \ln R_2 - 0.005 \ln R_3$$

Table 32: Result of Multiple regression for Production of paddy in *Virippu* season in Kottayam

Particulars	Regression Coefficient	Standard error	P value	t value	VIF
Intercept	-75.620	47.136	0.131	-1.604	
M1	7.131	7.702	0.370	0.926	2.632
M2	-1.642	13.492	0.905	-0.122	6.731
M3	15.923	8.798	0.092*	1.81	2.472
N1	13.410	7.1	0.080*	1.889	4.028
N2	-16.501	10.055	0.123	-1.641	8.681
N3	8.630	6.745	0.221	1.28	4.259
R1	-0.005	0.592	0.993	-0.009	1.835
R2	-1.061	0.567	0.082*	-1.872	3.622
R3	-0.005	0.395	0.989	-0.013	2.613
Number of observations		24			
F (9, 14)		2.456			
R^2		0.612			
Adj. R^2		0.363			
P – value		0.064			
Durbin-Watson d-statistic (9, 23)		1.259			

It is evident from Table 32 that the estimated model has good explanatory power of 61.2 percent with DW statistic of 1.259. Moreover, VIF values less than 10 for all the independent variables underscore the absence of multicollinearity. The estimated coefficients of maximum temperature in August (15.92), minimum temperature in June (13.41) had positive sign and significant at 9 and 8 percent level of significance respectively establishing a positive effect of these two variables on Virippu Paddy production in Kottayam. In contrast to this rainfall during July had negative significant

(10%) influence on Paddy production emphasize that excess rainfall during July was not a favourable condition for Paddy production in Virippu season in Kottayam district.

Susha (2011) studied climate change impacts and adaptation strategies in paddy production and the study concluded that weather variables in Kerala had been changing which resulted in a shift from wetness to dryness. Minimum Temperature and rainfall had a negative growth rate and maximum temperature had a positive growth rate and maximum temperature and rainfall during the initial growth phase (first two months) of the crop in Kuttanad region exerting significant positive impact on yield while these variables during second phase cause a decline in income.

4.4.2. Impact of weather parameters on Production of paddy in *Puncha* crop

In order to analyse the influence of weather parameters on the production of Paddy in puncha season a multiple regression equation was fitted by considering the independent variables as maximum temperature, minimum temperature and rainfall during October, November and December and the dependent variable as production of paddy during *puncha* season without considering the effect of other influencing factors of production. The details regarding the dependent and independent variables are presented in Table 33. Logarithmic transformation was used for only for dependent variable and the independent variables were taken as such and OLS technique was used for estimating the parameters. The result of multiple regressions using OLS method is presented in Table 34.

The best estimated model was *4.11*

$$ln\, y_t = -12.997 + 0.298\, M_1 - 0.428\, M_2 + 0.405\, M_3 + 0.307\, N_1 + 0.155\, N_2 - 0.426\, N_3 - 0.003\, R_1 - 0.004\, R_2 + 0.003\, R_3$$

Table 33. Trends in rainfall, maximum temperature and minimum temperature of Kottayam district (1995-2018) –Puncha crop

year	Average maximum temperature (°C)			Average minimum temperature (°C)			Total rainfall (mm)		
	oct	nov	dec	oct	nov	dec	oct	nov	dec
1995	32.39	32.13	33.08	21.81	18.02	21.35	219.40	78.00	0.00
2000	31.60	32.87	32.55	23.52	23.74	21.62	157.60	102.20	24.60
2005	30.70	30.73	31.71	23.07	23.29	22.81	407.90	172.80	71.60
2010	30.81	30.92	30.98	21.42	23.41	23.42	503.70	269.40	84.70
2015	31.62	32.76	32.72	23.14	23.05	22.26	313.00	133.60	67.40
2018	33.12	32.89	32.44	22.91	22.81	21.06	448.60	0.00	40.20

The results presented in Table 34 clearly shows that maximum and minimum temperature during October had a positive significant effect on production of paddy in puncha season while and minimum temperature during December and excess rainfall during October and November had a negative significant effect on Puncha paddy production. The VIF value of all the independent variables was below 10 indicating the absence of multicollinearity between the independent variables. Durbin-Watson d-statistic value also indicated that there is no autocorrelation. The estimated R^2 value for the model was 0.797, indicating that 79.7 percent of variation in the dependent variable was explained by the independent variables by the regression.

Table 34: Result of Multiple regression for *Puncha c*rop in Kottayam

Particulars	Regression Coefficient	Standard error	P value	t value	VIF
Intercept	-12.997	9.94	0.212	-1.308	
M1	.0.739	0.298	0.026**	2.482	2.954
M2	-0.428	0.402	0.305	-1.065	4.364
M3	0.405	0.308	0.210	1.315	3.014
N1	0.307	0.154	0.066*	1.991	2.025
N2	0.155	0.132	0.260	1.173	3.574
N3	-0.426	0.153	0.015**	-2.784	3.153
R1	-0.003	0.001	0.014**	-2.797	1.996
R2	-0.004	0.001	0.028**	-2.448	1.61
R3	0.003	0.003	0.353	0.961	1.482
Number of observations		24			
F (9, 14)		6.105			
R^2		0.797			
Adj. R^2		0.666			
P – value		0.001			
Durbin-Watson d-statistic (9, 23)		1.463			

4.5. IMPACT OF WEATHER PARAMETERS ON YIELD OF CARDAMOM IN IDUKKI DISTRICT

The production of cardamom in Kerala is mainly concentrated in Idukki district which contributes 70 percent to all Indian production of Cardamom. Cardamom is a perennial crop growing under shades required watering during the hot summer and rain during south west monsoon which helps in panicle initiation, flowering and fruit set. In general, flower initiation takes place in March-April and from initiation to full bloom it takes 30 days and from full bloom to maturity it requires 5-6 months. This implies that this crop requires good rainfall distribution especially summer showers during February to April are essential for panicle initiation, otherwise it will affect the yield. In order to assess the influence of weather parameters on the production of cardamom in Kerala, the data related to area and production cardamom from Idukki was collected for a period from 1997-1998 to 2018-2019 along with weather parameters such as rainfall, maximum temperature and minimum temperature. In Kerala, the peak period of harvesting of cardamom was from September to December. January to March (Q1) was as considered as the first quarter April to June (Q2) as the second quarter, July to September as the third quarter (Q3). The details of the independent and dependent variables included in the regression analysis are presented in Table 35.

Multiple regression equation was fitted by considering production as dependent variable and quarterly temperature and rainfall as the independent variables. A semi log model by taking the logarithm of dependent variable was found to be the best regression model for explain the variability in the production of cardamom. Table 36 represents the results obtained after performing multiple regressions using the OLS method along with VIF and Durbin-Watson statistics. VIF values of all the variables were found to be less than 10 confirm the absence of multicollinearity among the independent variables. Durbin-Watson d-statistic 1.69, which was very close to two concluded that there is no autocorrelation. The adj, R^2 value for the model was 0.89, indicated that 89 percent of variation in the dependent variable was explained by the independent variable included in the regression.

The estimated regression coefficients of rainfall during July to September, maximum temperature during April to June and minimum temperature in Q1 and Q3 are significant and have negative sign indicating the adverse influence of these parameters on cardamom production. Studies have reported that excess temperature and rainfall during April to June adversely affect the yield of cardamom and hence the production of the crop. In this analysis it was found that a reasonable increase in minimum temperature positively influences the yield of cardamom. Moreover, the coefficient of rainfall in Q1, Q2 and Q3 had negative sign indicating the negative effect of excess rainfall on cardamom productivity particularly during the harvesting period. For a perennial crop like cardamom, so many other factors like cultivation practices, fertilizer and pesticide usage etc. also had greater impact on yield in addition to climate parameters especially in the high range region Idukki which may be the reason for getting nonsignificant impact for some of the weather parameters. Maximum temperature during July to September, minimum temperature during April to June and had positive impact on yield once again suggesting the negative impact of excess rain during this period. Murugan et al. 2012 also got similar results in their study on climate change and crop yields in the Indian Cardamom Hills. The warming temperature trend coupled with frequent wet and dry spells especially in summer will negatively influence cardamom yield.

The best estimated model was *4.12*

$$ln\, y_t = 12.36 - 0.012\, M_1 - 0.173\, M_2 + 0.028\, M_3 - 0.117\, N_1 - 0.326\, N_2 - 0.166\, N_3 - 0.0001\, R_1 - 0.0003 R_2 - 0.0003\, R_3$$

Table 35: Trends in rainfall, maximum temperature and minimum temperature of Idukki district (1997-2018)

year	Average maximum temperature (°C)			Average minimum Temperature (°C)			Total rainfall (mm)		
	QM_1	QM_2	QM_3	QN_1	QN_2	QN_3	QRf_1	QRf_2	QRf_3
1997	28.83	29.33	25.00	13.74	17.33	16.50	25.30	414.40	882.10
2001	26.58	25.73	23.32	16.84	18.50	17.56	147.60	698.20	744.70
2006	25.80	26.82	22.89	16.51	18.71	17.79	77.10	444.40	741.40
2011	26.22	26.00	23.07	16.28	18.84	17.76	206.70	563.20	805.50
2016	22.80	24.32	21.07	18.74	20.46	17.23	16.00	469.00	438.10

Table 36: Results of multiple linear regressions on production of cardamom**.**

Particulars	Regression Coefficient	Standard error	P value	t value	VIF
Intercept	12.36	2.84	4.35	0.001	
QM1	-0.012	0.04	-0.31	0.76	7.62
QM2	-0.173	0.04	-3.92	0.002***	6.98
QM3	0.028	0.05	0.59	0.57	5.18
QN1	-0.117	0.06	-2.06	0.06*	7.39
QN2	0.326	0.07	4.65	0.001***	8.69
QN3	-0.166	0.07	-2.34	0.04**	4.33
QRf_1	-0.0001	0.0005	-0.23	0.82	1.50
QRf_2	-0.0003	0.0002	-1.28	0.23	1.58
QRf_3	-0.0003	0.0001	-2.29	0.04**	1.40
Number of observations		22			
F (9, 12)		19.31			
R^2		0.93			
Adj. R^2		0.89			
P – value		0.000			
Durbin-Watson d-statistic (9, 21)		1.689			

SUMMARY

5. SUMMARY

Agricultural production in India primarily depends on various climatic parameters especially the monsoon rainfall. Studies on large scale changes especially in the occurrence and distribution of rainfall and temperature are foremost factors in the planning and management of irrigation projects, reservoir operation, crop growth simulation models and agricultural production. The variation of climatic parameters has great consequences in the planning of future productions, and therefore, such studies are important for agricultural planning in India.

The air temperature is one of the most important meteorological factors from the environmental, ecological and agricultural point of view and an understanding of the trends in rainfall at the regional level from the past data is also very important for the perspective of agriculture. In rainfed agriculture, the condition of success or failure of a crop is closely linked with rainfall patterns. Therefore, assessing rainfall variability has been an integral field of time series modelling of weather parameters like temperature and rainfall variations using monthly average temperature and rainfall records. Thus, the present research study entitled “Statistical modelling of climate change in Southern Kerala” was formulated with the objective to develop statistical models to analyze climate change overtime across different regions in Southern Kerala and to determine its impact on the yield of paddy and cardamom.

The weather data required for this study was collected from four agrometeorological stations under KAU in Southern Kerala viz., College of Agriculture, Vellayani, RARS, Kumarakom, and CRS Pampadumpara for a period of 29 years (1991-2019) and from RARS, Moncompu for a period of 22 years (1997-2018). Secondary data on production of Paddy and cardamom was also collected from the report of agricultural statistics, GOK for a period of 24 years (1995-2018) and from the Spices Board for 22 years (1997-2018) respectively.

5.1. SALIENT FINDINGS OF THE STUDY

1. Descriptive statistics such as mean, standard deviation, range, coefficient of variation and box plot are utilized to summarize maximum temperature, minimum temperature and rainfall data for the four station separately, which indicated that the average monthly maximum temperature over the years varied from 30.01(° C)to 32.94 (° C) at , Vellayani, the range was 30.27(° C) to 34.34(° C) at Kumarakom, the range was from 29.97 (° C) to 33.72 (° C) at Moncompu and it was from 22.82(° C) to 28.87(° C) at Pampadumpara . Regarding minimum temperature, the highest value was found during the month April, May and lowest in January. In case of rainfall, highest rainfall of 8098 mm was recorded in June followed by 7876 mm in October and 6146 mm in November at Vellayani, the maximum rainfall of 15685.8 mm in June followed by 14299.4 mm rainfall in July and least in January (318.4 mm) was recorded at Kumarakom. Highest rainfall of 10904 mm in June followed by 9620.02 mm rainfall in July and very poor in January (294.7 mm) was observed at Moncompu. In Pampadumpara, the maximum rainfall of 10543.9 mm was recorded in July followed by 8251.5 mm rainfall in August and very low in February (519.9 mm) over the study period.

2. CV of monthly maximum and minimum temperature over the years in four regions was very low indicated a less variability in these parameters while a very high CV for monthly rainfall in all the months especially during December to March revealed high instability in rains in a month overtime. .

3. A number of extremities are present in month wise temperature and rainfall over the years in four stations. A deviation from normal rainfall was recorded during February 1999, March 2013, June 1991 and 1992 and August 2000, 2018 and 2019 at Vellayani. An extreme maximum temperature was recorded during February (1996, 2019), April (2016, 2019), August (2000, 2016), September (2018), October (1997), November (2016) and December (2016) at Vellayani. For minimum temperature many years showed deviation from normal minimum temperature since almost all the months have outliers except for February and September.

At Kumarakom a deviation from average rainfall was recorded during January (1998), February (1994, 2000), March (2008), May (2004), June (2013), July (2007) and August (2014). The interquartile range of January, February, March and December was very small indicating lower variation in this parameter over the study period. For maximum temperature March (2008), April (1994, 1999), May (1999), November (1993, 2010) and December (2010) showed deviation from normal temperature. For minimum temperature February (2000), March (1992, 2008), June (1995, 2008), November (1995) and December (1999) are spotted as outliers.

Deviations from normal precipitation were recorded during January (1995), February (2007), March (2002), May (1998), June (2003), September (1991, 1992) and November (1996) at Monompu. The interquartile range for January, February, March was very small indicating small variation in rainfall during this period. For maximum temperature January (1993) and December (1992, 2006) have shown deviation from normal temperature at Moncompu. September (1998) was spotted as outlier for minimum temperature.

In case of CRS, Pampdumpara a deviation from average rainfall was recorded during January (1996, 2010), February (2011), March (2008), April (2010), May (1995), August (2018), November (1997) and December (2005). For maximum temperature January (1995, 2017, 2019), February (2017, 2019), March (2018, 2019), May (1991, 1993, 2015, 2017, 2018) and July (1996) showed deviation from normal temperature. The number of outliers were high indicating more variability in the data set. For minimum temperature January (2018), April (2017), May (2017), June (2019), July (2019), September (2017, 2019), October (1996, 2019) and November (2012) were spotted as outliers.

4. Trend analysis which is considered as one of the active areas of interest to investigate climate change occurred over the years, in this study trend analysis was performed using Mann-Kendall test and trend was estimated using Sen’s slope estimator for annual, deseasonalized annual and four seasons such as summer, winter, north east and south west monsoon corresponds to four stations. No significant trend was noticed in annual, seasonal rainfall while a decline in rainfall was noticed for south west and north east monsoon in Vellayani. At the same time an increase but a significant trend was observed for maximum and minimum temperature in all the seasons at Vellayani. In general, a slight decreasing trend in rainfall, and increase in maximum and minimum temperature was recorded annually and most of the seasons at Vellayani.

At Kumarakom a slight decrease in trend was observed for rainfall in all the seasons except during winter. But for maximum and minimum temperature an increasing trend was noticed in almost all the seasons except for maximum temperature in summer and winter and minimum temperature during monsoon. Significant and decreasing trend in annual and north east monsoon rainfall coupled with significant increase in north east and south west monsoon and decrease in winter maximum temperature at Kumarakom is an indication of adverse climate change overtime.

In Moncompu a slight decreasing trend was observed for annual and seasonal rainfall during the study period. But for maximum and minimum temperature a clear increase in trend was noticed except during summer and winter wherein a decline in trend was observed. Even though no significant trend was noticed in rainfall except for annual and north east monsoon the slope estimator was negative indicating a decline in rainfall and a non-significant increase in maximum temperature was observed at Moncompu with an exception of negative trend in summer and winter maximum temperature.

Pampadumpara in the high range zone also recorded a decrease in rainfall during all the seasons with a non-significant decline during summer and north east monsoon rains. A prominent decrease in temperature can also be observed for maximum temperature but an increasing trend was noticed for minimum temperature.

5. A comparative analysis of trend using trend plots for the three weather parameters in four stations was made which revealed a declining trend in rainfall and increasing trend in maximum temperature in most of the seasons excluding Pampadumpara wherein a decrease in trend was noticed for maximum temperature. For minimum temperature a positive trend was observed except at Kumarakom which showed a decline in trend for annual aswellas monsoon seasons.

6. The magnitude of trends in rainfall and maximum and minimum temperature of different stations provides another picture of change in weather variables. The magnitude of the negative trend for the annual rainfall was highest at Moncompu (-43.5 mmyear^{-1}) and lowest at Vellayani (-0.871 mm year^{-1}). But for temperature a positive trend was obtained for the majority of stations and a significant trend was seen at Pampadumpara. The magnitude of the positive slopes of the annual maximum temperature was highest at Vellayani (0.038 ^{0} Cyear^{-1}) and lowest at (Moncompu 0.004 ^{0} C year^{-1}). For minimum temperature CRS, Pampadumpara had highest positive slope of 0.121 ^{0} C year^{-1} was recorded at Pampadumpara followed by 0.024 ^{0} Cyear^{-1} year increase at Moncompu. . Over the years annual rainfall was decreasing and temperature was increasing in Southern Kerala.

7. The SARIMA model was fitted to monthly rainfall for all the regions Vellayani, Kumarakom, and Pampadumpara using the monthly data for the period from 1991 to 2019. The model parameters were obtained by using maximum likelihood method and the best model were selected using Akaike Information Criteria (AIC), Bayesian Information Criteria (BIC) and Hannan-quinn coefficient. ARIMA (1, 0, 0) × $(0, 1, 1)_{12}$ was found best fit for rainfall for Vellayani, ARIMA (0, 0, 0) × $(0, 1, 1)_{12}$ for Kumarakom and Pampadumpara. The adequacy of the check of the selected models confirmed that the selected models were free from autocorrelation and the residuals are normally distributed.

8. Multiple regression analysis was performed to analyse the impact of weather parameters on production of paddy in Kottayam indicated that rainfall during July had a negative significant effect, maximum temperature during August and minimum temperature during June had positive significant influence on production of paddy in Viruppu season without considering other influencing factors of production of paddy. While maximum and minimum temperature during October had a positive significant effect and minimum temperature during December and excess rainfall during October and November had a negative significant effect on Puncha paddy yield.

9. The estimated regression coefficients of rainfall during July to September, maximum temperature during April to June and minimum temperature during January to March and July to September are significant and have a negative sign indicating the adverse influence of these parameters on cardamom production. Studies have reported that excess temperature and rainfall during April to June adversely affect the yield of cardamom and hence the production of the crop. In this analysis it was found that a reasonable increase in minimum temperature during positively influences the yield of cardamom. Moreover, the coefficient of rainfall in all the quarters had negative sign indicating the negative effect of excess rainfall on cardamom productivity particularly during the harvesting period. Maximum temperature during July to September, minimum temperature during April to June had a positive impact on yield once again suggesting the negative impact of excess rain during this period.

5.2**. SUGGESTIONS**

- The present study focused on the climate change impact analysis for paddy and cardamom only. There is a huge scope for undertaking further studies on other important crops.
- In this study monthly data was used for fitting SARIMA models, even daily or weekly or quarterly data could be used in fitting models and efficient forecasting models like ARCH or GARCH models can also be fitted.
- More interpretations could be made if the study extended to the incorporation of non-linear regression models for impact analysis.

REFERENCE

6. REFERENCES

Akaike, H. 1974. A new look at the statistical model identification. *IEEE. Trans. Automatic Control* 19: 716-723.

Amin, M., Amanullah, M. and Akbar, A., 2014. Time series modeling for forecasting wheat production of Pakistan. *The Journal of Animal & Plant Sciences*, *24*(5), pp.1444-1451.

Benjamini, Y. 1988. Opening the box of a boxplot. *Am. Statist. Assoc,* 42(4): 257–262.

Bibi, U. M. 2014. Spatial-temporal variation and prediction of rainfall in North-Eastern Nigeria. *Clim.* 2: 206-222.

Bloomfield, P. 1992. Trends in global temperature. *Clim. Change*. 21: 1-16.

Box GEP, Jenkins GM, Reinsel GC. 1995. Time series analysis: Forecasting and control. Prentice-Hall. 592.

Brereton, R., Bennett, S. and Mansergh, I. 1995. Enhanced greenhouse climate change and its potential effect on selected fauna of south-eastern australia: a trend analysis. *Biol. Conserv*. 12: 339-354.

Chakraborty, S., Pandey, R. P., Chaube, U. C. and Mishra, S. K. 2013. Trend and variability analysis of rainfall series at Seonath River Basin, Chhattisgarh (India). *Int. J. Appl. Sci. Eng. Res.* 2(4): 424-435.

Chattopadhyay, S. and Chattopadhyay, G. 2010. Univariate modelling of summer monsoon rainfall time-series: Comparison between ARIMA and ARNN. *Geoscience*. 342: 100-107.

Cryer, J. D. and Chan, K. S. 2008. Time series analysis with application in R. *Springer Texts Statist*. 2: 501.

Dasyam, R., Pal, S., Rao, V. S. and Battacharyya, B. 2015. Time series modeling for trend analysis and forecasting wheat production of India. *Int. j. Agric. Environ. Biotechnol.* 8: 303-308.

Dean,S. and Illowsky, B. 2009. Descriptive Statistics: Box Plot. Collaborative Statistics Using Spreadsheets No. 2.5. OpenStax Textbooks, Texas. Available: https://www.free-ebooks.net/mathematics/Collaborative-Statistics-2/html [July 3, 2012].

Deka, R. L. 2015. Spatio-temporal variability of rainfall regime in the Brahmaputra valley of North East of India. *Theor. Appl. Climatol*. 124(3-4). 793-806.

Dhanya, G. 2019. Statistical modeling for the impact of weather and soil parameters on the yield of paddy under long term fertilizer experiment. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 100p.

El-Mallah,E. S. and Elsharkawy, S. G. 2016. Time-series modeling and short term prediction of annual temperature trend on coast libya using the box-jenkins arima model. *Adv. Res.* 6(5): 1-11.

Eslamian, S., Modarres, R. and Soltani, S., 2006. Spatial grouping of drought using standardized precipitation index in Isfahan province. *Water Wastewater J. 17*(57): 72-75.

Gautam, A., 2016. Impact of Climate Changes on Cultivation of Small Cardamom in Cardamom Hills Region (CHR) in India: An Opinion. *Indian Hortic. J.*, *6*(2):.268-270.

Gikungu, S.W., Waititu, A.G. and Kihoro, J.M., 2015. Forecasting inflation rate in Kenya using SARIMA model. *Am. j. Theor. Appl. Statist. 4*(1): 15-18.

Gopakumar C.S. 2011. Impacts of Climate variability on Agriculture in Kerala. Ph.D. thesis, Cochin University of Science and Technology, Cochin, 286p.

Gopika, S., Lekshmi Mudra, B., Chaidanya, K. and Varsha, K.M. 2014. Rainfall variability and rice productivity over kerala. *J. Aquat. Biol. Fish.* 2: 162-164.

Goswami, K., Patovary, A. N. and Hazarika, J. 2017. Monthly temperature prediction based on ARIMA model: a case study in Dibrugarh station of Assam, India. *Int. J. Adv. Res. Comput. Sci.* 8(8). 292-298.

Guhathakurta, P. and Rajeevan, M. 2008. Trends in the rainfall pattern over India. *Int. j. Climatol*. 28(11): 1453–1469.

Hannan, E.J. and Quinn, B.G., 1979. The determination of the order of an autoregression. *J. R. Statis. Soc*. *41*(2): 190-195.

Hare, W. 2003. Assessment of knowledge on impact of climate change, contribution to specification of art, 2 of UNFCCC. WBGU.

Heikkinen, R.K., Luoto, M., Araújo, M.B., Virkkala, R., Thuiller, W. and Sykes, M.T., 2006. Methods and uncertainties in bioclimatic envelope modelling under climate change. *Prog. Phys. Geogr.* 30(6): 751-777.

Hipel, K.W., McLeod, A. I. and Lennox, W. C. 1977. Advances in Box-Jenkins modeling: 1. Model construction. *Water Resour. Res.*13(3): 567-575.

Hosking, J. R. W. and Wallis, J. R. 1993. Some statistics useful in regional frequency analysis. *Water Resour. Res*. 29: 271-28.

Huchagoudar, M. 2019. Comparison of performance and its determinants of coffee and cardamom in South India: A statistical analysis. M.Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 168p.

Jhaiharia, D., Roy, S. and Ete, G. 2007. Climate and its variations: A case study of Agartala. J. soil and water conserve. 6(1): 29-37.

Janhabi, M. and Ramakar, J. 2013. Time-series analysis of monthly rainfall data for the Mahanadi River Basin, India. *Sci. Cold Arid Regions*. 5(1): 73 – 84.

John, C., George, U., Chukwuemeka, O. S. 2014. Time Series Analysis and Forecasting of Monthly Maximum Temperatures in South Eastern Nigeria. *Int. j. innovative Res. Dev.* 3(1): 165-171.

Kane, I. L. and Yusof, F. 2013. Assessment of risk of rainfall events with a hybrid of ARFIMA-GARCH. *Mod. Appl. Sci.* 7(12): 78-89.

Katz, R. W. and Brown, B.G. 1992. Extreme events in a changing climate: variability is more important than averages. *Clim. Change* 21: 289-302.

Kaushik, I. and Singh, S. M. 2008. Seasonal arima model for forecasting of monthly rainfall and temperature. *J. Environ. Res. Dev.* 3(2): 506-514.

Kendall, M. G. 1975. *Rank Correlation Methods,* Oxford univ. Press, New York, 202p.

Khan, R., Gurmani, A. R., Gurmani, A. H., and Zia, M. S. 2007. Effect of phosphorus application on wheat and rice yield under wheat- rice system. *Sarhad J. Agric*. 23(4). 851-856.

Kotra1, S. S. and Sahik, N. U. 2016. Prediction of tur production in Andhra Pradesh using arima model. *Int. J. Recent Sci. Res.* 7(10): 13664-13665.

Krishnakumar, K. N., Rao, G. S. L. V. and Gopakumar, C. S. 2009. Rainfall trends in twentieth century over Kerala. *India. Atmos. Environ*. 43:1940–1944.

Krishnamurthy, V. and Shukla, J. 2000. Intra-seasonal and inter-annual variability of rainfall over *India. J. of Clim*. 13: 4366-4377.

Krishnamurthy, K.S., Kandiannan, K., Chempakam, B., Ankegowda, S.J. and Anandaraj, M., 2015. Climate change impact on black pepper and cardamom. *Clim. Dyn. Hortic. Sci.*, 1:.201-217.

Kumar, K. R., Pant, G. B., Parthasarathy, B. and Sontakke, N. A. 1992. Spatial and sub seasonal patterns of the long term trends of Indian summer monsoon rainfall. *Int. J. of climatol*. 12: 257-268.

Kumar, S. N., Aggarwal, P. K., Rani, S., Jain, S., Saxena, R., and Chauhan, N. 2011. Impact of climate change on crop productivity in Western Ghats, coastal and northeastern regions of India. *Curr. Sci*. 101(3): 334- 341.

Kumar, U. and Jain VK. 2010. ARIMA forecasting of ambient air pollutants (O3, NO, NO2 and CO). *Stochastic Environ. Res. Risk Assessment*. 24:751-760.

Kumary, L. S. 2009. Climate change Adaptation strategies for rice (Oriza sativa. L.) in Kerala. In: *Proc. Natl. Seminar on Clim. Change Adaptation Strategies in Agric. and Allied Sectors,* KAU. pp. 158.

Kwiatkowski, D., Phillips, P.C., Schmidt, P. and Shin, Y., 1992. Testing the null hypothesis of stationarity against the alternative of a unit root. *J. econometrics, 54*(1-3):159-178.

Madsen, H., Lawrence, D., Lang, M., Martinkova, M., Kjeldsen, T. R. 2014. Review of trend analysis and climate change projections of extreme precipitation and floods in Europe. *J. Hydrol.* 519: 3634-3650.

Mate, C. and Arroyo, J. 2006. Descriptive statistics for boxplot variables. In: COMPSTAT-2006, *Proceedings in computational statistics,* Springer-Verlag,.Rome[Online].Availabl*e:http://www.upcomillas.es/presim/documentos/recu_03. pdf.*

Mathews, R. B., Krofpff, M. J., Horie, T and Bachelet, D. 1997. Simulating the impact of climate change on rice production in Asia and evaluating options for adoption. Agric. Syst. 54: 399-425.

Mathews, L. and James, P. P. 2017. Problems and Prospects of Cardamom Cultivation in Idukki District. *Int. J. Econ. Manag. Stud.* 4(6): 37-44.

Mann, H. B. *1945.* Nonparametric tests against trend, *Econometrica* 13: 245-259.

Millar, C. I., Stephenson, N. L., and Stephens, S. L. 2007. Climate change and forests of the future: managing in the face of uncertainty. *Ecol. Appl.* 17(8): 2145–2151.

Mishra, A. K. and Desai, V. R. 2005. Drought forecasting using stochastic models. *Stoch. Environ. Res. Risk Assess*. 19: 326–339.

Modarres, R. and Ouarda, T. B. M. J. 2014. Modeling the relationship between climate oscillations and drought by a multivariate GARCH model. *Water Resour. Res.* 50: 601–618.

Murat, M., Malinowska1, I., Gos, M., and Krzyszczak, J. 2018. Forecasting daily meteorological time series using ARIMA and regression models. *Int. Agrophysics*. 32: 253-264.

Murugan, M., Shetty, P. K., Ravi, R., Anandhi, A., Rajkumar, A. J. 2012. Climate change and crop yields in the Indian Cardamom Hills. *Clim. Change* 110(3-4): 737-753.

Murugan, M., Raj, N.M. and Joseph, C.R., 2000. Changes in climatic elements and their impact on production of cardamom (Elettaria cardamomum Maton) in the Cardamom Hills of Kerala, India. *J. Spices Aromat. Crops 9*(2): 157-160.

Naill, P. E. and Momani, M. 2009. Time series analysis model for rainfall data in Jordan: Case study for using time series analysis. *Am. J. Environ. Sci*. 5 (5): 599-604.

Nayagam, L. R., Janardanan, R. and Mohan, H. S. R., 2008. An empirical model for the seasonal prediction of southwest monsoon rainfall over Kerala, a meteorological subdivision of India. *Int. J. Climatol.* 28: 823- 831.

Pai, D.S. and Nair, R.M., 2009. Summer monsoon onset over Kerala: New definition and prediction. *J. Earth Syst. Sci.* 118(2): 123-135.

Pathak, H., Aggarwal, P. K. and Singh, S. D. 2012. *Climate Change Impact, Adaptation and Mitigation in Agriculture: Methodology for Assessment and Application*. Indian Council of Agricultural Research, New Delhi, 322p.

Pearson, A. V. and Hartley, H. O. 1972. Biometrical tables for statisticians. *Biometrical J.* 16(4): 235-295.

Potter,K. 2006. Methods for Presenting Statistical Information:The Box Plot. In: Hagen, H. Kerren, A. and Dannenmann, P. (eds), *Visualization of Large and Unstructured Data Sets.* Proceedings of an international workshop, Dagstuhl, Germany. GI-Edition Lecture Notes in Informatics (LNI), Germany. pp. 97-106.

Prakash, N. J., Maharjan, K. L., and Piya, L. 2011. Effect of climate variables on yield of major food-crops in Nepal -A time series analysis. [On- line]. Available: https://mpra.ub.unimuenchen.de/35379/[15 Dec. 2018].

Raj, N. P. P. and Azeez. P. A. 2012. Trend analysis of rainfall in Bharathapuzha River basin, Kerala, India. *Int. J. Climatol.* 32: 533–539.

Raj, N.P. P. and Azeez, P. A. 2010. Changing rainfall in the Palakkad plains of South India. *Atsosfera.* 23(1): 75-82.

Rao, B. B., Chowdary, P. S., Sandeep, V. M., Rao, V. U. M., and Venkateswarlu, B. 2014. Rising minimum temperature trends over India in recent decades: Implications for agricultural production. *Global Planetary Change*. 54(117): 1-8.

Rao, G. S. L. H. V. P., Krishnakumar, K. N. and Tony, X. 2001. Occurrence of meteorological droughts during monsoon and its impact on paddy yield in tropical monsoon climates. In: Proc. of the Thirteenth Kerala Science Congress. January 2001, Thrissur pp.504-507.

Saha, E., Hazra, A., and Banik, P. 2016. SARIMA modelling of the monthly average maximum and minimum temperatures in the eastern plateau region of India. *Mausam.* 67(4): 841-848.

Salmi, T., Maatta, A., Anttila, P., Ruoho-Airola, T. 2002. Detecting Trends of Annual Values of Atmospheric Pollutants by the Mann-Kendall Test and Sen's Solpe Estimates the Excel Template Application makesens. *Finnish Meteorological Institute, Finland,* 35p.

Saseendran, S. A., Singh, K. K., Rathore, L. S., Singh, S. V., and Sinha, S. K. 2000. Effects of climate change on rice production in the tropical humid climate of Kerala, India. *Clim. Change*. 44: 495–514.

Schwartz, G. 1978. Estimating the dimension of a model. *The An. Statist*. 6: 461-464.

Sen, P. K. 1968. Estimate of regression coefficient based on Kendall's Tau. *J. Am. Statist. Assoc.* 63(324): 1379-1389.

Simon, A. and Mohankumar, K. 2004. Spatial variability and rainfall characteristics of Kerala. *Curr. Sci. India*. 57: 7-12.

Singh, A. and Gosain, A. K. 2011. Climate-change impact assessment using GIS-based hydrological modelling. *Water Int.* 36(3): 386-397.

Singh, C. V. 1999. Principal components of monsson rainfall in normal, flood and drought years over India. *Int. J. Climatol*.19: 639-952.

Sonali, P., Kumar, D. N. 2013. Review of trend detection methods and their application to detect temperature changes in India. *J. Hydrol.* 476: 212-227

Sreenivas, G., Reddy, D. R. and Rao, S. B. S. N. 2005. Influence of weather parameters on yield of lowland rice (Oryza sativa L.). *J.of Agrometeorol*. 7(1): 69-75.

Sreeja, K. G., Eldo, T. I. and Madhusoodhanan, C. G. 2015. Climate and landuse impacts on sub-sea level rice farming in a tropical wetland. *Proceedings of thirty sixth IAHR world congress*, 28 June – 3 July 2015, Hague, Netherland, pp. 1-9.

Srivastava, A. K., Guhathakurta, P. Rajeevan, M., Dikshit, S. K. and Kshirsagar, S. R., 2007. Did unusual warming over the mid and higher latitudes play some role in causing the unprecedented failure of the southwest monsoon during July 2002?. *Meteorol. Atmos. Phys*. 96(3-4): 193-201.

Sallehuddin, R., Shamsuddin, S.M.H., Hashim, S.Z.M. and Abraham, A., 2007. Forecasting time series data using hybrid grey relational artificial neural network and auto regressive integrated moving. *Neural Network World* 17(6): 573.

Sun, Y. and Genton,M. G. (2011). Functional Boxplots. *J. computational Graphical Ststist.* 20(2): 316-334.

Surendran, U., Sushanth, C. M., Mammen, G., Joseph. E. J. 2014. Modeling the impacts of increase in temperature on irrigation water requirements in palakkad district: A case study in humid tropical Kerala. *J. water Clim. Change* 5(3): 472 – 485.

Susha, P. S. 2011. Climate change impacts and adaptation strategies in paddy production. M. Sc. (Ag) thesis, Kerala Agricultural University, Thrissur, 122p.

Takahashi, J. M., Yangisawa, M., Kono, F. and Yoshida, T. 1995. Studies on nutrient absorption by crops. Bull. Natl. Inst. Agric. Sci. 14: 1-83.

Tao, F., Yokozawa, M., Liu1, J., and Zhang, Z. 2008. Climate–crop yield relationships at provincial scales in China and the impacts of recent climate trends. *Clim. Res*. 38: 83–94.

Tularam, G. A. and Mahbub, I. 2010. Time series analysis of rainfall and temperature interactions in coastal catchments. *J. Math. Statist.* 6(3):372-380.

Tylkowski, J. and Hojan, M. 2019. Time Decomposition and Short-Term Forecasting of Hydrometeorological Conditions in the South Baltic Coastal Zone of Poland. *Geoscience* 9(2): 68.

Unnikrishnan, T., Anilkumar, P. and Gopakumar, C. S. 2018. *Int. J. Statis. Appl. Math*. 3(1): 360-367.

Weesakul, U. and Lowanichchai, S. 2005. Rainfall forecasting for Agricultural water allocation planning in Thailand. *J. sci. Technol*. 10: 18-27.

Wu, C. L., Chau, K. W. 2013. Prediction of Rainfall Time Series Using Modular Soft Computing 1 Methods. *Eng. Appl. Artif. Intelligence.* 26 (3): 997-1007.

Yao, F., Yinglong, X., Lin, E., Yokozawa, M., and Zhang, J. 2006. Assessing the impacts of climate change on rice yields in the main rice areas of China. *Clim. Change*. 80: 395–409.

Yureki, K., Ozturk,F., Kurunc,A., 2005. Testing the residuals of an arima model on the Cekerek stream watershed in turkey. *J. Eng. Environ. Sci.* 29(2): 61-74.

ABSTRACT

STATISTICAL MODELLING OF CLIMATE CHANGE IN SOUTHERN KERALA

by

NEETHU R. S.

(2018-19-003)

Abstract of thesis

Submitted in partial fulfilment of the

requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture

Kerala Agricultural University

DEPARTMENT OF AGRICULTURALSTATISTICS

COLLEGE OF AGRICULTURE

VELLAYANI, THIRUVANANTHAPURAM-695 522

KERALA, INDIA

2020

ABSTRACT

The research work entitled 'Statistical modelling of climate change in Southern Kerala' was carried out at College of Agriculture Vellayani during 2018-2020. The objective was to develop statistical models to analyze climate change overtime across different regions in Southern Kerala and to determine its impact on the yield of paddy and cardamom. The weather data corresponds to maximum temperature, minimum temperature and rainfall was collected from four agrometeorological stations under KAU in Southern Kerala viz., College of agriculture, Vellayani, RARS, Kumarakom, CRS, Pampadumpara for a period of 29 years (1991-2019) and from RRS, Moncompu for a period of 22 years (1997-2018). Secondary data on production of Paddy and cardamom was collected from the Report of Agricultural Statistics, GOK for a period of 24 years (1995-2018) and from the Spices Board for a period of 22 years (1997-2018) respectively. The entire analysis was done with the help of Microsoft excel, SPSS, Gretl and R programming software.

Descriptive statistics includes mean, range, standard deviation and coefficient of variation and box plot was used to describe the features of monthly weather parameters over the years. The results from the box plot and descriptive statistics indicated that heavy rainfall was received in July, August 2018 at Kumarakom and Moncompu followed by Pampadmpara and Vellayani. Rainfall patterns in Kumarakom, Moncompu and Idukki showed more deviations from normal rainfall as compared to Vellayani over the study period. Among the four regions the highest annual maximum temperature was observed at Kumarakom and the lowest at Pampadumpara and highest precipitation was observed in Kumarakom followed by Moncompu, Pampadumpara and lowest in Vellayani.

Trend analysis was performed to understand the climate change on the basis of rainfall, maximum and minimum temperature with the help of Mann-Kendall test and Sen's slope estimator for annual and different seasons in four regions. No significant trend was noticed in annual and different seasons rainfall while a decline in rainfall was noticed for south west and north east monsoon at

Vellayani. At the same time a significant increasing trend was observed for maximum temperature in all the seasons at Vellayani. Whereas a significant and decreasing trend in annual and north east monsoon rainfall with a significant increase in north east and south west monsoon maximum temperature and a decrease in winter maximum temperature at Kumarakom is an indication of the adverse change in climate change overtime. Even though no significant trend was noticed in rainfall except for annual and north east monsoon, the slope estimator was negative indicating a decline in rainfall with a non-significant increase in maximum temperature at Moncompu. Pampadumpara in the high range zone also recorded with decrease in rainfall during all the seasons.

The magnitude of trends in rainfall and maximum and minimum temperature of different stations provides a more precise picture about the change in weather variables. The magnitude of the negative trend for the annual rainfall was highest at Moncompu (-43.5 mmyear^{-1}) and lowest at Vellayani (-0.871 mm year^{-1}). But for maximum temperature a positive trend was obtained in majority of the stations and a significant negative trend was seen at Pampadumpara. The magnitude of the positive slopes of the annual maximum temperature was highest at Vellayani (0.038 ^{0} Cyear^{-1}) and lowest at Moncompu (0.004 ^{0} C year^{-1}). Pampadumpara had recorded with a highest positive slope of 0.121 ^{0} C year^{-1} for minimum temperature followed by 0.024 ^{0} Cyear^{-1} at Moncompu. In general a decrease in annual rainfall and an increase in temperature were observed in Southern Kerala over the years.

Seasonal ARIMA models were used to model rainfall data of the three stations. Rainfall data in the level form was stationary and a prominent seasonality was found out which indicated that the order of integrating factor was 0 for non-seasonal component and 1 for seasonal component. Using trial and error method the best model among the randomly chosen models was selected on the basis of least AIC, BIC and Hannan- Quinn criteria. The best identified SARIMA models for rainfall were respectively ARIMA (1, 0, 0) (0, 1, 1)$_{12}$ for Vellayani, ARIMA

(0, 0, 0) (0, 1, 1)$_{12}$ for Kumarakom and ARIMA (0, 0, 0) (0, 1, 1)$_{12}$ for Pampadumpara to forecast monthly rainfall in these regions.

Multiple regression analysis was performed to analyse the impact of weather parameters on the production of paddy in Kottayam indicated that rainfall during July had a negative significant effect, maximum temperature during August and minimum temperature during June had a positive significant influence on the production of paddy in Viruppu season without considering the influence of other factors of production. While maximum and minimum temperature during October had a positive significant effect and minimum temperature during December and excess rainfall during October and November had a negative significant effect on Puncha paddy yield.

The estimated regression coefficients of rainfall during July to September, maximum temperature during April to June and minimum temperature during January to March and July to September were found to be significant and the negative sign of the parameters indicating the adverse influence weather parameters on the production of cardamom. However, maximum temperature during July to September, minimum temperature during April to June had a positive impact on yield once again suggesting the negative impact of excess rain during this period. Moreover, the coefficient of rainfall in all the quarters had a negative sign indicating the negative effect of excess rainfall on cardamom productivity particularly during the harvesting period.

The results of the study based on trend analysis indicated clear evidence about climate change in terms of weather parameters occurred across different regions in Southern Kerala during the study period. SARIMA model was found to be the best model for prediction of rainfall in the selected regions. The impact analysis of weather parameters on the production concluded that the weather parameters during different months had either a positive or a negative influence on the production of paddy and cardamom.