STATISTICAL MODELS FOR CLIMATE CHANGE IN NORTHERN AND CENTRAL KERALA

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STATISTICAL MODELS FOR CLIMATE CHANGE IN NORTHERN AND CENTRAL KERALA

by

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THESIS

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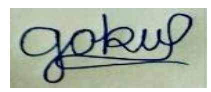
KERALA, INDIA

2020

DECLARATION

I, hereby declare that this thesis entitled **“Statistical models for climate change in northern and central 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 to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.



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Certified that this thesis entitled **“Statistical models for climate change in northern and central Kerala”** is a record of research work done independently by Mr. Gokul Krishnan K B under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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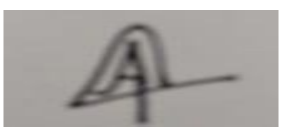

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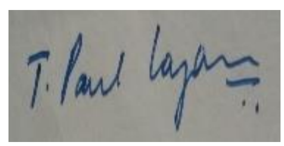

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LIST OF ABBREVIATIONS AND SYMBOLS USED

ACF	Autocorrelation Function
ADF	Augmented Dickey-Fuller
AIC	Akaike's Information Criterion
AR	Autoregressive
ARCH	Autoregressive Conditional Heteroskedasticity
ARIMA	Autoregressive Integrated Moving Average
ARMA	Autoregressive Moving Average
BIC	Bayesian Information Criterion
CERES	Crop Estimation through Resource and Environment Synthesis
CFC	Chlorofluorocarbon
Cm	Centimeter
CV	Coefficient of Variation
℃	Degree Celsius
E	East
et al.,	Co-workers
etc.	et cetera
FAO	Food and Agriculture Organization
Fig.	Figure
GARCH	Generalized Autoregressive Conditional Heteroskedasticity
GOK	Government of Kerala
HQC	Hannan-Quinn Criterion
IPCC	Intergovernmental Panel on Climate Change
ITA	Innovative Trend Analysis
KAU	Kerala Agricultural University
MA	Moving Average
MAE	Mean Absolute Error
MK	Mann-Kendall
Mm	Millimeter
MMK	Modified Mann-Kendall
MWP	Mann-Whitney-Pettitt
N	North
OLS	Ordinary Least Squares
RARS	Regional Agricultural Research Station
PACF	Partial Autocorrelation Function
P value	Probability Value
%	Percentage
PMW	Pettitt–Mann–Whitney
RCM	Regional and Climate Model
SARIMA	Seasonal Autoregressive Integrated Moving Average

SBC	Schwarz's Bayesian Criterion
SPI	Standardized Precipitation Index
STI	Standardized Temperature Index
σ	Standard Deviation
SNH	Standard Normal Homogeneity
UK	United Kingdom
VIF	Variance Inflation Factor
Viz	Without a full stop
$\overline{X}$	Mean
Z value	Standard score

INTRODUCTION

1. INTRODUCTION

India is a country in South Asia which is the seventh largest country in the world and also the second most populous country beside China. India is bounded by Indian-ocean in the south, the Bay of Bengal in the south east, and the Arabian Sea in the south west and Himalayas in the north. Indian climate is strongly influenced by the Thar Desert and the Himalayas, both of which drive the economically and culturally pivotal summer and winter monsoons. Himalayas prevent the cold central Asian katabolic winds which keeps the Indian subcontinent warmer as compared to other places with similar latitudes. The Thar Desert which lies in northwest India attracts the southwest monsoon winds and plays a crucial role in providing the majority of the rainfall in India.

Climate of India consists of a wide range of weather conditions which comprise of different topography and geographical areas, which makes generalization of a climate difficult. Climatic condition in North India is generally cooler than South India. Most of the parts across India experienced above 40℃ during the summer whereas in the winter, the temperature won't get reduce below 10℃ in India except the Himalayan and in the Western Ghats region. The average rainfall in India is about 125cm in which the southwest monsoon accounts for the most. The entry point of southwest monsoon in Indian subcontinent is almost near to Kerala. The rainy season in Kerala is scheduled in between June-September (southwest monsoon) and October-November (northeast monsoon). The March– May (pre-monsoon) months are depicted by major thunderstorm activity in the state, and the December–February (winter) months are shown by low clouding and low rainfall. The average annual rainfall in Kerala is 310.4cm. The average minimum and maximum temperature of Kerala is 29℃ and 35℃ respectively. The winter in Kerala starts by the late of November and ends in late February or the beginning of March. The summer will start from late March and ends in May.

Climate change is an important global issue which is debated in recent times and it is also one of the crucial global challenges in the present century. The climate of our planet is found to be changing since the last century and it is also expected to continue.

The indication of climate change is remarked in the environment through the rise in global and regional temperature and also change in precipitation in the hydrological cycle in India and also other parts of the world. The rainfall is an important measure to determine the changes and understand the trend for a long period in a fixed place. The maximum temperature and minimum temperature also helps to determine the seasonal and regional variation over a specific period. This measure will provide the knowledge to take important decisions on agriculture, industry, irrigation, generation of hydroelectricity, and other human activities. The seasonal, spatial and temporal trends are important to determine climate change of a specific place in a certain duration. The different researchers from various parts of the world have been examining the annual trend in rainfall patterns and also about global warming due to rising temperatures.

Climate change showed a warmer atmosphere which results in more water evaporation from the oceans and land. Although when the water vapour condenses, results in more clouds, thus there will be decrease in temperature since there is a reduction in solar radiation reaching the earth surface. The long-wave radiation from the ground gets absorbed by the uncondensed form of the water vapour present in the atmosphere which results in the greenhouse heating of the atmosphere. Several statistical and computer models have been processed to determine the level of climate change in different parts of the world. Due to the increase in water vapour present in the atmosphere, it is predicted that there will be 50 percent increase in temperature. Different models suggested that there is an increase of temperature of about 4℃ over land by 2100. The greenhouse gases and water vapour play a crucial role in estimation of climate change over large areas of the world. Moreover, these two factors play a critical role in estimating the variations of the climate change during seasons and regions across India. The mean trends and variations in average global temperature has been sufficiently calculated by Hadley centre for climate prediction and research (UK) by making Global climate models over a period of past 150 years. The warming trends have been supplemented by both maximum and minimum temperature over the last three periods. Several studies has been conducted, the result showed that there was a significant increase in minimum temperature over the winter and post-monsoon seasons, such that 0.4℃ and 0.7℃ respectively.

The study of precipitation trends are demanding seriousness for a country like India whose economy, employment and food security are based on timely availability of water. The average precipitation is expected to be both increase and decrease at the regional and in a continental scales whereas there will be an increase in global average precipitation. The increase and decrease in rainfall, or variation in its seasonal and spatial distribution would influence the factors like runoff, soil moisture and groundwater reserves, and it might also effect on the occurrence of flood and drought. The cropping pattern and productivity will be affected by temporal change in precipitation distribution. The Intergovernmental Panel on Climate Change (IPCC, 2007) claimed that the future climate change will be directly affected on agriculture, water scarcity, rapid melting of glaciers and also increase the risk of hunger and poverty. Climate change is the main reason behind the decrease in availability of freshwater in river basins and lakes of India. These reductions with increasing population growth and rise in standard of living can affect a large number of people in India by the 2050s. The frequency and damage due to glacier melt related floods, slope destabilization and a decrease in river flows as glaciers recede has been observed due to accelerated glacier melt.

Rice *(Oriza sativa)* is the staple food of over half the population of the world. It almost provides the 20 percent of the world's dietary energy supply. It is an outstanding food crop which is low in fat and high in starchy carbohydrates. It also consists of a pack full of vitamins and minerals like thiamine, niacin and potassium, sodium respectively. The white rice is more processed and it is enriched with other vitamins to increase its nutritional value. Despite this, brown rice is more nutritious and eventually healthier. It is regarded as the first cultivated crop of Asia. South East Asia is considered as the place of origin of rice. It is cultivated in more than 100 countries, with a total area of 158 million hectares, producing more than 700 million tons annually. The world's largest producer of rice is China which consists of 193 million metric tons (FAO 2016) which is almost 35 percent of total world rice production.

Rice is the staple crop of India which is consumed by the majority of the population of our country. India is not only the second largest producer in the world (106.5 million tonnes) but also the leading consumer of the rice crop. The growth in the rice production of India is mainly due to the green revolution. The rice crop is an adaptable crop and can be cultivated in different climates. It can be cultivated in plains and mountains such that it can be grown as a Kharif crop or even as a Rabi crop. But the major season is Kharif and hence it is mainly cultivated in June to July and in Rabi season the sowing time is November to February. The Kharif rice crop will be harvested in November to December whereas the Rabi crop will be harvested in March-June. The rice crop is cultivated in almost half of the states in India. West Bengal is the leading state in terms of production with 14.71 million tonnes followed by Uttar Pradesh with 12.22 million tonnes.

Rice is the most important food crop grown in Kerala. The paddy fields are the vital part of Kerala's environment and ecological system. The rice almost covers 7.46 percent of the total cropped area of the state. The major important problem in Paddy production in the state is that the area under rice is falling at an alarming rate from the 1980s. The cultivated area under paddy is 8.82 lakh hectare in 1974-75, but it has come down to 1.96 lakh ha in 2015-16. The gross cropped area of paddy in the state is only 12 percent of total cropped area at present. The two major rice producing districts in Kerala are Palakkad and Alappuzha. The Palakkad district is considered as the rice granary of Kerala which has 83,000 ha under paddy cultivation which accounts for the 40% of total area under paddy in the state.

Climate change has adverse effect on crop production and it also affects the quantity and quality of the produce. The agriculture productivity get reduced due to increase in temperature, changes in rainfall, change in extreme weather events and lack of availability of water (Panikar, 1973). The fluctuation in temperature will not only affect the growth pattern but also the duration and yield of the rice crops. The increase in temperature can results in both positive and negative impacts on rice crops, depending on the location. In hilly regions the increase in temperature get benefited whereas in plain region the yield get deteriorated. The higher temperature results in spikelet sterility, reduce quality of grain and also nutrients accumulation get reduced. The variation in the amount and distribution of rainfall led to changing of the planting season of the rice crop. The moisture stress prevailing for a long period of time can leads to several damages to the crop. The severe drought take place at the reproductive stage can led to complete failure of the rice crop (Sharifunnessa and Islam, 2017). The flood can reduce the rice yield and it also indirectly affect the rice crop. The infrastructure support of rice production get destructed or destroyed due to flood. The frequent occurrence of heavier drought and flood occur in different parts of the world due to variation in the pattern of rainfall distribution.

In this context a study on "Statistical models for climate change in northern and central Kerala" is proposed with the following objectives

- To develop statistical models to evaluate climate change overtime across different regions of northern and central Kerala
- To determine the effect of climate change on paddy production

1.1 SCOPE OF THE STUDY

Climate change is an important issue faced by all over the world. The descriptive statistic and boxplots for rainfall, maximum and minimum temperature helps to determine the deviation from the normal values. The climate change over the years was identified by detection and estimation of the trends in rainfall, maximum and minimum temperature. The modelling of weather parameters over the years supported understanding of the pattern of climate change and also for the prediction of future values. The impact of climate change in production of paddy in Palakkad district of Kerala was determined. It also assisted to understand the influence of weather parameters in different growth stages of paddy production.

1.2 LIMITATION OF THE STUDY

The weather parameters included in the study are rainfall, maximum temperature and minimum temperature since 35 years continuous data was absent for other parameters. The data for the analysis was collected only from RARS Pilicode and RARS Pattambi since other research stations like RARS Panniyoor and RARS Ambalavayal didn’t have continuous weather data for 35 years. The paddy production from Pattambi block was having insufficient data which made use of the paddy production data from Palakkad district for the research work.

1.3 PRESENTATION OF THE THESIS

The current study consist of five chapters particularly introduction, review of literature, materials and methods, result and discussion and summary. The first chapter introduction gives a brief idea about the importance, objective, scope, limitations and future aspects of the current study being conducted. The second chapter consists of reviews related to the old works from which different methods were identified and used for the present study. The third chapter, material and methods consist of different statistical methods applied in the current study. The fourth chapter results and discussions included with the interpretation of various analysis conducted for the present study. The summary of the present study is included as the last chapter along with reference and abstract.

1.4 FUTURE LINE OF THE STUDY

The present study mainly focused on seasonal ARIMA models for modeling the weather parameters. All other modeling like GARCH and ARCH can be tried for the weather parameters. Detection and estimation of trends for other weather parameters of Pilicode and Pattambi can be also identified in the future. Impact of rice production can also be analyzed by including other weather parameters like rainy days, relative humidity and sunny days. Impact of climate change on crop production of other districts can also be studied.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

The reviews related to past research works can give sufficient knowledge and information about the area in which research work was carried out and it also helped the researcher in identifying and understanding the concepts and methodology used for the study. This gave better ideas for the researcher in collecting the necessary data, helped to undergo proper research work and also to derive meaningful results. The review about the research works related to the present study are completed by considering the objective of the research work and it is presented under following headings

2.1 Trends in Weather parameters

2.2 Modelling of Weather parameters

2.3 Impact of Weather parameters on paddy production.

2.1 TREND IN WEATHER PARAMETERS

Arora *et al*. (2005) conducted a study on impact of climate change by evaluation of temperature trends over India. The investigation was carried out to find out the trends in temperature of 125 stations from different parts of India. It was found that the annual mean temperature, mean maximum temperature and mean minimum temperature have increased at the rate of 0.42, 0.92 and 0.09 °C respectively. On a regional basis the stations of southern and western India showed a rising trend of 1.06 and 0.36 °C respectively whereas northern parts showed a declining trend of –0.38°C. For the post monsoon and winter season the seasonal mean temperature has increased by 0.94°C and 1.1°C respectively.

A study was conducted on the recent changes in surface temperature trends over India (Kothwale and Kumar, 2005). The data is collected from 388 well-spread stations in India for the period of 1951–2003. The MK test and Sen's slope were used for detection and estimation of trend. The results showed that there is a significant increase in mean annual temperature of 0.05°C/10yr. The results also showed there is an accelerated warming trend in both daytime and nighttime temperatures.

Alexander *et al*. (2006) investigated the global observed changes in daily climate extremes of temperature and precipitation. The seasonal and annual trends were analysed over a period of 52 years (1951–2003). Trend detection and estimation were done with the help of Mann-Kendall and Sen's slope estimator respectively. The results showed that there was a significant increase in temperature extremes especially for the daily minimum temperature. The results also revealed that there was a significant decrease in the annual occurrence of cold nights and a significant increase in the annual occurrence of warm nights. The precipitation changes showed a widespread and significant increase, but the changes are much less spatially coherent compared with temperature change.

A study was conducted on some evidence of climate change in twentieth-century India where the spatial and temporal variability in precipitation and temperature was estimated (Dash *et al*., 2007). The trend estimation was done with the help of MK test and detection with the help of Sen's slope estimator. The results showed that the maximum temperature has been increasing during the last century over all the regions of India such that the West coast shows maximum increase in its maximum temperature by about 1.2°C followed by 1°C in the north east, 0.9°C in the western Himalaya, 0.8°C in the north central, 0.6°C in the north west, 0.6°C in the east coast and the least amount of 0.5°C in the interior peninsula. The rainfall pattern during different seasons indicate small increase during winter months of January and February, pre-monsoon months of March, April and May and post monsoon months of October, November and December.

Guhathakurta and Rajeevan (2008) investigated trends in the rainfall pattern over India over a long period of 103 years (1901–2003). The monthly, seasonal and annual rainfall time series of 36 meteorological subdivisions of India were constructed using the monthly rainfall data from a fixed network of 1476 rain gauge stations. The long-term trends in rainfall over different subdivisions and monthly contribution was carried out by using linear trend analysis. The result showed that the south-west monsoon season had a significant decreasing trend in three subdivisions Jharkhand, Chhattisgarh and Kerala and also it showed a significant increasing trends in eight subdivisions Gangetic WB, West

UP, Jammu and Kashmir, Konkan and Goa, Madhya Maharashtra subdivision, Rayal seema, Coastal AP and North Interior Karnataka. The result also revealed that contribution of June, July and September rainfall to annual rainfall is decreasing for few subdivisions while contribution of August rainfall is increasing in few other subdivisions.

Dash *et al.* (2009) conducted a study on changes in the characteristics of rain events in India over a long duration of 54 years (1951–2004). The weather parameters were analysed to find the changes in the frequency of rain events in India in terms of their duration and intensity per day. The result showed that frequencies of moderate and low rain days have significantly decreased over the last half century. The long spells show a significant decreasing trend and dry spells show an increasing trend over a period of time. This study also revealed that the summer monsoon circulation has reduced over India.

A study was conducted on trend analysis of Indian summer monsoon rainfall at different spatial scales over a large region (Ghosh *et al*., 2009). The study was conducted to analyse the summer monsoon rainfall all over India and also to find out the places in India having significant trend in both rainfall occurrence and amount. The trend was detected and estimated using MK test and Sen's slope estimator respectively. The results showed that there is an increasing trend of occurrence of heavy rainfall and decreasing trend of occurrence of moderate rainfall. The present study also revealed that there is a spatially varying mixed responses of global warming toward rainfall occurrence and amounts all over India.

Ajayamohan *et al*. (2010) undergo a study on increasing trend of synoptic activity and its relationship with extreme rain events over Central India is investigated by using a long record of the paths and intensities of monsoon synoptic disturbances. The results showed that there was a strong correlation between extreme rain events and synoptic index such that both showed an increasing trend. The results also revealed that synoptic activity increased from a rising trend in relatively weak low pressure systems.

Bhutiyani *et al*. (2010) conducted a study on climate change and the precipitation variations in the north western Himalaya over a long period of 140 years (1866 to 2006). The long term trends of SPI (Standardized Precipitation Index) and STI (standardized temperature index) series were analysed by using standard parametric and nonparametric statistical techniques, such as linear regression analysis and the Mann–Kendall (MK) test. The power spectrum analysis was used to determine periodicity and the cubic spline method is used for data smoothing. The result showed that there was no trend in the winter precipitation but there was a significant decreasing trend in the monsoon precipitation. The results also revealed that there was a significant increasing trend in annual temperature in all three stations. It was also identified that there was a strong negative relationship between mean winter air temperature and snowfall amounts recorded at different meteorological stations in this period.

A study was underwent on analysis of long-term rainfall trends in India over a long period of 135 years (1871–2005) (Kumar *et al*., 2010). The monthly rainfall data is collected from 30sub-divisions of India from which monthly, seasonal and annual trends of rainfall have been studied. The non-parametric test MK test was used for detection of the trend. The results showed that annual and monsoon rainfall decreased whereas pre-monsoon, post-monsoon and winter rainfall increased at the national scale. The results also revealed that the five main regions of India showed no significant trend in annual, seasonal and monthly rainfall in most of the months.

Joshi and Pandey (2011) conducted a study on trend and spectral analysis of rainfall over India during 1901–2000. The data is obtained from 1384 rain gauge stations by the Indian meteorological department from which spectral analysis of gridded rainfall is done for four sub regions, namely, southwest, southeast, central, and northwest for a long duration of 100 years. The results showed that the significant cycles lie in between the periods 10–20 days, 20–30 days, 30–40 days, and 40–50 days and are highly variable on an inter decadal basis. No significant trend was obtained when the linear least squares fitting method and Mann-Kendall test were applied to the annual rainfall data for whole India and sub regions.

A study was underwent on trend analysis of rainfall in Bharathapuzha river basin, Kerala, India (Nikhil and Azeez, 2011). The data of general rainfall pattern in Bharathapuzha River basin of Malabar coast of Kerala was collected over a long duration of 34 years from 28 rain gauge stations. The trend of rainfall was analysed by using Mann Kendal's rank correlation statistics and wavelet analysis. The results showed that there was a significant decrease in annual rainfall, southwest monsoon, and pre-monsoon rainfall of the basin.

A study was conducted on trend analysis of long term weather variation in mid altitude Meghalaya, North East India over a long duration of 27 years (1983-2010) (Choudhury *et al*., 2012). The weather parameters were analysed by non-parametric Mann Kendall test to detect the trend changes. The results showed that total annual rainfall increased non-significantly at the rate of 3.72mm per year. Maximum temperature showed a significant rising trend (+ 0.0860°C per year) whereas minimum temperature showed a non-significant decreasing trend (-0.0110°C per year). Mean temperature also manifested a significant rising trend at an annual rate of 0.0310 °C.

A study was underwent on trend analysis of rainfall and temperature data for India (Jain and Kumar, 2012). The trend was estimated by using Mann-Kendall test and magnitude is estimated by using Sen's slope. The trend analysis showed that there is a decreasing trend in annual rainfall for 15 basins where only one basin showed significant decreasing trend at 95% confidence level. The result also showed that among six basins showing increasing trend, one basin showed significant positive trend. The mean maximum temperature showed a rising trend, annual mean temperature showed a falling trend whereas the mean minimum temperature showed a rising as well as a falling trend.

A study was underwent on time series analysis by exploring the relationship between climate change and rice yield in Bangladesh (Sarkar *et al*., 2012). In this study the data was collected for a period of 1972-2009 to assess the relationship between climate variables and rice yield using ordinary least squares and regression methods. The increase in maximum temperature has a positive effect on the rice yield whereas the increase in minimum temperature has a negative effect on rice yield. The result also revealed that the rainfall also showed a significant effect on rice yield.

A study was underwent on review of trend detection methods and their application to detect temperature changes in India (Sonali and Kumar, 2013). The present study focussed on the spatial and temporal analysis annual, monthly and seasonal maximum and minimum temperature in India. The trends in annual, monthly, winter, pre-monsoon monsoon and post-monsoon extreme temperatures had been analysed for three time slots viz, 1901-2003, 1948-2003 and 1970-2003 over seven homogenous regions and India as a whole. The result showed that there was a significant trend in minimum temperature for all seven regions and India as a whole for the past three decades all over India.

Chakraborty *et al*. (2013) conducted a study on trend and variability analysis of rainfall series at Seonath River Basin, Chhattisgarh. The spatial and temporal variability of rainfall at Seonath sub basin in Chhattisgarh State have been studied for a long period of 49 years (1960-2008).The trend was detected using Mann-Kendall (MK) or Modified Mann-Kendall (MMK) (nonparametric) and Spearman's rho test (parametric) and magnitude is estimated by using Sen's slope. The results showed that there was a decreasing trend found in annual and seasonal rainfall series for the whole river basin. The maximum decreased annual rainfall was found for Bodala station (-13.8mm/year) and minimum at Simga station (0.1mm/year).

Mandal *et al*. (2013) undergo a study on trend analysis of weather variables in Sagar Island, West Bengal, India over a period of 28 years (1982–2010). The trend of rainfall data was analyzed by using the Mann–Kendall test. The results showed that the island experienced a decreasing trend in mean annual (–5.79 mm year–1) and seasonal (monsoon and post-monsoon months: –3.84 to –4.42 mm year–1) rainfall, with an increase in pre-monsoon rainfall. The results also revealed that there is a significant rising trend in mean maximum and average temperature, and a declining trend in minimum temperature. These results indicated that during the post monsoon months, water scarcity would increase further and all these changes and interaction among them would influence the vulnerability of the island to climate change.

Madsen *et al*. (2014) conducted a study on the trend analysis and climate change projections of extreme precipitation and floods in Europe. The analyses of extreme precipitation and flood records show that there is a slight increase in extreme precipitation. The results showed that there is no significant trend in large-scale regional or national level of extreme streamflow. The results also revealed that future changes based on climate projections indicates a general increase in extreme precipitation under a future climate.

A study was underwent on spatial and temporal analysis of rainfall and temperature trend of India (Mondal *et al*., 2014). The climate change in rainfall for 141 years (1871–2011) and temperature for 107 years (1901–2007) for different parts of the country were analysed to find out the annual, seasonal and monthly changes in different regions of India. The Mann-Kendall test was used to identify the rainfall and temperature trend and magnitude of the trend was obtained by using Sen's slope estimator. The break point detection in the series was obtained by using Mann-Whitney-Pettitt (MWP) test. The results showed that there was a decreasing trend in both annual and monsoon rainfall and the minimum temperature, maximum temperature and mean temperature were showing a significant increasing trend particularly in the winter and post-monsoon time.

Murumkar and Arya (2014) conducted a study on trend and periodicity analysis in rainfall pattern of Nira basin, Central India over a long period of 104 years. The trend and periodicity for the seasonal and annual rainfall data of Akluj, Baramati, Bhor and Malshiras stations were analysed by using Mann-Kendall (MK), Modified Mann- Kendall (MMK). Theil and Sen's slope estimator used to determine the magnitude of the rising trend. The results showed that Bhor station showed the maximum increase in percentage change i.e. 0.28% in annual rainfall. The results also revealed that monsoon and post-monsoon seasonal rainfall depicted an increasing trend while the summer and winter seasonal rainfall showed a decreasing trend.

Pranuthi *et al*. (2014) conducted a study on trend and change point detection of precipitation in urbanizing districts of Uttarakhand in India. The monthly, seasonal and annual rainfall data was collected from Haridwar, Dehradun, Udham Singh Nagar, Almora and Nainital where the long-term trends were analysed by using Mann–Kendall test and linear regression tests. The change point was estimated by using both cumulative deviation and Worsley likelihood statistic. The results showed that there is a significant increase in rainfall only for Haridwar district. The monthly trends test showed that July rainfall is increasing whereas December rainfall is decreasing due to the seasonal shift.

A study was conducted on statistical analysis for change detection and trend assessment in climatological parameters (Jaiswal *et al*., 2015). The analysis of change detection and trend on monthly, seasonal and annual historical series of different climatic variables of Raipur have been carried out. The Pettitt's test, von Neumann ratio test, Buishand's range test and standard normal homogeneity (SNH) test were used to analyse the change detection whereas non-parametric tests including linear regression, Mann-Kendall and Spearman rho tests have been applied for trend analysis. The results showed that the annual series of minimum temperature, wind speed, sunshine hour showed significant change points, while evaporation indicated a doubtful case and maximum temperature confirmed the homogeneity at 95 % confidence level. The change point analysis showed different change points from 1990 to 2000, with maximum change points in and around 1995. The results also revealed that the annual minimum, maximum temperatures and relative humidity showed a rising trend but the pan evaporation showed a falling trend.

Meena *et al*. (2015) investigated long term trend analysis of mega cities in northern India using monthly rainfall data collected from 17 megacities in India over a period of 111 years (1901-2011). The trend of historical rainfall data was analysed by using the Mann–Kendall test. The magnitude of the data was estimated by Sen's slope estimator. The results showed that there was an increasing trend in Jaipur, Jodhpur, Faridabad, Meerut, Ghaziabad, Delhi, Chandigarh, Ludhiana, Amritsar, Srinagar whereas decreasing trend in Allahabad, Varanasi, Patna, Kanpur, Gwalior and Agra. No trend was observed in Kota. The monsoon rainfall showed a decreasing trend in most of the regions of north India. The result also revealed that monsoon rainfall serves the major water demand for agriculture and water resources. The rainfall variability percentage showed the highest increasing percentage in Delhi (32.43%) and lowest increasing percentage in Patna (- 16.22%).

Chandniha *et al*. (2016) underwent a study on trend analysis of precipitation in Jharkhand State, India where the spatial and temporal variability in precipitation was estimated over a period of 111 years (1901–2011) from 18 meteorological stations. The long term trends were analysed by using Autocorrelation and Mann–Kendall/ modified Mann–Kendall tests and the magnitude of changeover is determined by using the Theil's and Sen's slope estimator test. The Pettitt–Mann–Whitney test was used to determine the most probable change year. The results obtained using R software showed that annual precipitation exhibited a decreasing trend in 5 out of 18 stations and also the slope test for annual, monsoon and winter periods of precipitation showed a decreasing trend for all stations during 1901–2011. The results also revealed that the highest variability was observed in post-monsoon precipitation (77.87%) and the lowest variability was observed in the annual series (15.76 %) over the 111 years.

Pingale *et al*. (2016) studied the trend analysis of climatic variables in an arid and semi-arid region of the Ajmer district, Rajasthan, India were the trends and variations in climatic variables analysed on seasonal and annual time scales. The study was conducted for a period of 100 years by using non-parametric statistical techniques, i.e. the Mann–Kendall (MK) and Modified Mann–Kendall (MMK) tests. The temporal shift in climatic series was detected by using the Pettitt–Mann–Whitney (PMW) test. The results revealed that annual and seasonal rainfall did not show any statistically significant trend at a 10% significance level whereas wet day frequency, surface temperature and reference evapotranspiration showed a noticeable increasing trend. The results also revealed that there was a statistically significant decrease in maximum temperature found during the non-monsoon season by the MK–PW test.

Swain *et al*. (2015) conducted a study on trend analysis of monthly rainfall for Raipur district, Chhattisgarh for the period of 102 years that is from 1901 to 2002. The trend of rainfall data was analysed by using the Mann–Kendall test. The magnitude of the data was estimated by Sen's slope estimator. The results showed a significant decrease for the months of Southwest monsoon i.e. June, July, August and September, thereby inferring a consequent decrease in annual rainfall.

A study was conducted on trend analysis and ARIMA model for forecasting precipitation patterns in the Wadi Shueib catchment area in Jordan (Al Balasmeh *et al*., 2019). In this study daily precipitation data was collected for a period of 44 years from 5 gauging stations and it was used for finding the trend and prediction of precipitation for the water deficit area of Wadi Shueib. Mann–Kendall (MK) test with Sen's slope estimator and innovative trend analysis (ITA) were carried out for monthly, average, and seasonal data. The MK test using R software detected no trend except at two stations whereas ITA method detected trends at all stations. The changes in precipitation was predicted by using Box–Jenkins forecasting method and ARIMA model. The results revealed that the heavy rain is depleting at all stations and normal rain is increasing, except in the month of December, which shows a positive trend.

2.2 MODELLING OF WEATHER PARAMETERS

Chattopadhyay and Chattopadhyay (2010) underwent a study on univariate modelling of summer and monsoon rainfall over India for a period 1871-1999. The trend and stationarity of the summer and monsoon rainfall are identified. The result revealed that the ARIMA (0,1,1) model selected as the best model for rainfall.

A study was conducted on modelling and predicting the monthly rainfall in Tamilnadu as a seasonal multivariate process (Nirmala and Sundaram, 2010). In this study the rainfall data is collected for the preparation of a suitable time series model for the prediction of monthly rainfall of Tamilnadu. The Box-Jenkins model is used for making the ARIMA model for the rainfall data.

A study was conducted on modeling of weather parameters using stochastic methods Abadeh region, Iran (Shamsnia *et al*., 2011). In this study ITSM time series analysis software was used for analysing the 20 years statistics of relative humidity, monthly average temperature and precipitation of Abadeh Station. The results revealed that ARIMA (0 0 1) (1 1 1)12 was the best precipitation model, seasonal ARIMA (2,1,0)(2,1, 0)12 is the best monthly average temperature and ARIMA (2,1,1) (1,1,0)12 was the best for precipitation model.

Tanusree and Kishore (2012) conducted a research on the time series analysis of Dibrugarh air temperature. The study was undergone by collecting the data of the air temperature for a period of 1981–2010 in the Dibrugarh city of Assam. The main aim of the research was time series modelling of the average monthly mean temperature. The results showed that seasonal ARIMA (0,0,1) (0,1,1)12 model was found adequate and this model is used to forecast the monthly temperature.

Narayanan *et al*. (2013) conducted a study on trend analysis and ARIMA modelling of pre-monsoon rainfall data for western India. The Mann-Kendall test was used to identify the rainfall trend in the pre-monsoon period. The results showed that there is a significant trend in two stations; Ajmer and Bikaner. The magnitude of the rainfall trend is measured using Theil and Sen's median slope estimator. The ARIMA model for pre-monsoon months showed that there is a significant rise in the pre-monsoon rainfall for the North-West part of India.

A study as underwent on spatial-temporal analysis and simulation of recent temperature and rainfall data using GIS and time series analysis model climate change in Bangladesh (Rahman and Lateh, 2015). In this study the temperature and rainfall data were collected from 34 meteorological stations over a period of 40 years (1971 to 2010). The trends, variability and spatial patterns of temperature and rainfall were analysed through linear regression, coefficient of variation, inverse distance weighted interpolation techniques and geographical information systems. The temperature and rainfall data were simulated using the ARIMA time series model. The result showed an increasing trend for both minimum (range of 0.80–2.4°C) and maximum temperature (range of 1.20–2.48°C) respectively. The result also revealed that there was a decreasing trend for the annual rainfall observed during this period.

Papalaskaris *et al*. (2016) underwent a study on time series modelling and forecasting of stochastic monthly rainfall in Kavala city in Greece. The model applied for the rainfall was Box-Jenkins seasonal ARIMA methodology. The selection of best model was based on least AIC (Akaike’s Information Criterion), BIC (Bayesian Information Criterion) and SBC (Schwarz’s Bayesian Criterion) values. The results revealed that the best model determined for the rainfall was seasonal ARIMA (0,0,0)(0,1,1)12 model.

Goswami *et al*. (2017) conducted a study on monthly temperature prediction based on the ARIMA model in Dibrugarh station of Assam, India. The study was undergone for a period of 50 years (1966-2015) to develop a Seasonal Autoregressive Integrated Moving Average (SARIMA) model to long term temperature data of Dibrugarh, Assam. The results showed that SARIMA(2,1,1)(0,1,1)12 is the best model for monthly maximum and SARIMA(2,1,1)(0,1,1)12 is the best model for monthly minimum temperature data respectively.

A study was undergone on modelling and forecasting rainfall patterns of south west monsoons in North East India (Murthy *et al*., (2017). The model identification, diagnostic checking and forecasting was done with the help of Box-Jenkins seasonal ARIMA methodology using Gretl an open source software. The results revealed that seasonal ARIMA (0,1,1)(1,0,1) was the best model identified for the south west monsoon rainfall in north India.

Praveen and Sharma (2017) conducted a study on climate variability and its impacts on agriculture production and future prediction using the ARIMA model. In this study the data was collected for 50 years from (1967–2016) with 15 crops across India which was used to study the impacts of climate variation on land productivity for major

Indian food and non-food grain crops. The results showed that a rise in annual mean temperature decreased the land productivity. The ARIMA model was used for forecasting for 20 years. The result showed that the increase in rainfall and temperature increase the production of gram, sesamum, jowar, groundnut, sugarcane, and bajra whereas decrease in the production of arhar, wheat, rice, cotton, and tea.

Karmakar *et al*. (2018) underwent a study on the assessment of rainfall patterns using ARIMA technique for Pachmarhi region, Madhya Pradesh, India. The main aim of the study was forecasting the rainfall in the Pachmarhi region by collecting and analysing the rainfall data of 18 years (2000 to 2017). The ARIMA model was applied on the data and the rainfall for next five years was predicted.

A study was conducted on development of an ARIMA model for monthly rainfall forecasting over Khordha district, Orissa (Swain *et al.*, 2018). In this study the monthly rainfall data was collected over a period of 1901-2002 which was used to develop the ARIMA model for predicting the monthly rainfall. The result showed that ARIMA (1,2,1)(1,0,1)12 is the best model fit for the monthly rainfall data and the model was outstanding since it can predict accurately the monthly rainfall for next 20 years.

Murthy *et al*. (2018) underwent a study on stochastic modelling of the monthly average maximum and minimum temperature patterns in India 1981–2015. The modelling for both maximum and minimum temperature was done with the help of seasonal ARIMA models using “Gretl” an open software. The box plots and cumulative distribution function are used for determining the variations and distribution of monthly maximum and minimum temperature. The minimum Bayesian information criteria was used for the selection of the best model for both maximum and minimum temperature. The result showed that the Seasonal ARIMA model (1,0,0)(0,1,1)12 was selected as the best model for both maximum and minimum temperature. The diagnostic checking of the best model was done with the help of ACF, PACF and P value of Ljung–Box test statistic of residuals.

2.3 IMPACT OF WEATHER PARAMETERS ON RICE PRODUCTION.

Matthews *et al*. (1997) conducted a study on simulating the impact of climate change on rice production in Asia and evaluating options for adaptation. In this study the impacts of climate change on rice production in Asia were evaluated using two rice crop simulation models, ORYZAI and SIMRIW. The results showed that an increase in Carbon dioxide level was found to increase yields while increases in temperature reduce the yields. The result also revealed that the rice production in the Asian region may decline by -3.8% in the next century due to climate change.

A study was underwent on vulnerability of rice and wheat yields in North West India to future changes in climate (Lal *et al*., 1998). In this study the effect of the climate change on vulnerability of wheat and rice crops in northwest India is examined. The models adopted for the study were CERES wheat and rice models. The results showed that the wheat crops are found to be sensitive to increase in maximum temperature, the rice crops are vulnerable to increase in minimum temperature. The result also revealed that shortage of water led to adverse effects on wheat and a more severe effect on rice productivity in North West India.

Saseendran *et al*. (2000) conducted a study on effects of climate change on rice production in the tropical humid climate of Kerala, India. The CERES-Rice v3 crop simulation model was used for analysing the effect of climate change on rice productivity in the state. The result showed that there is an increase in monsoon seasonal mean surface temperature of the order of about 1.5◦C, and an increase in rainfall of the order of 2 mm per day, over the state of Kerala in the decade 2040–2049 with respect to the 1980s. The results also revealed that the rice maturity period is projected to shorten by 8% and yield increase by 12%.The temperature sensitivity experiments have shown that for a positive change in temperature up to 5◦C, there is a continuous decline in the yield.

Aggarwal and Mall (2002) conducted a study on climate change and rice yields in diverse agro-environments of India and effect of uncertainties in scenarios and crop models on impact assessment. In this study the impact of various climate change scenarios has been assessed on grain yields of irrigated rice with two popular crop simulation models- Ceres-Rice and ORYZA1N at different levels of N management. The results showed that the direct effect of variation in climate on crops in different agro-climatic regions in India would always be positive irrespective of the various uncertainties.

Thomas (2002) underwent a study on problems and prospects of paddy cultivation in Kuttanad region of Kerala. The results revealed that there had been a complete shift in agriculture over the years from food crops to garden crops. The area for cultivation of arecanut, cashew and coconut has increased over the years on expense of food crops.

A study was conducted on the impact of climate change on Indian agriculture. In this study the impact of climate change on agricultural production and food security using the crop simulation model (Mall *et al*., 2006). The results showed that simulation models can be used to make appropriate crop management decisions and to provide farmers and others with alternative options for their farming system. The results also revealed the impacts of climate change on yield of crops.

Yao *et al*. (2007) underwent a study on assessing the impacts of climate change on rice yields in the main rice areas of China. In this study the impact of climate change on irrigated paddy yield was determined using RCM (Regional and Climate Model) and CERES (Crop Estimation through Resource and Environment Synthesis) model. The results showed that the climate change scenario has a negative impact on rice yield.

Aggarwal *et al*. (2008) conducted a study on global climate change and its impacts, adaptation and mitigation of Indian agriculture. In this study the effect of climate change on the Indian agriculture was assessed. The result revealed that climate change has increased crop damage due to pests and diseases. The increase in temperature and carbon dioxide concentration also affect the crop growth. Simple adaptation strategies like change in planting dates and tolerant varieties could help in reducing impacts of climate change on a certain extent. The other strategies include development of climate tolerant genotypes, specific land use systems, climate risk management for farmers, improved land use policies, early warning systems and crop insurance.

A study was underwent on climate change, the monsoon, and rice yield in India. In this study the rainfall and rice data was collected for a period from 1966–2002 which was used to determine the effect of flood and drought on rice crop yield (Auffhammer *et al*., 2012). The results showed that that yield would have been 1.7% higher on average if monsoon was not often such that drought showed a significant negative effect on rice yield which is much greater impact than extreme rainfall (flood). The result also revealed that there would be an increase of 4% in the rice yield if there were no warmer nights and lower rainfall at the end of the growing season.

Bindi *et al*. (2015) undergone a study on modelling the impact of climate change on crop production for food security. The results revealed improved crop modelling in integrated assessment of risk and sustainability and crop resilience in order to face the climate change required to overcome the obstacles faced in crop production.

Singh and Sharma (2018) conducted a study on measuring the productivity of food-grain crops in different climate change scenarios in India taking evidence from time series investigation. In this study time series analysis was undergone for a period of 30 years (1980-2010) where the Cobb-Douglas production function model was used to investigate the climate change impact on food-grain productivity in India. The food-grain production/hectare land is used as a dependent variable that is regressed with different socio-economic and climatic variables. The results revealed that increase in maximum and minimum temperature, and change in rainfall pattern have a negative and significant impact on productivity of rice, arhar, bajra, jowar, wheat, ragi, gram and barley crops. The results also showed that productivity of crops are likely to be declined significantly by 2025, 2040, 2050, 2075 and 2100 in different climate change scenarios in India.

Abraham (2019) underwent a study on paddy cultivation in all the districts of Kerala and identified the trend in area, production and productivity at district level. The result showed that area and production of paddy was decreasing over the years. The lowest decrease in yield and production was at Palakkad district whereas the highest reduction of yield and production was at Kollam district. The study also concluded that inefficient land use policy led to the food insecurity and reduction of agriculture activities in Kerala.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

The present study was conducted under the objective of developing suitable statistical models to evaluate climate change overtime across different regions of northern and central Kerala and also to determine the effect of climate change on paddy production. The different methods adopted and brief description about the data collected for the study is presented in this chapter. This chapter is subdivided in to following headings.

3.1 AREA OF THE STUDY

The present study was mainly focused on applying various statistical methods to model the change and variation of weather parameters over the years based on meteorological data collected from different meteorological stations in northern and central regions under KAU. The meteorological weather data consist of rainfall, maximum temperature and minimum temperature. This data was collected from RARS Pilicode which belongs to the Kasaragod district, northern region of Kerala. The latitude and longitude of Pilicode is 12.1997°N and 75.1633°E. The altitude of Pilicode is 11m above the sea level. The weather data was also collected from RARS Pattambi which belongs to the Palakkad district, central region of Kerala. The latitude and longitude of Pattambi is 10.8027°N and 76.1957°E. The altitude of Pattambi is 63m above the sea level. The secondary data on paddy production of Palakkad district was collected and regressed with weather parameters in order to determine the influence of climate change over the years.

The data which includes rainfall, maximum temperature and minimum temperature was collected from RARS Pilicode over the period 1983-2018 and RARS Pattambi over the period 1982-2018 respectively. The secondary data on season wise unirrigated and total (irrigated and unirrigated) paddy production of Palakkad district was also collected from a report on agriculture statistics, GOK over a period of 23 years (1995-2017). The paddy production data was expressed in tonnes, rainfall in millimetres (mm) and maximum and minimum temperature in degree Celsius (℃).

3.2 DESCRIPTIVE STATISTICS

The different descriptive statistical measures like range, mean, standard deviation coefficient of variation, skewness and kurtosis were calculated for each month for the collected data.

3.2.1 Range

The range of a data set is the difference between the highest and the smallest value in the data set. The unit of range is the same as that of the data set.

Range = Maximum value – Minimum value

3.2.2 Mean

The mean is a measure of central tendency which is defined as the value obtained by dividing the sum of all observations by the total number of observations. The mean is the rigidly defined measure of central tendency which is based on all observations and is also affected by extreme observations.

$$\text{Mean} = \frac{\text{Sum of all observations}}{\text{Total no of all observation}}$$

$$\text{ie.,} \quad \bar{X} = \frac{\sum_{i=1}^{n} Xi}{n} \qquad 3.1$$

3.2.3 Standard Deviation

The Standard deviation is the measure of dispersion which is defined as the square root of the mean of the squared difference of all observations from the mean. The Standard deviation helps to determine the spread of the data about the mean value. It is helpful in analyzing the sets of data which may have similar mean but unequal ranges. It is calculated as the square root of variance by determining the variation between each data point relative to the mean.

$$\sigma = \sqrt{\frac{\sum(X-\bar{X})^2}{N}} \qquad 3.2$$

Where $\sigma -$ standard deviation, $\overline{X}$ - Mean and N is the number of observations

3.2.4 Coefficient of Variation (CV)

Coefficient of Variation (CV) is a relative measure of dispersion which is defined as the ratio of the standard deviation to the mean expressed in percentage. It is a unit free measure which is used to determine the degree of variability several data set. The higher the CV, less precise the data since it widens the acceptable range within the deviation.

$$CV = \frac{\sigma * 100}{\overline{X}} \qquad 3.3$$

3.2.5 Skewness

The skewness is the measure of asymmetry of the probability distribution of a real valued random variable about its mean. The value of skewness can be positive, negative or zero. Negative skewness indicated that the left tail was longer, and also the mean of the lies on the left side of the data. In negatively skewed distribution mean, median and mode will be in ascending order of magnitude. Positive skewness indicated that the right tail was longer, and also the mean was on the right side of the data. In a positively skewed distribution mean, median and mode will be descending order of magnitude. Zero skewness indicates that asymmetry is absent or the curve is symmetrical which indicates that probability distribution of the data is normal. In asymmetric distribution mean, median and mode are equal. The right side and left side of symmetric curves are equal.

$$\text{Skewness} = \frac{\text{Mean} - \text{Mode}}{Standard\ deviation}$$

$$\text{Skewness} = \frac{\overline{X} - v}{\sigma} \qquad 3.4$$

Where $\overline{X}$ – Mean, v – Mode and σ – Standard deviation

3.2.6 Kurtosis

The kurtosis is a measure of the peakedness of the probability distribution of a real valued random variable. The kurtosis value of normal distribution is 3 which indicated that the curve is a mesokurtic curve. If the kurtosis value was greater than 3 it indicated that the curve is more peaked, that is the curve is leptokurtic. If the kurtosis value was less than 3 it indicated that the curve was flat which was called a platykurtic curve. The kurtosis can be also defined as the ratio of fourth central moment and square of the variance of the data.

$$\text{Kurtosis} = \frac{\mu_4}{(\sigma^2)^2} \qquad 3.5$$

Where $\mu_4 = E(X - \mu)^4$ and $\sigma^2 - \text{Variance}$

3.3 TIME SERIES DATA

The time series data consisted of a sequence of numerical data points arranged in a sequential order. The time series evaluates the development of the data points at regular intervals over a specific period. The time series data used to determine the changes associated with the data points during a definite period of time. Time series consist of four components:

3.3.1 Trend

The trend is the component of a time series that indicates deviation of low frequency in a time series by filtering the high and medium frequency fluctuations. The general tendency of the data to increase or decrease over the time was detected by the trend. A trend is a smooth, general, long-term, average tendency. It is not always necessary that the trend follow the same direction throughout the given period of time.

3.3.2 Seasonality

The seasonality in time series data indicate the changes that occur at particular intervals less than a year, such as weekly, monthly, or quarterly. Seasonal fluctuations in a time series can be contrasted with cyclical patterns. It can also be described as the recurring short-term cycle in the series. Seasonality is an attribute of a time series in which the data experiences routine and expected changes that are repeated every calendar year. Any expected deviation or pattern that recurs or repeats over a one-year span is forenamed to be seasonal.

3.3.3 Irregular variation

Irregular variations or random variations constitute one of four components of a time series. It corresponds to the shifts that occur randomly and generally during a short span. Irregular variations don’t follow a specific model and they can’t be forecasted.

3.3.4 Cyclical variation

The oscillatory developments in the time series with the span of more than one year are called the cyclical variation. The word 'cycle' refers to the period of affluence and depression, ups and downs, booms and slumps of a time series, most commonly seen in business cycles.

3.4 TREND ANALYSIS

The trend analysis is used to identify the increasing or decreasing trend for the weather parameters like rainfall, maximum temperature and minimum temperature using different methods. If the time series data follows normal distribution, regression with ordinary least square method can be used for detecting the trend by identifying the slope of regression line but if the data didn’t follow normal distribution non-parametric tests can be used. The presence of increasing and decreasing trends in the weather data were carried out using the Mann-Kendall test whereas the magnitude and nature of the trend is estimated by using the Sen’s slope estimator.

3.4.1 Test for Normality

The Shapiro-Wilk test is a semi-parametric test which is used for detection of the normality of the data before undergoing parametric or non-parametric test.

H_o: The data follows normal distribution

H_1: The data doesn't follow normal distribution

Test statistic for Shapiro-Wilk test is

$$W= \frac{(\sum_{i=1}^{n} a_i x_i)^2}{\sum_{i=1}^{n}(x_{i-}\bar{x})^2} \qquad 3.6$$

Where x_i represent the observations, $\bar{x}$ is the mean of observations

The coefficients of a_i are expressed as

$$(a_1, a_2, \dots, a_n) = \frac{m^T V^{-1}}{C} \qquad 3.7$$

Where V is the variance covariance matrix, C is the vector norm and m is a vector

$(m_1, m_2, \dots, m_n)^T$ is the expected values for the independent and identically distributed random variables.

3.4.2 Mann-Kendall Test

The Mann-Kendall test is a non-parametric test used for determination of linear and the non-linear trends as well as the turning point of the distribution by using the Kendall test statistics. The Mann-Kendall method (MK) is used to detect the trend in a time series data without fixing whether the trend is linear or nonlinear. It has been established to be an outstanding tool for trend identification and many researchers have successfully used this test to assess the significance of trends in hydro-climatic time series such as water quality, stream flow, temperature and precipitation (Sethi *et al.*, 2015). The nonparametric MK test is applied to a time series were x_k ranked from k = 1, 2 . . . n – 1 and x_j ranked from j = k + 1, 2. . . n. Each data point x_k is used as a reference point and is compared with all other data points x_j such that,

$$sgn\left(x_j - x_i\right) = \begin{bmatrix} 1, & if\left(x_j - x_k\right) > 0 \\ 0, & if\left(x_j - x_k\right) = 0 \\ -1, & if\left(x_j - x_k\right) < 0 \end{bmatrix} \qquad 3.8$$

The MK test statistic, S is given below;

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n=1} sgn\left(x_j - x_k\right) \qquad 3.9$$

Where, sgn (x_j–x_k) is the sig num function. The test statistic, S is assumed to be asymptotically normal, with E(S) = 0 for the sample size n ≥ 8 and variance as follows:

$$\mathrm{V(S)} = \frac{\left[\mathrm{n\,(n-1)(2n+5)} - \sum_{t_i} t_i\,(t_i-1)(2t_i+5)\right]}{18} \qquad 3.10$$

Where, t_i denotes number of ties up to sample i. The standardized MK test statistics Z_{mk} is estimated as follows:

$$Z_{mk} = \begin{cases} \frac{S-1}{\sqrt{V(S)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{V(S)}} & if\ S < 0 \end{cases} \qquad 3.11$$

The standardized MK test statistics (Z_{mk}) follows the standard normal distribution with mean of zero and variance of one (Siraj *et al*., 2013). If $\pm Z_{mk} \leq Z_{1-\alpha/2}$ (here α = 0.1, 10 percent instead of usual 5 percent since most of the weather parameter showed significant at 10 percent level of significance), then null hypothesis for the no trend is accepted in a two sided test for trend and the null hypothesis for the no trend is rejected if $\pm Z_{mk} \geq Z_{1-\alpha/2}$ (Kundu *et al*., 2014). Failing to reject H_o *i.e.* null hypothesis does not mean that there is no trend. Rather, it is a statement that the evidence available is not sufficient to conclude that there is a significant trend. A positive sign of Z_{mk} indicates an ‘upward trend’ and negative sign indicates ‘downward trend’ (Pingale *et al*., 2016). For 5 percent and 10 percent level of significance, the critical value $Z_{1-\alpha/2}$ from the Standard Normal Table is 1.96 and 1.645 respectively. The significance levels (*p*-values) for each trend test can be obtained from,

$$p = 0.5 - \varphi(|Z_{mk}|) \qquad 3.12$$

Where (φ) denotes the cumulative distribution function (cdf) of a standard normal variate. If P value is less than 0.05 then present trend is significant at 5% level of significance whereas at the significance level of 0.1, if $p \leq 0.1$, then the existing trend is considered to be statistically significant.

3.4.3 Sen's Estimator of Slope

If a linear trend is present in a time series, then the true slope of trend can be estimated by using a simple non-parametric procedure. The slope estimates is computed by:

$$Q_i = median\left\{\frac{x_j - x_k}{j-k}\right\} \forall\, k < j \qquad 3.13$$

Where x_j and x_k are data values at times *j* and *k* ($j > k$) respectively. The median of N values of Q_i is Sen's estimator of slope. If N is odd, then Sen's estimator is computed by Q_{med} = $Q_{(N+1)/2}$ and if N is even, then Sen's estimator is computed by Q_{med} = [$Q_{N/2}$+ $Q_{(N+2)/2}$]/2 (Sharma *et al*., 2016). Finally, Q_{med} is tested by a two-sided test at 100 (1-α) % confidence interval and the true slope may be obtained by the non-parametric test (Meshram *et al*., 2017).

After the decomposition of time series, the trend analyses followed by smoothing tools like exponential smoothing or moving average prior to the modelling of the time series data.

3.5 MODELLING OF TIME SERIES DATA

Time series model frequently used for time series analysis for predict the future values or for the better interpretation of the data. These models are applied on the data which is non-stationary. The non-stationary can be removed by an initial difference step and by repeating it one or more times.

3.5.1 Auto Regressive (AR) model

In an autoregressive model a value from a time series is regressed on preceding values of the same time series. The response variable in the preceding time period has become the predictor and the errors have the same assumptions as in simple linear regression models.

Let $\{Y_t\}; t = 1,2,3 \ldots, N$ express a time series data of N period of time. Assume that μ is the mean of Y. Then Y_t follows a first order Auto Regressive AR stochastic process if Y_t is modeled as;

$$(Y_t) = \mu + \varphi_1 Y_{t-1} + e_t \qquad 3.14$$

Where e_t is the independent random error with mean = 0 and variance = σ^2

In general, the AR model is represented as

$$(Y_t) = \varphi_1 Y_{t-1} + \varphi_2 Y_{t-2} + \ldots\ldots + \varphi_p Y_{t-p} + e_t \qquad 3.15$$

The AR model can be also written by including back shift operator (B) as

$$\varphi(B) Y_t = e_t \qquad 3.16$$

$$\varphi(B) = 1 - \varphi_1 B - \varphi_2 B^2 - \cdots - \varphi_p B^p \qquad 3.17$$

3.5.2 Moving Average (MA) model

The moving average model or moving-average process, is a simple accession for modelling the univariate time series. Opposite to the AR model, the finite MA model is always static. The output of moving-average model consist of a white noise input (e_t) and transient response (θ_q).

Let $\{Y_t\}; t = 1,2,3 \ldots, N$ express a time series data of N period of time. Assume that μ is the mean of Y. Then Y_t follows a first order Moving Average (MA) if Y_t is modeled as;

$$Y_t = \mu + e_t + \theta_1 e_{t-1} \qquad 3.18$$

Where μ is a constant or mean. In general, MA process is defined as

$$Y_t = \mu + e_t + \theta_1 e_{t-1} + \cdots + \theta_q e_{t-q} \qquad 3.19$$

MA process depends only on the error term e_t, which is the moving average of the present and the past error terms.

The MA model can be also written by including back shift operator (B) as

$$Y_t = \theta(B) e_t \qquad 3.20$$

$$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_q B^q \qquad 3.21$$

3.5.3 Autoregressive moving average (ARMA) model

The ARMA model is an application for perceiving and forecasting the future value of the time series. It consists of two parts, AR part which is engaged with regressing the variable on its own past values and MA part associated with the modelling of linear combination of error terms appearing simultaneously in the preceding time periods.

The autoregressive moving average model expressed as ARMA (p,q) where p stands for autoregressive part and q stand for moving average part. The ARMA model can be written as

$$Y_t = \mu + e_t + \sum_{i=1}^{p} \varphi_i (Y_{t-i}) + \sum_{i=1}^{q} \theta_i e_{t-i} \qquad 3.22$$

ARMA process depends on both the preceding values of time period Y_{t-i} and the error terms e_t.

The ARMA model can be also written by including back shift operator (B) as

$$\varphi(B) Y_t = \theta(B) e_t \qquad 3.23$$

Where

$$\varphi(B) = 1 - \varphi_1 B - \varphi_2 B^2 - \cdots - \varphi_p B^p \qquad 3.24$$

$$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_q B^q \qquad 3.25$$

3.5.4 Autoregressive Integrated Moving Average (ARIMA) Model

The autoregressive integrated moving average (ARIMA) is a generalisation of the autoregressive moving average (ARMA) model. The ARIMA model is also used as an application for understanding and predicting the future values of the time series (Chattopadhyay *et al*., 2012). The difference between ARIMA and ARMA model is that ARIMA deals with time series data which showed evidence of non-stationarity (Chaudhury and Dutta, 2014). The non-stationarity can be removed by applying differencing step one or more times.

The autoregressive integrated moving average model expressed as ARIMA (p,d,q) where p indicate for autoregressive (AR) order which deals with regression of prior values and q indicate for moving average (MA) order which deals with linear combination of error terms occurring simultaneously in various times in the past (Al Balasmeh *et al*., 2019). The integrated (I) stands for number of differencing between the values and preceding values for attaining stationarity of the data. These processes are carried out in order to make the model best fit for the data. ARIMA model can be represented as

$$\varphi(B)\nabla^{d}Y_{t} = \theta(B)e_{t} \tag{3.26}$$

Where

$$\varphi(B) = 1 - \varphi_1 B - \varphi_2 B^2 - \cdots - \varphi_p B^p \tag{3.27}$$

$$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_q B^q \tag{3.28}$$

Where Y_t and e_t represent the time series and error terms at time t respectively. B represents the backward shift operator. ∇^{d} indicated the differencing operation in data series in order to make it stationary. d represents the number of differencing(Jain and Mallick, 2017). φ_p and θ_q represent the model parameters and $\varphi(B)$ and $\theta(B)$ indicate the order of p and q respectively.

The time series data may have a seasonal effect which can be removed by seasonal differencing of the time series data. The ARIMA model has two general forms, model with seasonality is known as seasonal ARIMA model represented as SARIMA (p,d,q)(P,D,Q)m and model without seasonality is the non-seasonal ARIMA model represented as ARIMA (p,d,q).

3.5.5 Seasonal Autoregressive Integrated Moving Average (SARIMA) Model

The seasonal ARIMA is an extension of ARIMA which completely deals with the time series data consisting of seasonal components. The seasonal component of the model is composed of terms which are identical to the non-seasonal components of the model. The Seasonal ARIMA consists of three new parameters for representing the auto-regression (AR), differencing (I) and moving average (MA) for the seasonal component of the series and also an extra parameter for representing the period of seasonality.

The Seasonal ARIMA can be represented as Seasonal ARIMA (p,d,q)(P,D,Q)m. It consists of two components, non-seasonal and seasonal components (Hung Ken *et al*., 1998). The non-seasonal part is represented as (p,d,q) where the 'p' stands for autoregressive order, 'd' stands for number of differencing for attaining stationarity and 'q' stands for moving average order. The seasonal component of seasonal ARIMA is indicated as (P,D,Q)m where the 'P' stands for autoregressive order of the seasonal component, 'D' stands for number of differencing with preceding values for achieving stationarity for the seasonal component, 'Q' stands for moving average order of the seasonal component (Rahman and Lateh, 2015) and 'm' stands for the additional parameter for representing the period of the seasonality for the data.

The seasonal ARIMA can be represented as:

$$\boldsymbol{\varphi}_{\mathbf{P}}(B^m)\varphi_p(B)\nabla_m^D\nabla^d Y_t = \mu + \boldsymbol{\theta}_{\boldsymbol{Q}}(B^m)\theta_q(B)e_t \qquad 3.29$$

Where

$$\boldsymbol{\varphi}_{\boldsymbol{P}}(B^s) = 1 - \boldsymbol{\varphi}_{\mathbf{1}}B^m - \boldsymbol{\varphi}_{\mathbf{2}}B^{2m} - \cdots - \boldsymbol{\varphi}_{\boldsymbol{P}}B^{Pm} \qquad 3.30$$

represents the seasonal autoregressive operator of order P

$$\varphi_p(B) = 1 - \varphi_1 B - \varphi_2 B^2 - \cdots - \varphi_p B^p \qquad 3.31$$

denotes the non-seasonal autoregressive operator of order p

$$\nabla_m^D = (1 - B^m)^D;\ \nabla^d = (1 - B)^d;\ B^k Y_t = Y_{t-k}$$

Where μ is the intercept term or mean term.

$$\boldsymbol{\theta Q}(B^m) = 1 - \boldsymbol{\theta_1} B^m - \boldsymbol{\theta_2} B^{2m} - \cdots - \boldsymbol{\theta_Q} B^{Qm} \qquad 3.32$$

indicated the seasonal moving average operator of order q.

$$\theta_q(B) = 1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_q B^q \qquad 3.33$$

denotes the non-seasonal moving average operator of order q.

e_t represents the error terms which are identical and independently distributed with mean zero and variance σ_e^2, m is the specific time period and B is the back shift operator (Murthy *et al*., 2019).

3.5.6 Test for stationarity

The stationary of the time series data indicates that the series has constant mean and variance which does not change over the time. The test of presence of stationarity for the time series data is done by Augmented Dickey Fuller (ADF) test (Sultana and Hasan, 2015).

H_o: The data consists of unit roots or data is not stationary ($\hat{\gamma} = 0$)

H_1: The data doesn't consist of unit roots or data is stationary ($\hat{\gamma} < 0$)

The test statistic for ADF test is

$$DF_T = \frac{\hat{\gamma}}{SE(\hat{\gamma})} \qquad 3.34$$

Where $\hat{\gamma}$ is ordinary least square estimate and $SE(\hat{\gamma})$ is the standard error. If the DF value more than critical value, H_o is rejected or if the P value is significant.

3.6.7 Model Selection Criteria

The selection of the best model was based on the different criteria. The choosing of the best model for the seasonal ARIMA was done by considering the least value of AIC, BIC and Hannan-Quinn criterion.

The Akaike information criterion (AIC) is an important criteria used for the detection of the best model. The model with the least value of AIC will be considered as the best model.

$$\text{AIC} = -2 * \ln(L) + 2 * k \qquad 3.35$$

Where L is the value of likelihood and k is the number of estimated parameters

The Bayesian information criterion (BIC) is another important criteria used to identify the best model. The model which has the lowest BIC value is selected as the best model.

$$\text{BIC} = -2 * \ln(L) + 2 * \ln(N) * k \qquad 3.36$$

Where L is the value of likelihood, N is the number of recorded measurements and k is the number of estimated parameters.

The Hannan- Quinn information criterion (HQC) is an alternative for both AIC and BIC which is used for determining the best model. The model with the smallest value of HQC will be expressed as the best model.

$$\text{HQC} = -2 * \ln(L) + 2 * k * \ln(\ln(N)) \qquad 3.37$$

Where L is the value of likelihood, k is the number of estimated parameters and N is the number of observed measurements.

3.5.8 Diagnostic Checking of Model

The diagnostic checking of the selected best model is done with the help of Box-Ljung test. The test is conducted on the residuals of the time series data after selecting the best model. The test checks the autocorrelation between the residuals and absence of autocorrelation among the residuals indicated that the selected model is the best. The Box-Ljung test can be express

H_0 : The model does not exhibit lack of fit or autocorrelation is absent in between residuals

H_1: The model exhibit lack of fit or autocorrelation is present in between residuals

Test statistic for Box-Ljung test

$$Q = n(n+2)\sum_{k=1}^{m}\frac{T_k^2}{n-k} \qquad 3.38$$

Where n is the number of measurements, T_k is the autocorrelation between the residuals at lag k and m is the number of lags being tested.

3.5.9 Evaluation of the forecasting of the best selected Model

The evaluation of the best model selected is done with the help of determining the mean absolute error. The best model selected based on different criteria mentioned above and it is used for forecasting the weather parameter. If the forecasted values from the best selected model have least mean absolute error then it is considered as the best fitted model. The mean absolute error can be expressed as:

$$MAE = \left(\frac{1}{N}\sum_{t=1}^{N}\left(\frac{|\widehat{Y_t} - Y_t|}{Y_t}\right)\right) \qquad 3.39$$

Where $\widehat{Y_t}$ is the forecasted value of the data at time t, Y_t is the actual value at time t and N is the number of forecasted values.

After modelling the climate change next objective is determine the impact of climate change on paddy production using regression models.

3.5 MULTIPLE LINEAR REGRESSION

Multiple linear regression is a statistical technique used to identify the impact on dependent variables due to the unit change in independent variables. In this study the impact of weather parameters on rice production was identified by conducting multiple linear regression. The Palakkad district and Kuttanad region are considered as the rice bowl of Kerala. The rice yield from 1995-2017 of Palakkad district was taken for regression from *virippu* and *mundakan* season respectively. The rainfall, maximum temperature and minimum temperature of respective months of the same district were taken as the independent variables.

In this section production of *virippu* rice was taken as the function of different weather parameters. The magnitude of production is very high compare to the weather parameters, double log transformation was done for the data before undergoing regression.

$$log_{10}Y_t = \beta_0 + \sum_{i=1}^{3}\beta_i log_{10}(R_{it}) + \sum_{i=1}^{3}\gamma_i log_{10}(MxT_{it}) + \sum_{i=1}^{3}\delta_i log_{10}(MnT_{it}) + e_t \quad 3.40$$

Where

Y_t= Rice production in Palakkad during *virippu* season at t^{th} period.

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

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

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

MxT_{1t} = Maximum Temperature during May in t^{th} period

MxT_{2t} = Maximum Temperature during June in t^{th} period

MxT_{3t} = Maximum Temperature during July in t^{th} period

MnT_{1t} = Minimum Temperature during May in t^{th} period.

MnT_{2t} = Minimum Temperature during June in t^{th} period.

MnT_{3t} = Minimum Temperature during July in t^{th} period.

e_t = residual in t^{th} period

The model for production of *mundakan* rice specified as the function of weather parameters

$$log_{10}Y_t = \beta_0 + \sum_{i=1}^{3} \beta_i log_{10}(R_{it}) + \sum_{i=1}^{3} \gamma_i log_{10}(MxT_{it}) + \sum_{i=1}^{3} \delta_i log_{10}(MnT_{it}) + e_t \quad 3.41$$

Where

Y_t= Rice production in Palakkad during *mundakan* season at 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

MxT_{1t} = Maximum Temperature during October in t^{th} period

MxT_{2t} = Maximum Temperature during November in t^{th} period

MxT_{3t} = Maximum Temperature during December in t^{th} period

MnT_{1t} = Minimum Temperature during October in t^{th} period.

MnT_{2t} = Minimum Temperature during November in t^{th} period.

MnT_{3t} = Minimum Temperature during December in t^{th} period.

e_t = residual in t^{th} period

The ordinary least square method is used for the estimation of coefficients

3.6.1 Coefficient of Determination (R^2)

The coefficient of determination explains the changes in the dependent variable which is predictable from the independent variable. It can be also defined as the square of the coefficient of multiple correlation. The range of coefficient of determination ranges from 0 to 1.

Let p be the number of variables, y_i is the set of observed variables and $\hat{y_i}$ is the set of fitted values, the coefficient of determination can be expressed as

$$R_p^2 = \frac{SS_{reg}}{SS_{tot}} or\ 1 - \frac{SS_{res}}{SS_{tot}} \qquad 3.42$$

Where

$$SS_{reg} = \sum_{i=1}^{p}(\hat{y_i} - \bar{y})^2 \qquad 3.43$$

$$SS_{res} = \sum_{i=1}^{p}(y_i - \hat{y_i})^2 \qquad 3.44$$

$$SS_{tot} = \sum_{i=1}^{p}(y_i - \bar{y})^2 \qquad 3.45$$

The value of R_p^2 increases as the number of p variables increase and it will reach the highest value when all the independent variables are included in the model.

3.6.2 Adjusted ($\bar{R}_p^2$)

The adjusted $\bar{R}_p^2$ is used to account the problems in automatic increasing of the coefficient of determination (R_p^2) when extra independent variables are included in the model.

$$\bar{R}_p^2 = 1 - \frac{(n-1)\,(1-R_p^2)}{(n-p)} \qquad 3.46$$

Where p is the number of explanatory variables and n is the sample size. $\bar{R}_{p+1}^2$ will exceed $\bar{R}_p^2$ if and only if the partial f statistics for testing the significance of the additional independent variable exceeds 1. The model with the highest $\bar{R}_p^2$ should be selected.

3.6.3 Test for detection of Multicollinearity

The linear relationship between all or some of the independent variables of the regression model is known as multicollinearity. Multicollinearity is a serious issue which can affect the estimation, prediction and inference using the regression. The multicollinearity can be determined using the variance inflation factor (VIF) test.

Let consider a regression model

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_k x_k + \cdots + \beta_t x_t + e \qquad 3.47$$

The variance inflation factor at k^{th}variable is given as

$$VIF_k = \frac{1}{1-R_k^2} \qquad 3.48$$

Where R_k^2 is the square of multiple correlation coefficient of k^{th} variable on all other independent variables. If the VIF value is greater than 10, multicollinearity is detected for that variable with all other independent variables.

3.6.4 Test for detection of autocorrelation

The autocorrelation is the correlation that exist among the current and past values of a series of observations according to a specific time period or space. The correlation between successive residuals of the same variable is also referred to as autocorrelation. The assumptions of ordinary least squares (OLS) get violated due to presence of autocorrelation. The autocorrelation can be detected using the Durbin-Watson test.

Durbin-Watson test statistic is expressed as

$$d = 2(1 - \rho) \qquad 3.49$$

$$\rho = \frac{\sum e_t e_{t-1}}{\sum e_t^2} \qquad 3.50$$

Where,

d = Durbin-Watson value

ρ = Correlation coefficient between the residuals.

e_t = Error terms at the t^{th} period

e_{t-1} = Error terms at the $(t-1)^{th}$ period

The model is said to have no autocorrelation if the value of d = 2.

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. The trend detection and estimation was done with the help of R programming software whereas X12 ARIMA an extension of open source software "Gretl" was used for ARIMA model fitting for weather data.

RESULTS AND DISCUSSION

4. RESULTS AND DISCUSSION

The data which includes rainfall, maximum temperature and minimum temperature required to analyse the impact of climate change over time was collected from RARS Pilicode for a period of 36 years from 1983 to 2018 and RARS Pattambi for a period of 37 years from 1982 to 2018 respectively. This chapter describes the different results obtained from the statistical analysis of the data collected from the research stations of KAU and a comparison among the regions was done based on the results. The results obtained are presented under the following sections.

4.1 Descriptive statistics of weather parameters

4.2 Trend analysis of weather parameters

4.3 Models for change in weather parameters

4.4 Impact of weather parameters on paddy yield

4.1 DESCRIPTIVE STATISTICS OF WEATHER PARAMETERS

4.1.1 Descriptive Statistics of Monthly Weather Parameters of RARS, Pilicode

The data collected from RARS Pilicode includes rainfall, maximum temperature and minimum temperature, for a period of 36 years (1983-2018). Measures of central tendency and measures of dispersion provide an idea about the overall range which include the mean, standard deviation and coefficient of variation were obtained for the data.

Box plot is a graphical representation used to describe the distribution of weather parameters over the years. Box plot is also used for the data from RARS, Pilicode to determine the distribution and variability of the observations over the years. The box plot represents the quartiles of the respective numerical data graphically with the end points as minimum and maximum whereas the outliers are plotted as individual points.

In order to get an idea about the pattern of change in monthly rainfall, maximum temperature and minimum temperature, different measures including mean, range, CV, skewness and kurtosis were obtained. These results are given in Table 1 for rainfall, Table 2 for maximum temperature and Table 3 for minimum temperature.

Table 1. Descriptive statistics for monthly Rainfall over the period 1983-2018 at Pilicode

Month	**Range (mm)**	**Average (mm)**	**Stand.dev (mm)**	**CV (%)**	**Skewness**	**Kurtosis**
Jan	0-131	7	25	378.46	4	19
Feb	0-21	2	5	315.99	4	13
Mar	0-345	19	59	317.84	5	28
Apr	0-166	42	51	120.54	1	0
May	0-945	163	203	124.21	2	7
Jun	0-994	487	381	78.17	0	-2
Jul	101-956	472	332	70.30	0	-2
Aug	102-901	537	185	34.44	-1	1
Sep	18-849	283	218	77.15	1	0
Oct	0-621	238	157	65.69	1	0
Nov	0-433	89	88	98.45	2	6
Dec	0-131	15	26	165.31	3	11

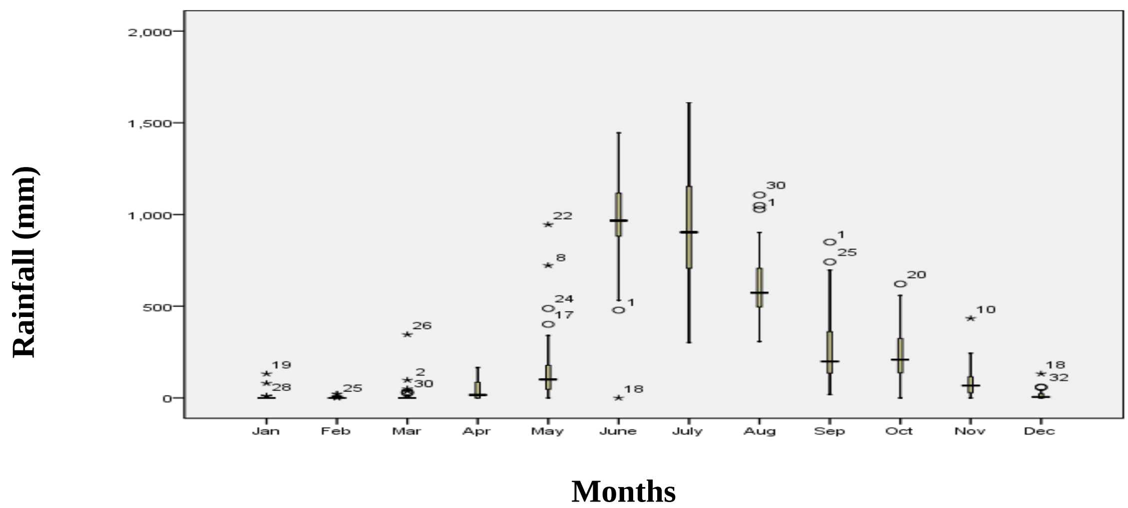

Figure 1. Month wise Rainfall over the period 1983-2018 at Pilicode

The result presented in Table 1 showed that the lowest rainfall observed was 0 mm in the month of December to February in the winter season and also in March to May in summer respectively and the highest rainfall was 994 mm in the month of June (monsoon). The range of rainfall was very high during the month of October (0-621mm), November (0-433mm) and June (0-994mm) respectively. The highest average rainfall was observed in the month of August (537mm) and the lowest average rainfall was observed in the month of February (2mm). The standard deviation was more in the month of June and least in the month of February. However the coefficient of variation was highest during the months January to March and December clearly indicated that winter and summer period receives no rain to rain in some days.

The result also revealed that skewness and kurtosis were highest in the month of March (5 and 28 respectively) and lowest value of skewness was shown in the month of June (0) whereas April (0) showed the least value for kurtosis. Most of the months are positively skewed except August which also indicated that the rainfall didn’t follow normal distribution.

The outliers are represented in the box plot as dots which indicated the deviation from average monthly rainfall in respective years. The highest number of outliers are present in the month of May which revealed that higher rainfall received during May in

1990, 1999, 2014 and 2016. It is also evident from Fig. 1 that excess rainfall received during the month of August in 1983 and 2012 and September in 1983 and 2007.

Table 2. Descriptive statistics for monthly Maximum Temperature over the period 1983-2018 at Pilicode

Month	Range (℃)	Average (℃)	Stand.dev (℃)	CV (%)	Skewness	Kurtosis
Jan	30.42-32.77	31.89	0.55	1.71	-0.65	0.05
Feb	30.65-33.34	32.30	0.59	1.81	-0.58	1.14
Mar	31-33.93	32.89	0.66	1.99	-0.79	0.98
Apr	31.73-34.71	33.43	0.75	2.24	-0.59	0.04
May	30.31-34.68	32.98	1.00	3.04	-0.79	0.43
Jun	28.22-32.00	30.06	0.77	2.56	0.48	1.22
Jul	27.60-30.67	29.19	0.68	2.34	-0.40	0.10
Aug	27.65-29.87	29.12	0.46	1.59	-0.80	1.43
Sep	28.64-31.04	29.96	0.58	1.92	-0.48	0.12
Oct	29.13-32.14	30.77	0.65	2.10	-0.32	0.20
Nov	30.62-32.85	31.75	0.52	1.65	0.13	0.58
Dec	30.42-33.08	31.90	0.59	1.85	-0.27	0.37

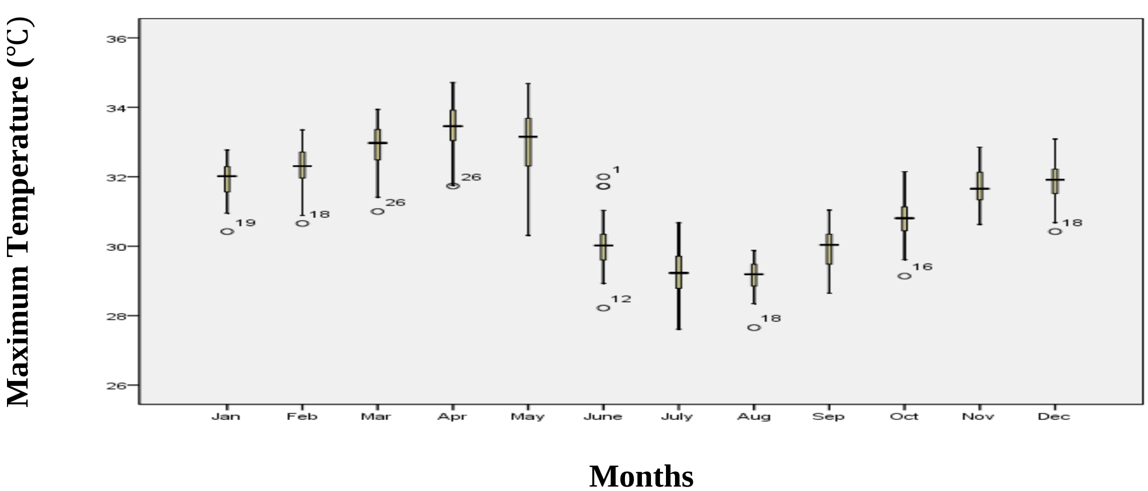

Figure 2. Month wise Maximum Temperature over the period 1983-2018 at Pilicode

The result recorded in Table 2 showed that the lowest maximum temperature of 27.60℃ was observed in the month of July and the highest maximum temperature of 34.71℃ was observed in the month of April. The highest average temperature of 33.43℃ was observed in the month of April and the lowest average maximum temperature of 29.12℃ was observed in the month of August. The standard deviation and coefficient of variation were found to be very low for maximum temperature as compared to rainfall. It is evident from Table 2 that temperature started to increase from November onwards and it has reached the peak during April.

It is also revealed that most of the months are negatively skewed except in June and November which indicated that the distribution of maximum temperature was not normal distribution. The kurtosis revealed that all the months have a platykurtic curve.

Box plot of maximum temperature provides the distribution of values from a central point and the extreme points in the monthly maximum temperature. It is very clear from Fig. 2 that the outliers of maximum temperature were in the lower part of the whisker suggesting decline in maximum temperature in most of the months over the years except in June at Pilicode. The most number of outliers are present in the year 2000 which indicated that there was a high deviation from the normal mean monthly maximum temperature, later it was removed and instead of that mean value was used for subsequent analyses.

Table 3. Descriptive statistics for monthly Minimum Temperature over the period 1983-2018 at Pilicode

Month	**Range** (°C)	**Average** (°C)	**Stand.dev** (°C)	**CV** (%)	**Skewness**	**Kurtosis**
Jan	17.03-21.88	19.71	0.93	4.73	-0.14	1.49
Feb	18.83-23.10	21.16	1.03	4.88	-0.32	-0.18
Mar	22.06-24.58	23.42	0.70	2.98	-0.37	-0.48
Apr	22.68-26.79	25.14	0.79	3.15	-0.85	1.68
May	23.61-26.84	25.29	0.81	3.18	-0.19	-0.59
Jun	22.29-25.12	23.82	0.63	2.66	-0.39	0.20
Jul	21.67-24.70	23.45	0.60	2.55	-0.61	1.38
Aug	20.36-24.25	23.29	0.68	2.90	-2.32	9.25
Sep	19.73-24.35	23.29	0.78	3.36	-2.70	11.55
Oct	19.43-24.36	23.17	0.87	3.75	-2.46	9.16
Nov	19.42-23.85	22.32	0.89	3.97	-0.90	1.89
Dec	18.28-22.13	20.20	1.02	5.04	0.14	-1.00

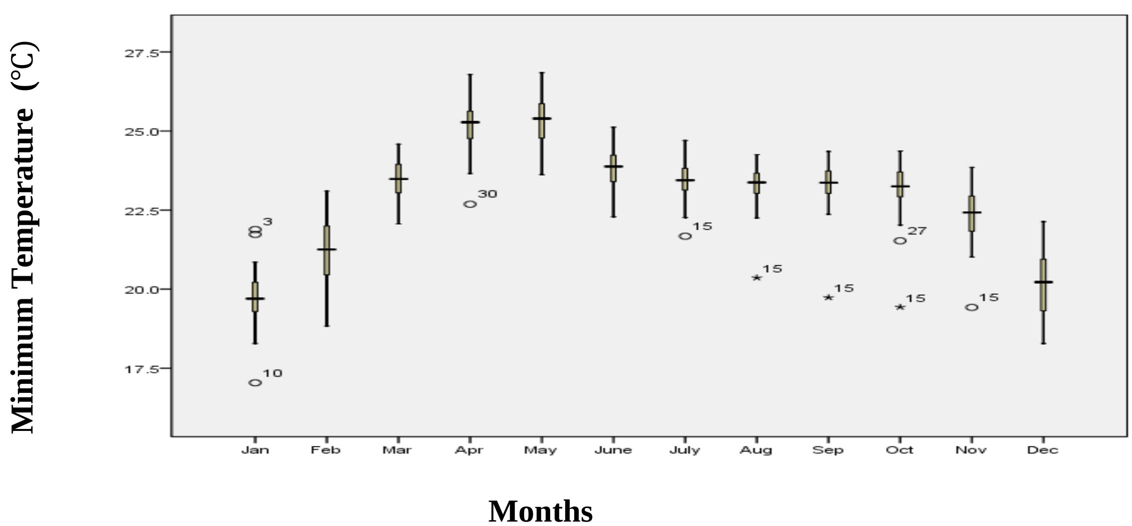

Figure 3. Month wise Minimum Temperature over the period 1983-2018 at Pilicode

The result reported in table 3 revealed that the smallest minimum temperature of 17.03℃ was observed in the month of January and the greatest minimum temperature of 26.84℃ was observed in the month of May. The highest average minimum temperature of 25.29℃ was observed in the month of May and the lowest average minimum temperature of 19.71℃ was observed in the month of January. The standard deviation and coefficient of variation of minimum temperature were commenced to be less compared to the rainfall. The result depicted in table 3 also underlines that the minimum temperature increased from January and reached the peak in May.

The result also conveyed that skewness of all the months except December was negatively skewed and kurtosis showed platykurtic curve for all months except August, September and October which suggested that minimum temperature for all months didn't follow normal distribution.

The box plot for minimum temperature depicted the distribution of values from a center point. Similar to the maximum temperature, the outliers of monthly minimum temperature were laid on the bottom part of the whisker which suggested that there was a reduction in minimum temperature except in January. The year 1997 showed low minimum temperature as compared to all the other years.

4.1.2 Descriptive statistics of monthly weather parameters of RARS, Pattambi

The data collected from RARS Pattambi includes rainfall, maximum temperature and minimum temperature for a period of 37 years from 1982 to 2018. Measures of central tendency and measures of dispersion represent the characteristics of the weather parameters using the range, the mean, standard deviation and coefficient of variation.

Box plot is a graphical representation that provides visual ideas about the changes in weather parameters over the different years. The box plot was also used to determine the distribution and variability of the observations over the years of the weather parameters from RARS Pattambi. The box plot is constructed with the help of the quartiles of the respective numerical data to represent the box and the whiskers marked by minimum and maximum values whereas the outliers are plotted as individual points.

The pattern of deviation in monthly rainfall, maximum temperature and minimum temperature are determined by different measures including mean, range, standard deviation, coefficient of variation, skewness and kurtosis. These results are given in Table 4 for rainfall, Table 5 for maximum temperature and Table 6 for minimum temperature.

Table 4. Descriptive statistics of monthly Rainfall over the period 1982-2018 at Pattambi

Month	**Range (mm)**	**Average (mm)**	**Stand.dev (mm)**	**CV (%)**	**Skewness**	**Kurtosis**
Jan	0 - 56.20	4.05	11.72	289.3	3.33	11.68
Feb	0 - 90.60	13.02	24.23	186	1.95	2.95
Mar	0 - 141.90	21.16	34.44	162.7	2.03	4.15
Apr	0 - 238.30	69.33	59.57	85.93	0.91	0.37
May	19.8 - 467.20	158.14	120.03	75.9	1.41	1.37
Jun	282.1 - 934.30	638.26	172.07	26.96	-0.10	-1.05
Jul	297.8 -1307.50	624.84	258.05	41.3	0.87	0.27
Aug	120.2 - 670.50	367.82	139.33	37.88	0.32	-0.55
Sep	38.2 - 629.00	229.72	153.75	66.93	0.70	-0.18
Oct	59.6 - 456.00	264.38	102.86	38.91	0.05	-0.64
Nov	4.1 - 279.10	105.85	79.30	74.91	0.80	-0.41
Dec	0 - 112.90	20.35	30.98	152.2	1.71	2.14

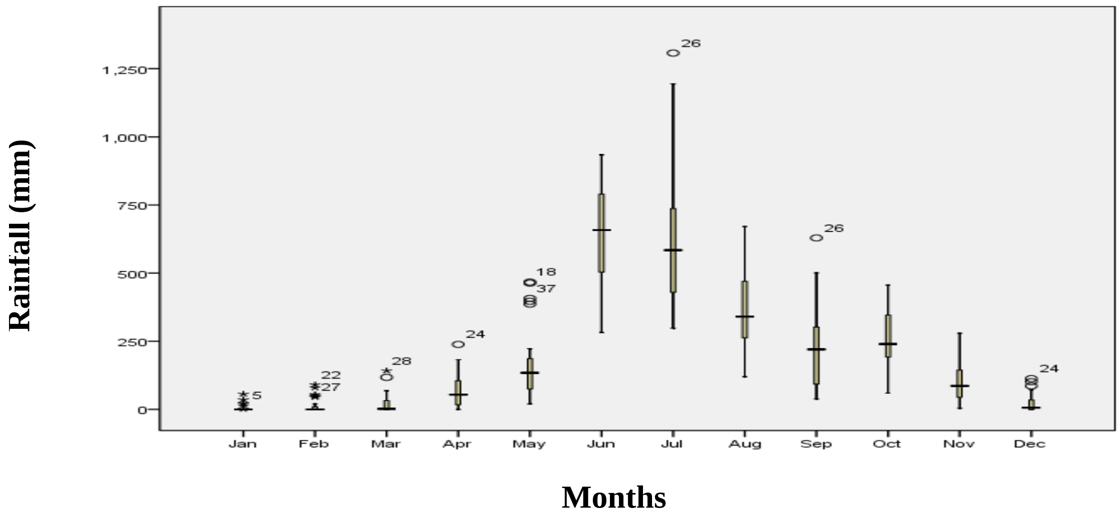

Figure 4. Month wise Rainfall over the period 1982-2018 at Pattambi

The result obtained from Table 4 revealed that the lowest rainfall observed was 0 mm in winter season from the month of December to February and in summer season from the month of March to May and the highest rainfall in the month of July (1307.5mm). The range of rainfall was very large during the months June (282.1 to 934.30mm), July (297.8 to 1307.50mm) and August (120.2 to 670.50mm). The topmost average rainfall was recorded in the month of June (638.26mm) and the smallest average rainfall was recorded in the month of January (4.05mm). The standard deviation and coefficient of variation was highest in the months of March to May and December to February respectively which indicated that rainfall was absent or very unoften during these periods.

The result also revealed that skewness and kurtosis were highest in the month of January (3.33 and 11.68 respectively) and lowest in the month of October and September (0.05 and -0.18) respectively. The skewness for most of the months are positive except in the month of June which indicated the absence of normal distribution for rainfall. The kurtosis also showed a platykurtic shape for all the months except in January and March which also suggested absence of normal distribution.

The outliers of rainfall were depicted in the box plot as dots which revealed the deviation of monthly rainfall during respective years. The outliers observed in Fig. 4 revealed that excess rainfall was received during the months July and September in the year 2007 and April and December in 2005 respectively. The variation in rainfall of Pattambi was less as compared to Pilicode.

Table 5. Descriptive statistics for monthly Maximum Temperature over the period 1982-2018 at Pattambi

Month	**Range (℃)**	**Average (℃)**	**Stand.dev (℃)**	**CV (%)**	**Skewness**	**Kurtosis**
Jan	32.6-34.4	33.33	0.48	1.45	0.57	-0.38
Feb	33.9-36.3	35.01	0.57	1.62	0.25	-0.20
Mar	33.9-37.8	36.24	0.74	2.03	-0.71	1.50
Apr	33.4-37.0	35.44	0.93	2.63	-0.18	-0.79
May	30.5-35.7	33.93	1.12	3.28	-1.12	2.00
Jun	28.5-32.1	30.32	0.78	2.58	-0.00	0.00
Jul	28.1-30.5	29.34	0.53	1.80	-0.18	-0.14
Aug	28.6-31.0	29.58	0.52	1.74	0.69	0.67
Sep	26.9-32.2	30.62	0.96	3.13	-1.51	4.96
Oct	28.2-33.0	31.32	0.91	2.91	-0.94	2.46
Nov	30.7-33.4	32.03	0.52	1.63	0.32	0.93
Dec	27.0-33.9	32.22	1.09	3.37	-2.96	13.85

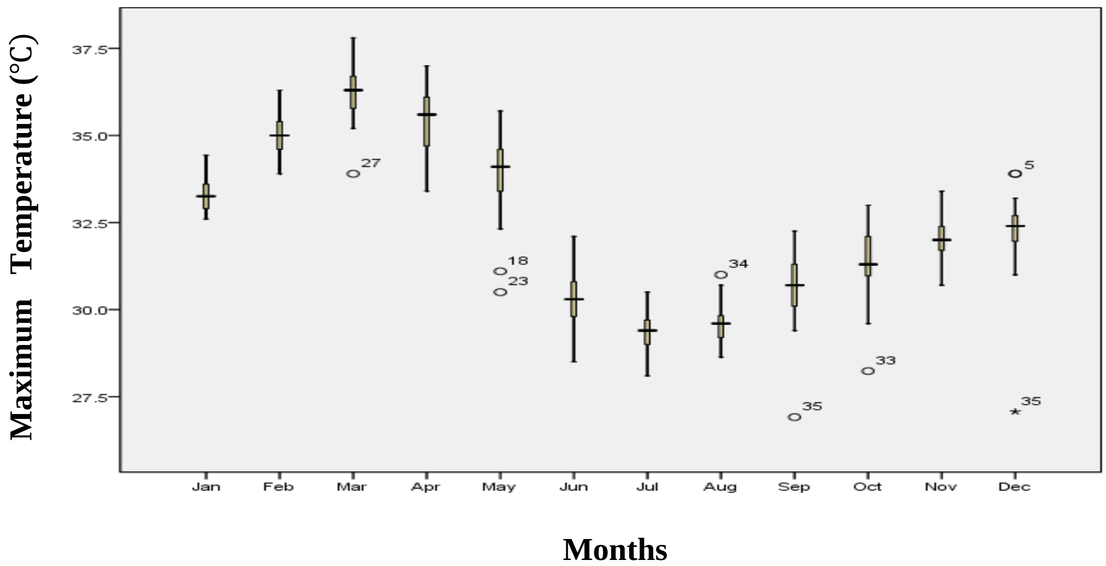

Figure 5. Month wise Maximum Temperature over the period 1982-2018 at Pattambi

The results reported in Table 5 showed that the smallest maximum temperature of 27℃ was observed in the month of December and the highest maximum temperature of 37.8℃ was observed in the month of March. The highest average maximum temperature was observed in month of March (36.24℃) and the least average maximum temperature was observed in month of July (29.34℃). The standard deviation and coefficient of variation of maximum temperature was very less as compared to the rainfall. The result from Table 5 also revealed that temperature starts to rise from the month of June and reach the peak value in March.

All the months except January, February and August were negatively skewed which indicated that the rainfall didn't follow normal distribution. The kurtosis of all months except September and December are platykurtic which also suggested that maximum temperature didn't follow normal distribution.

Box plot of maximum temperature provides the distribution of values from a central point and the extreme points in the monthly maximum temperature. The box plot of maximum temperature (Fig. 5) showed that all the outliers were lying on the bottom part of the whisker indicating a reduction in maximum temperature over the years in all the months except in August and December. The deviation in maximum temperature was observed during the month May in 1999 and 2004 and December in 1986 and 2017. The number of outliers were very less compared to maximum temperature at Pilicode.

Table 6. Descriptive statistics for monthly Minimum Temperature over the period 1982-2018 at Pattambi

Month	**Range** (℃)	**Average** (℃)	**Stand.dev** (℃)	**CV (%)**	**Skewness**	**Kurtosis**
Jan	17.1-22.0	20.34	1.10	5.38	-0.78	0.74
Feb	17.5-23.8	21.05	1.27	6.04	-0.54	0.96
Mar	19.0-24.96	23.07	1.12	4.86	-1.56	3.63
Apr	20.9-26.5	24.46	1.08	4.40	-1.33	2.84
May	20.4-25.86	24.33	1.23	5.05	-1.33	1.96
Jun	19.2-24.7	23.17	1.07	4.61	-1.83	4.52
Jul	19.7-23.9	22.82	0.98	4.29	-2.01	4.03
Aug	20.4-23.9	23.03	0.79	3.43	-1.52	2.99
Sep	20.2-27.77	23.26	1.28	5.48	1.37	6.56
Oct	20.7-26.25	23.01	0.95	4.10	0.27	3.65
Nov	19.3-23.5	22.17	0.94	4.24	-0.90	1.23
Dec	17.7-23.1	20.80	1.25	6.03	-0.55	0.43

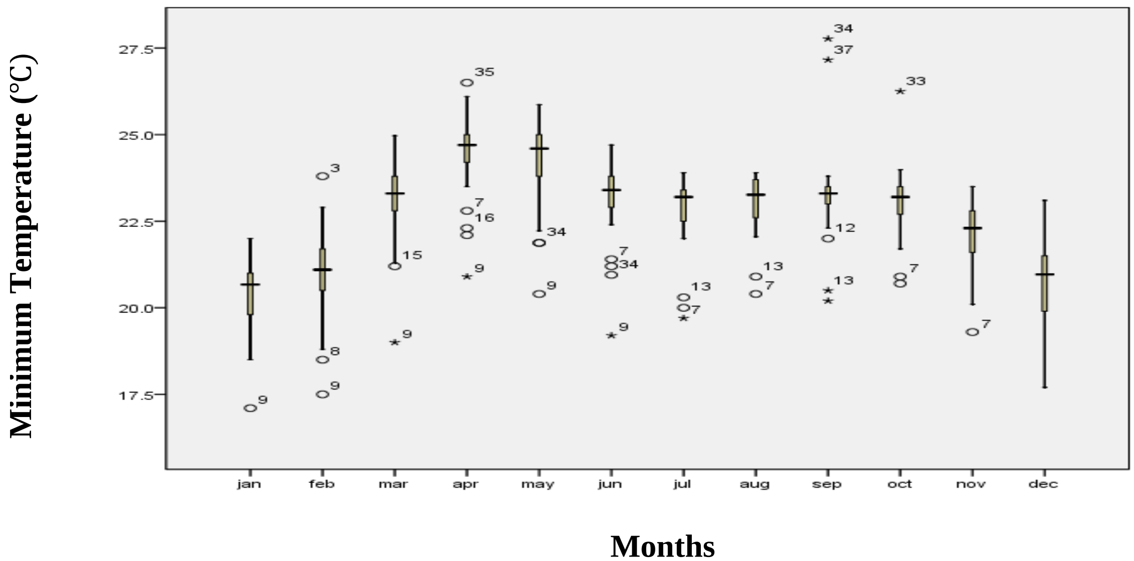

Figure 6. Month wise Minimum Temperature over the period 1982-2018 at Pattambi

The result presented in Table 6 showed that the lowest minimum temperature of 17.1℃ was recorded in the month of January and the highest minimum temperature of 20.2℃ was recorded in the month of September. The highest average minimum temperature was recorded in the month of April (24.46℃) and the lowest average minimum temperature was recorded in the month of January (20.34℃). The standard deviation and coefficient of variation of minimum temperature were very low as compared to the rainfall.

All the months except September and October are positively skewed which also indicated that the rainfall didn’t follow normal distribution. The kurtosis also showed both platykurtic and leptokurtic curves for different months which indicated absence of symmetric distribution for minimum temperature at Pattambi.

The outliers of minimum temperature were depicted in the box plot as dots which revealed the deviation of monthly minimum temperature during respective years. The box plot of minimum temperature depicted on Fig. 6 showed that all the outliers are below to the minimum value or the lower part of the whisker indicating reduction in maximum temperature in most of the months except February, April, September and October. The

Fig. 6 also showed that years 1988, 1990, 1994 and 2015 showed high negative deviation from mean monthly minimum temperature. The number of outliers were more for the minimum temperature of Pattambi as compared to Pilicode.

4.2 TRENDS IN WEATHER PARAMETERS

Precipitation and temperature are the two important variables that are usually used to study the extent of climate change and climate variability. The extent of climate change overtime can be expressed in terms of trends in weather variables such as rainfall, maximum and minimum temperature. Inter annual or seasonal trends across the regions would be helpful to suggest some adaptation strategy to improve crop production. In general an OLS regressions help to estimate the trend coefficient, which requires normality assumption of the data. To check the normality, Shapiro Wilks test was used and it is discussed in the following section.

4.2.1 Test for Normality of weather variables at Pilicode

The test for normality was conducted for the rainfall, maximum temperature and minimum temperature for the data collected from RARS Pilicode. The test used for determining the normality of the data was Shapiro-Wilk test. These results are given in Table 7.

Table 7. Shapiro-Wilk test for normality of weather parameters at Pilicode

Weather Parameter	**Shapiro-Wilk Test (W)**	**P value**
Rainfall (mm)	0.75	1.27e-024 ***
Maximum Temperature(°C)	0.97	6.54e-006 ***
Minimum Temperature(°C)	0.96	2.31e-009 ***

*** P value significant at 1% level of significance

The result given in Table 7 showed that the P values are greater than 0.05, indicating that all the weather parameters are not following the normal distribution. This led to the use of a non-parametric test known as Mann-Kendall test for the detection of the trend and Sen's slope estimator for quantifying the trend. The R software package was used for trend detection and estimation of weather parameters. The deseasonalisation of weather parameters is done by using moving average method. The central moving average of order 12 is calculated for obtaining trend estimate and the initial estimate of the seasonal component is identified by taking ratio between the original data and trend estimate. The averages of initial seasonal component is identified in order to remove the irregular component. The new factors are adjusted to obtain sum as 1 and the seasonal factors was obtained which is removed from the original data and deseasonalisation is completed.

4.2.2 Detection and estimation of trend in weather parameters at Pilicode

The detection of the trend was done by using the Mann-Kendall test which is a non-parametric test. The presence of trend was detected for rainfall, maximum temperature and minimum temperature for annual, deseasonalized annual and seasonal weather data. These results are presented in Table 8, Table 9 and Table 10 respectively.

Table 8. Mann-Kendall test and Sen's slope estimator for rainfall at Pilicode

Rainfall	**Z value**	**P value**	**Tau**	**Sen's slope estimate**
Annual	0.99	0.32	0.117	9.50
Deseasonalized annual	2.00	0.04 **	0.234	38.44
Summer	0.92	0.35	0.109	2.14
Monsoon	0.83	0.40	0.098	8.17
Post Monsoon	-0.01	0.98	-0.003	-0.06
Winter	0.90	0.36	0.110	0.00

** P value significant at 5% level of significance

The MK test provides Z- test statistic value and it is evident from Table 8 that none of the Z value is greater than 1.96 except for annual deseasonlized rainfall suggesting that trend was present only for annual rainfall data. The Sen's estimator and Kendall's tau was 38.44 and 0.234 respectively which indicated the presence of a significant positive trend for the deseasonalized annual rainfall which revealed that there was a significant and increasing trend in annual rainfall over the years in Pilicode and the rate of increase was 38.44 mm year^{-1}. This is also evident from Fig. 7 and Fig. 8 Moreover, there was an increase in summer, monsoon and winter rainfall but it was not significant.

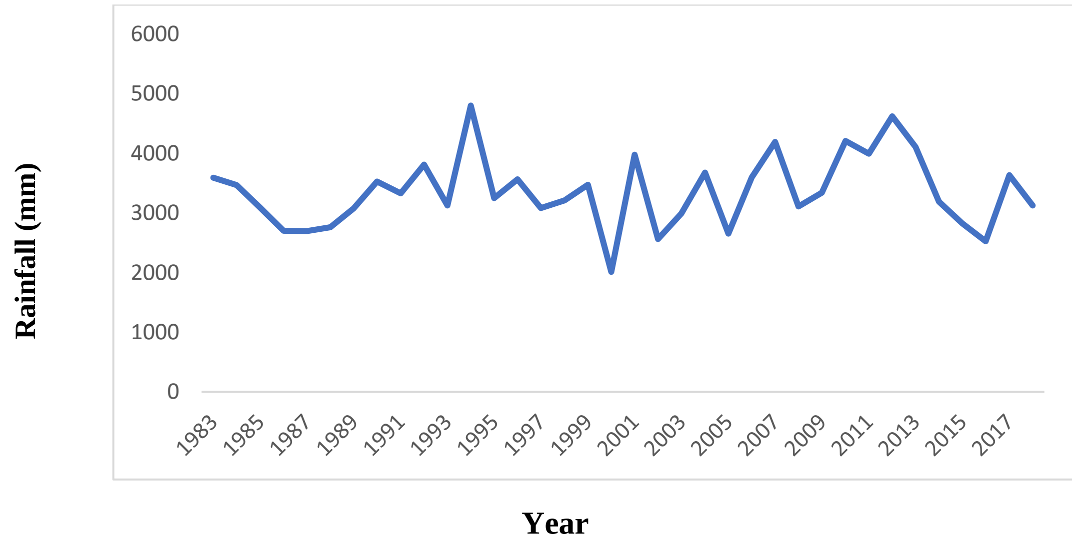

Figure 7. Trends in annual Rainfall vs Year at Pilicode

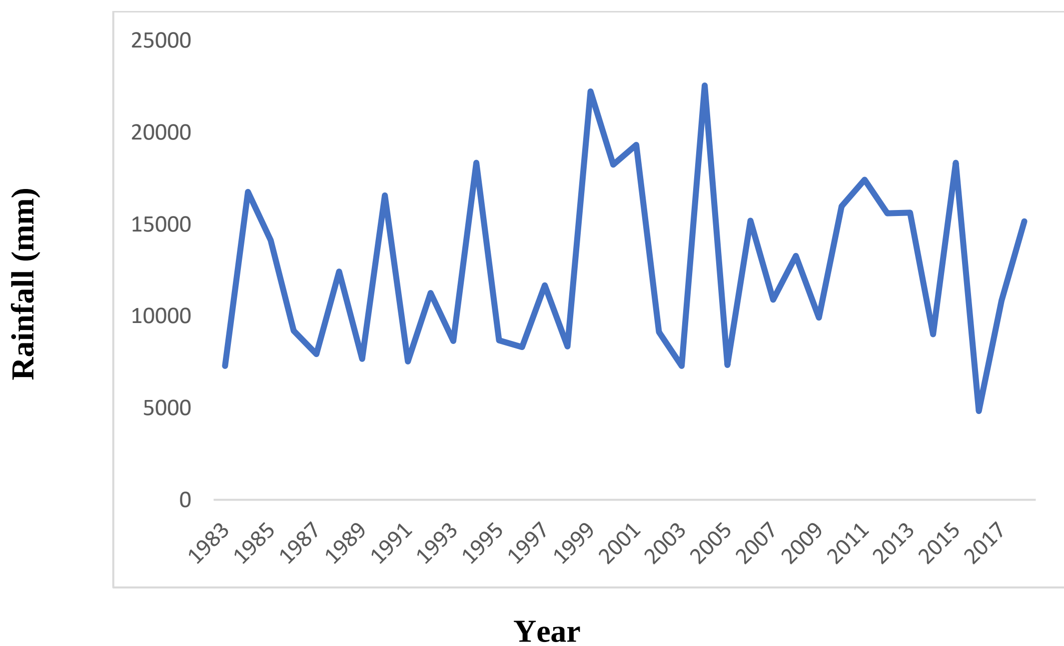

Figure 8. Trends in annual deseasonalized Rainfall vs Year at Pilicode

Table 9. Mann-Kendall test and Sen's slope estimator for Maximum Temperature at Pilicode.

Classification	**Z value**	**P value**	**Tau**	**Sen's slope**
Annual	0.79	0.42	9.372e-02	0.004
Deseasonalized annual	0.53	0.59	6.349e-02	0.003
Summer	0.59	0.54	7.148e-02	0.005
Monsoon	0.49	0.62	5.877e-02	0.002
Post Monsoon	1.30	0.19	15.409e-02	0.009
Winter	0.77	0.43	9.206e-02	0.003

The results from Table 9 revealed that the Z value for annual (0.79), deseasonalized annual (0.53), summer (0.60) and all other seasons maximum temperature were less than critical value of Z or the estimated p values were greater than 0.05 showed that absence of significant trend in maximum temperature at Pilicode. The Fig. 9 and Fig. 10 also suggested that the annual and deseasonalized maximum temperature didn't have a significant trend. However, the Sen' slope estimates for annual (0.005) and all other seasons are positive suggesting an increase in maximum temperature over the years. The average annual increase in maximum temperature at Pilicode was 0.005^{0}C $year^{-1}$.

Similar conclusions are reported by Dash *et al*. (2007) based on a study on climate change in the twentieth century in India. The results revealed that maximum temperature showed an increasing trend in most parts of India whereas minimum temperature showed decreasing trend in most parts of India.

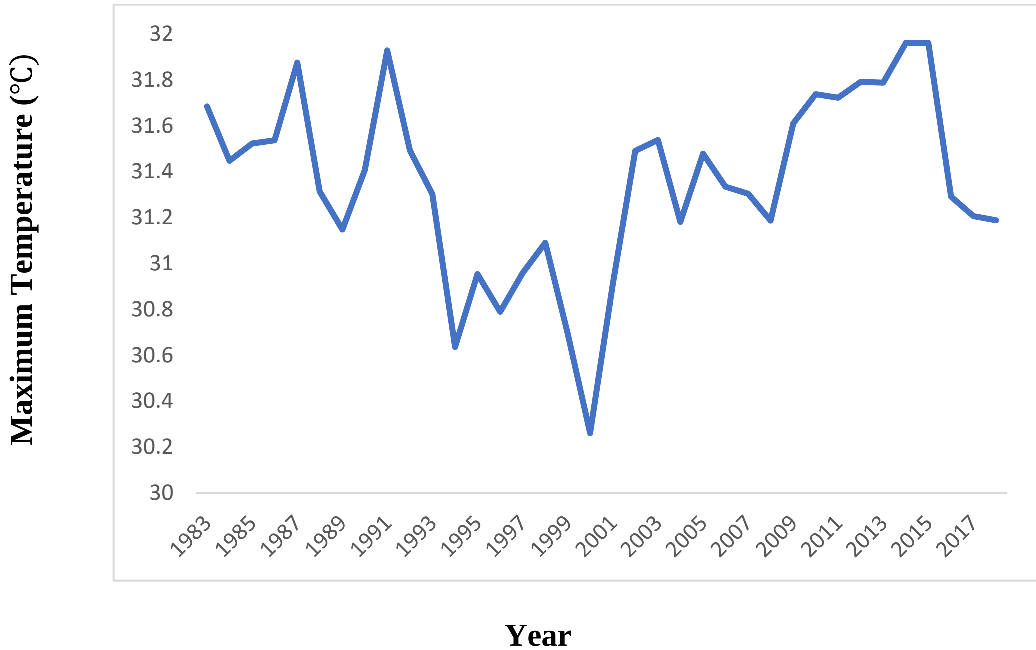

Figure 9. Trends in annual Maximum Temperature vs Year at Pilicode

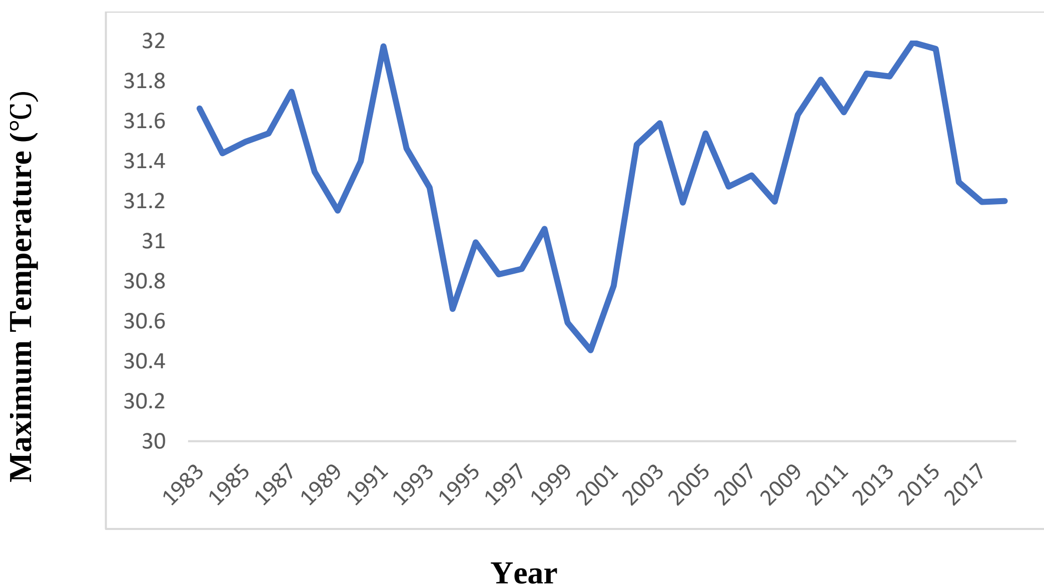

Figure 10. Trend in annual deseasonalize Maximum Temperature vs Year at Pilicode

Table 10. Mann-Kendall test and Sen's slope estimator for Minimum Temperature at Pilicode.

Minimum temperature	**Z value**	**P value**	**Tau**	**Sen's slope**
Annual	-2.90	0.00 ***	-0.34	-0.02
Deseasonalized annual	-3.01	0.00 ***	-0.35	-0.02
Summer	-2.65	0.00 ***	-0.31	-0.03
Monsoon	-3.50	0.00 ***	-0.41	-0.03
Post Monsoon	-0.96	0.33	-0.21	-0.01
Winter	-0.85	0.39	-0.10	-0.01

*** P value significant at 1% level of significance

The result from Table 10 revealed that Z value for annual minimum temperature (-2.90), deseasonlized annual (-3.01), summer (-2.66) and Monsoon (-3.50) minimum temperature was less than -1.96 indicates the presence of a significant trend. The P values of these parameters were also less than 0.05 confirmed a significant trend. The Sen's slope estimator and Kendall's tau for annual minimum temperature was -0.02 and -0.34 respectively which indicated the presence of a significant negative trend trend further suggested a decline in minimum temperature at the rate of 0.02^{0}C $year^{-1}$. The Fig. 12 and Fig. 13 suggested that significant trend was present for annual and deseasonalized minimum temperature. The Sen's slope estimator was -0.03 for summer and -0.03 for monsoon respectively indicated the presence of a significant negative trend. The post monsoon and winter showed an absence of significant trend since the Z value is less than 1.96 and P value was greater than 0.05. The sign of Sen's slope estimate indicated that there was a negative trend which was statistically not significant.

The results of the analysis on minimum temperature reported a significant decline in annual minimum temperature throughout the year over the study period in Pilicode.

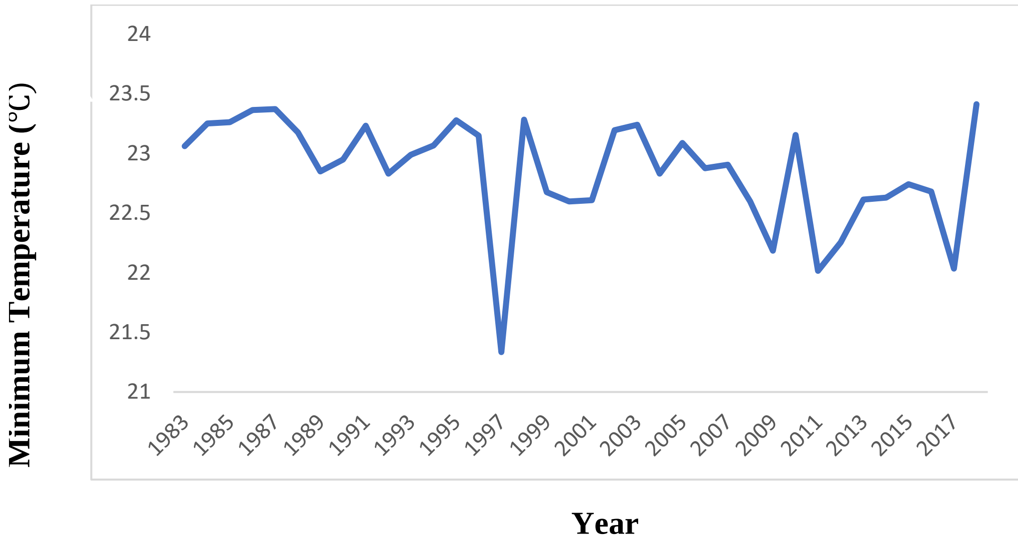

Figure 11. Trends in annual Minimum Temperature vs Year at Pilicode

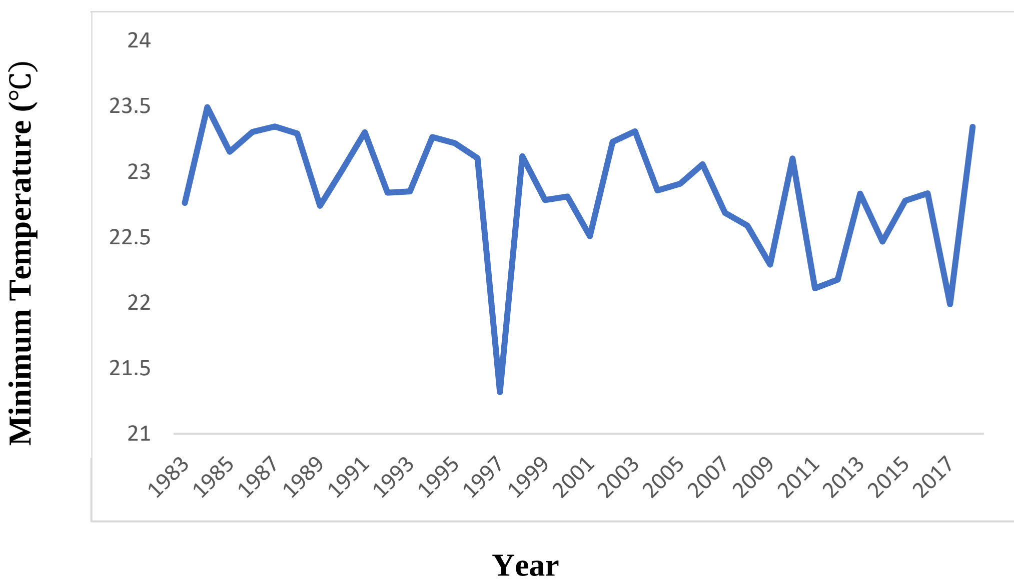

Figure 12. Trends in annual deseasonalized Minimum Temperature vs Year at Pilicode

4.2.3 Test for Normality of the weather variables from Pattambi

The test for normality was conducted for the rainfall, maximum temperature and minimum temperature for the data collected from RARS Pattambi. The test used for determining the normality of the data was Shapiro-Wilk test. These results were given in the Table 11:

Table 11. Shapiro-Wilk test for normality for weather data from Pattambi

Weather Parameter	**Shapiro-Wilk Test (W)**	**P value**
Rainfall (mm)	0.81	3.45e-022 ***
Maximum Temperature (℃)	0.96	5.88e-008 ***
Minimum Temperature (℃)	0.97	4.18e-006 ***

*** P value significant at 1% level of significance

The result in Table 11 showed that the P value was less than 0.05 for rainfall, maximum temperature and minimum temperature which indicated that all the weather parameters are not following normal distribution. This led to the use of a Non-Parametric test known as Mann-Kendall test for the detection of the trend and Sen's slope estimator for the estimation of the trend.

4.2.4 Detection and estimation of trend for weather parameters at Pattambi

The detection of the trend was done by using the Mann-Kendall test which is a non-parametric test. The Sen's slope estimator was done for estimation of trend. The presence of trend was detected for annual, deseasonal annual and seasonal classification of the weather parameters.

Table 12. Results of Mann-Kendall test and Sen's slope estimator for Rainfall at Pattambi.

Classification	**Z value**	**P value**	**Tau**	**Sen's slope**
Annual	-0.24	0.80	-0.030	-2.51
Deseasonalized annual	0.61	0.53	0.072	7.87
Summer	1.81	0.06 *	0.210	3.04
Monsoon	-1.03	0.30	-0.120	-6.90
Post Monsoon	-0.30	0.76	0.036	-0.65
Winter	0.61	0.53	0.074	0.16

* P value significant at 10% level of significance

The MK test results represented in Table 12 provides Z- test statistic value and the Z value was smaller than 1.96 expressed absence of trend for rainfall data. The p value for summer rainfall was 0.06 which showed presence of significant trend (P<0.1). The Sen's estimator and Kendall's tau was 3.04 and 0.210 respectively which suggested the presence of a significant positive trend for the summer rainfall and the rate of increase was 3.04 mm year^{-1}. The annual rainfall in Pattambi is decreasing over the years whereas the deseasonalized annual rainfall was increasing. This is evident from Fig. 13 and Fig. 14. However, there was an increase in winter rainfall and decrease in monsoon and post monsoon rainfall was recorded at Pattambi during the study period. The annual rainfall over the years showed a fall in rainfall at a rate of 2.51 mm year^{-1}.

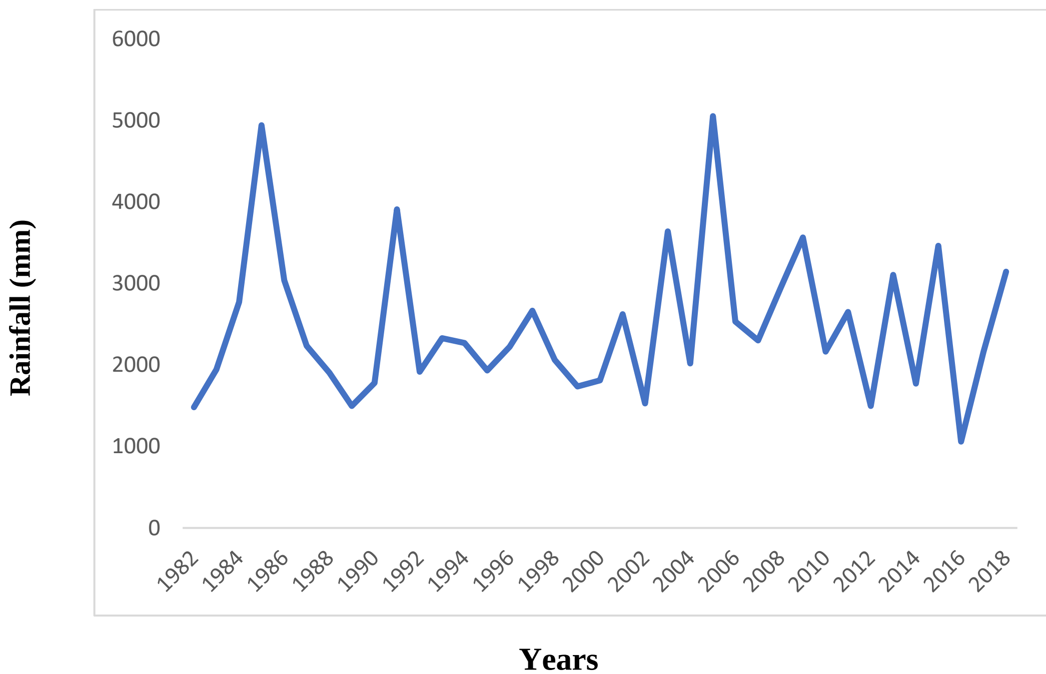

Figure 13. Trends in annual Rainfall vs Year at Pattambi

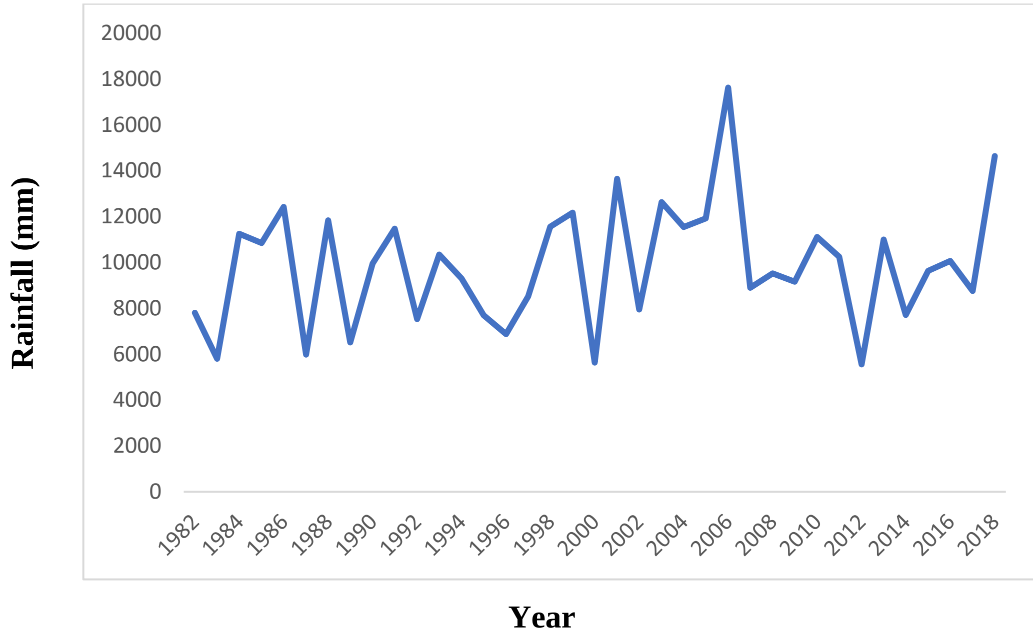

Figure 14. Trends in annual deseasonalized Rainfall vs Year at Pattambi

Table 13. Results of Mann-Kendall test and Sen's slope estimator for Maximum Temperature at Pattambi.

Classification	**Z value**	**P value**	**Tau**	**Sen's slope**
Annual	-1.67	0.09 *	-0.194	-0.008
Deseasonalized annual	-1.34	0.17	-0.156	-0.006
Summer	-2.73	0.00 ***	-0.317	-0.032
Monsoon	0.82	0.40	0.097	0.002
Post Monsoon	-0.09	0.92	-0.069	-0.001
Winter	-1.46	0.14	-0.170	-0.013

*** P value significant at 1% level of significance
** P value significant at 5% level of significance
* P value significant at 10% level of significance

The results recorded in Table 13 expressed that the Z value for annual (-1.67), deseasonalized annual (-1.34), all other seasons except summer maximum temperature were less than critical value of Z or the estimated p values were greater than 0.05

showed that absence of significant trend in maximum temperature at Pattambi. The Z value for summer maximum temperature (-2.73) and P Value was less than 0.05 indicated presence of a significant trend. The negative sign for Sen's slope estimator (-0.032) and Kendall's tau (-0.317) for summer maximum temperature respectively confirmed the presence of a negative trend and the rate of fall was 0.032^{0}C year^{-1}. The P value for annual maximum temperature at Pattambi is 0.09 which indicates the presence of significant trend ($P<0.1$). The Fig. 15 and Fig. 16 also expressed that the annual and deseasonalized maximum temperature didn't have a significant trend.

Moreover, the Sen' slope estimates for annual (-0.008) and all other seasons except monsoon are negative indicating decrease in maximum temperature over the years the decrease was at the rate of 0.008^{0}C year^{-1}.

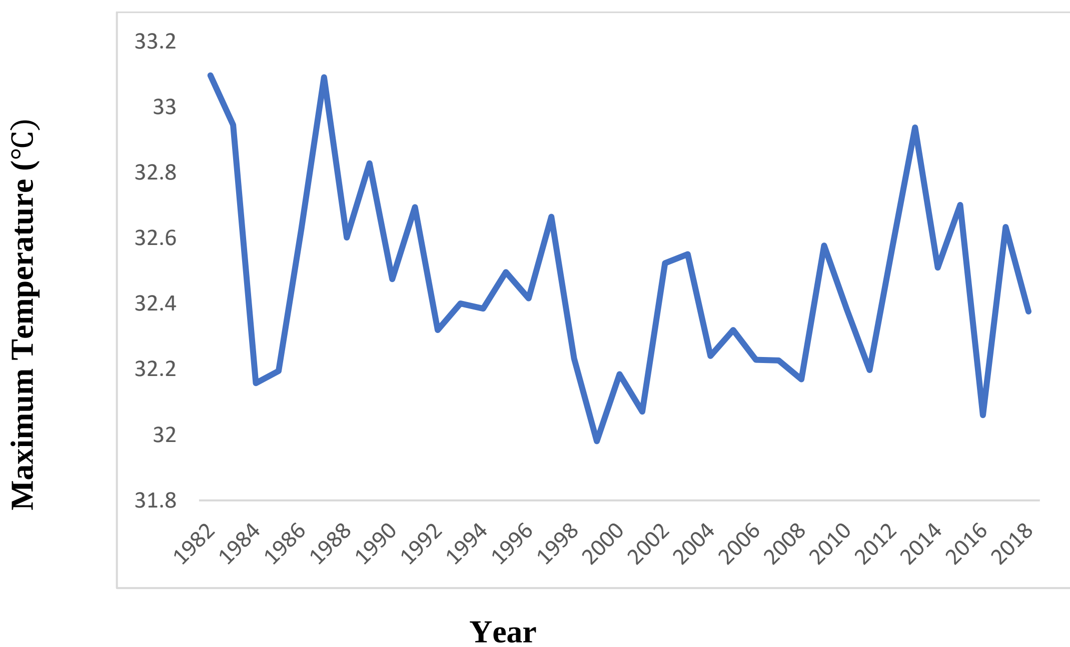

Figure 15. Trends in annual Maximum Temperature vs Year at Pattambi

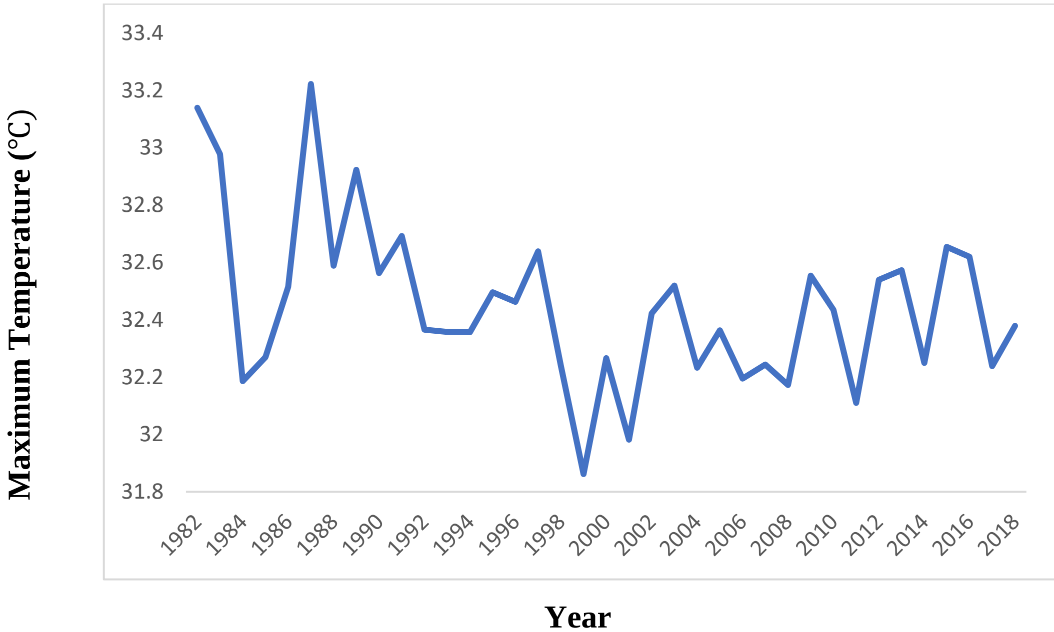

Figure 16. Trends in annual deseasonalize Maximum Temperature vs Year at Pattambi

Table 14. Mann-Kendall test and Sen's slope estimator for Minimum Temperature at Pattambi.

Classification	**Z value**	**P value**	**Tau**	**Sen's slope**
Annual	2.69	0.00 ***	0.311	0.03
Deseasonalized annual	2.73	0.00 ***	0.315	0.03
Summer	-2.91	0.00 ***	-0.336	-0.03
Monsoon	1.47	0.13	0.171	0.00
Post Monsoon	0.14	0.88	0.018	0.00
Winter	-1.55	0.11	-0.180	-0.01

*** P value significant at 1% level of significance

The MK test results were recorded in Table 14 revealed that Z value for annual minimum temperature (2.69), deseasonlized annual (2.73) and summer (-2.91) minimum temperature was greater than 1.96 suggested the presence of a significant trend. The presence of significant trend was confirmed since the P values of these parameters were also less than 0.05. The Sen's slope estimator and Kendall's tau for annual (0.03 and

0.311), deseasonalized annual (0.03 and 0.315) and summer (-0.03 and -0.336) minimum temperature which indicated the presence of a significant positive trend for the annual and deseasonalized annual minimum temperature whereas negative trend for summer season. The Fig. 17 and Fig. 18 suggested that significant trend was present for annual and deseasonalized minimum temperature. The monsoon, post monsoon and winter showed an absence of significant trend since the Z value is less than 1.96 and P value was greater than 0.05. The Sen's slope estimator for monsoon and post monsoon showed positive sign whereas winter showed negative sign but they were not significant.

The results of the analysis on minimum temperature reported a significant increase in annual minimum temperature throughout a year over the study period in Pattambi at the rate of 0.03^0C $year^{-1}$.

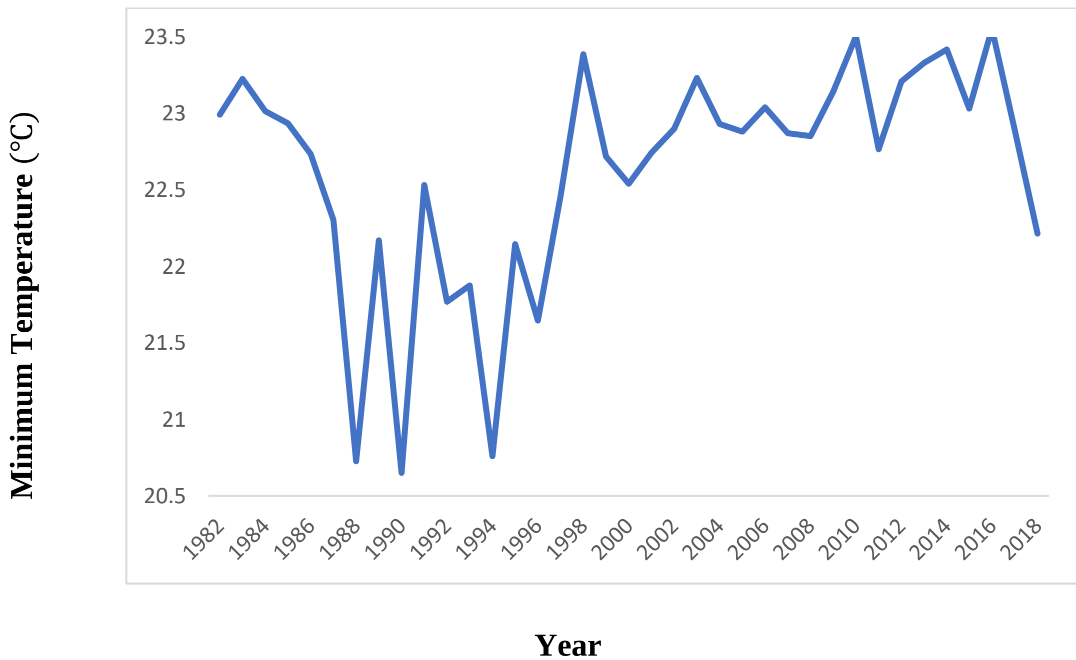

Figure 17. Trends in annual Minimum Temperature vs Year at Pattambi

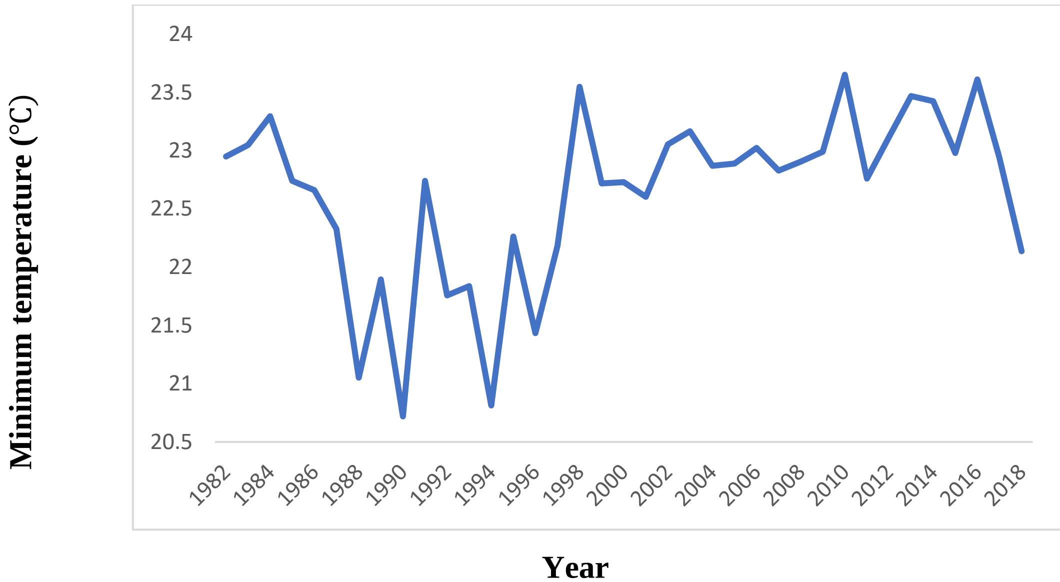

Figure 18. Trends in annual deseasonalize Minimum Temperature vs Year at Pattambi

4.2.5 Interregional variation in weather parameters in northern and central region of Kerala

The change weather parameters in annual and in different seasons during the study period was done to get an idea about the regional disparity in changes over a period of time This comparison was done with the help of graphical representation rainfall, maximum and minimum temperature in different seasons.

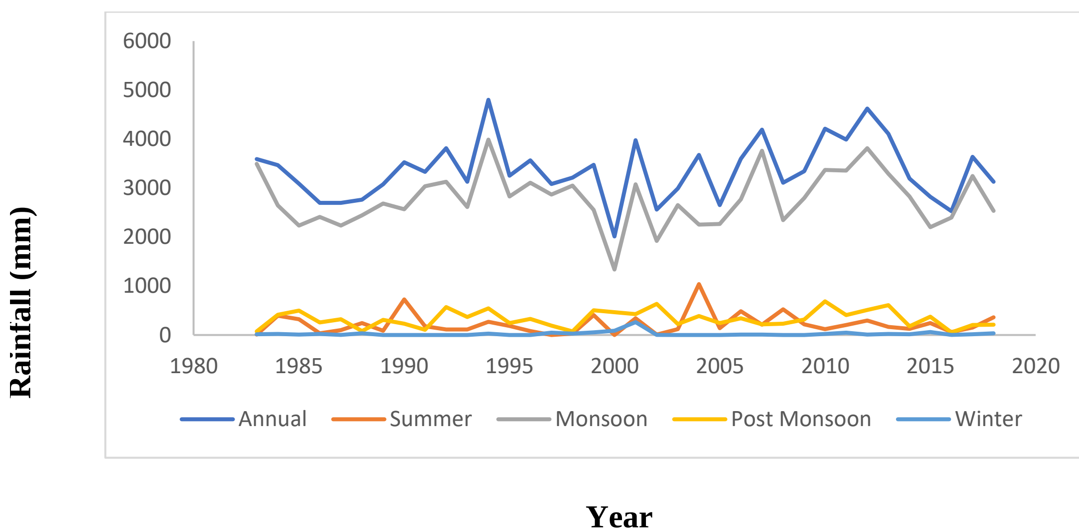

Figure 19. Trends in annual and seasonal Rainfall vs Year at Pilicode

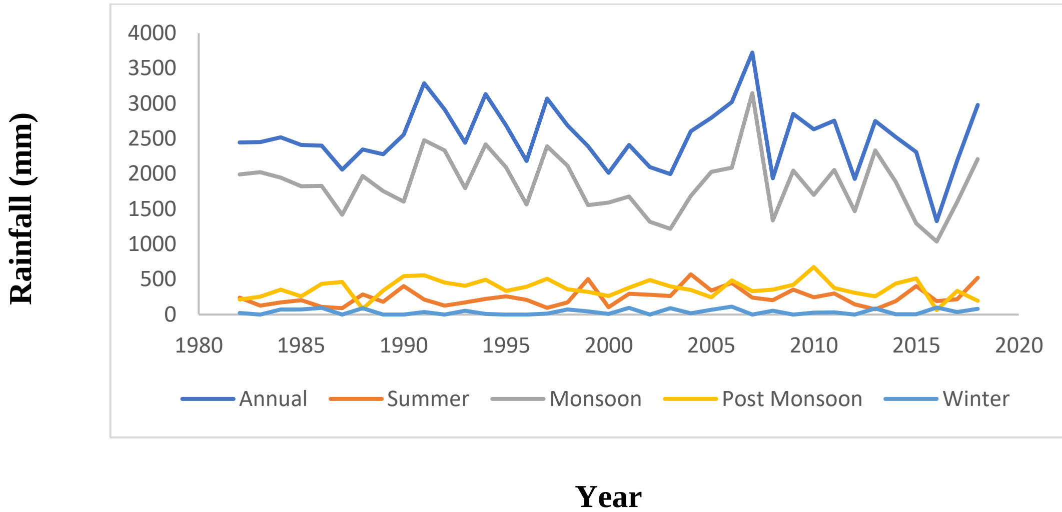

Figure 20. Trends in annual and seasonal Rainfall vs Year at Pattambi

It is concluded from both Fig. 19 and Fig. 20 that over the years the rainfall at Pilicode is much higher compared to the rainfall at Pattambi. The range of annual rainfall at Pattambi was recorded between 3000 mm to below 4000 mm with a decline in recent years whereas it ranged from 2500 mm to 3000 mm at Pattambi wih an increase in rains during the recent years. It is also observed from the graph that both regions receiving the major chunk of rains in a year.

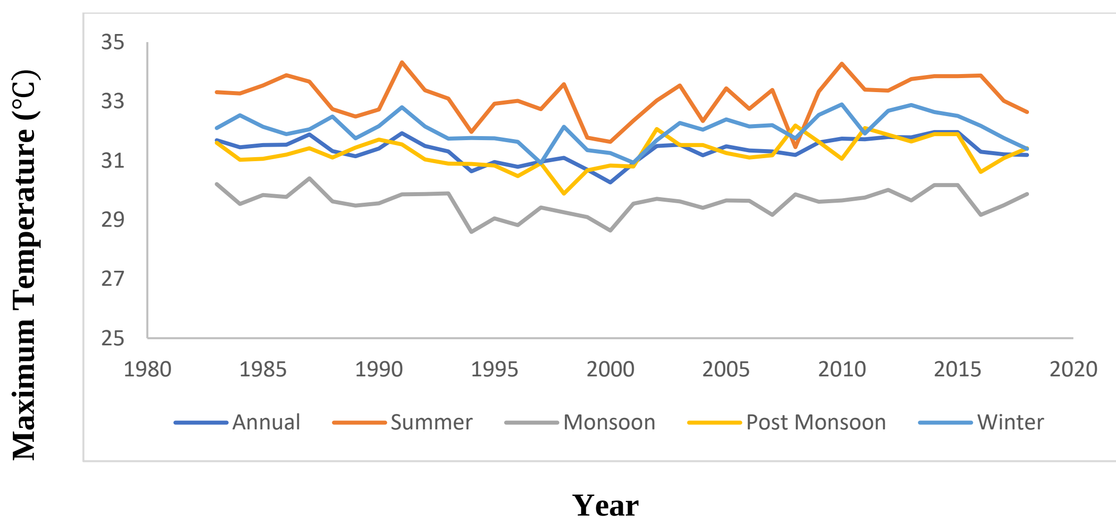

Figure 21. Trends in annual and seasonal Maximum Temperature vs Year at Pilicode

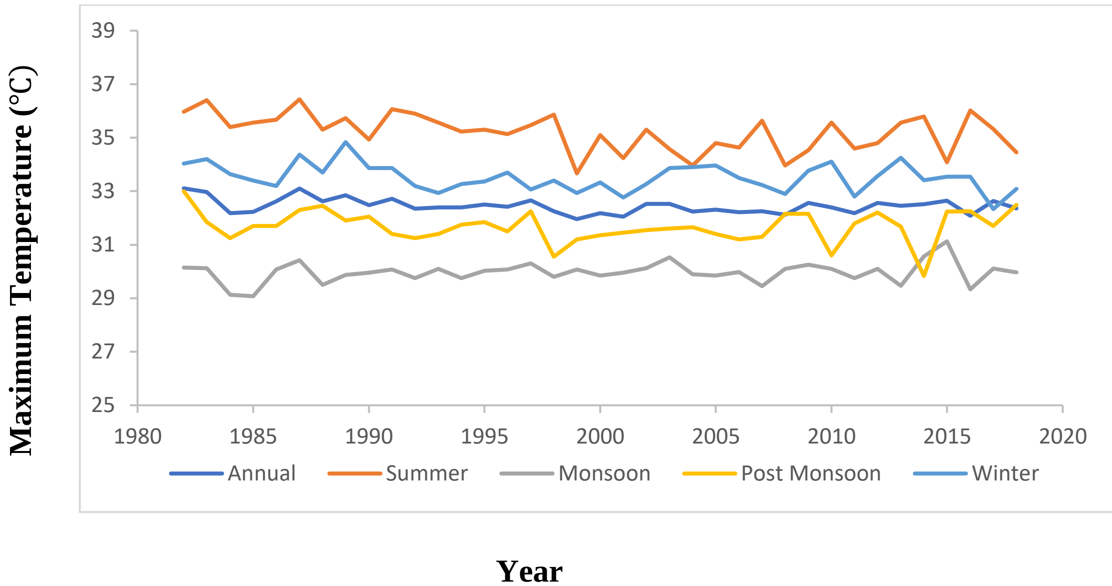

Figure 22. Trends in annual and seasonal Maximum Temperature vs Year at Pattambi

It is interpreted from both Fig. 21 and Fig. 22 that Pattambi was warmer than Piliocode. The summer maximum temperature recorded at Pattambi ranged from 34^0C to 37^0C while it was low at Pilicode (32 to 34^0C). The maximum temperature in all the seasons at Pattambi has shown much higher temperature as compared to the Pilicode. In both regions Pattambi and Pilicode the maximum temperature in monsoon and post monsoon showed much lower temperature compared to winter season.

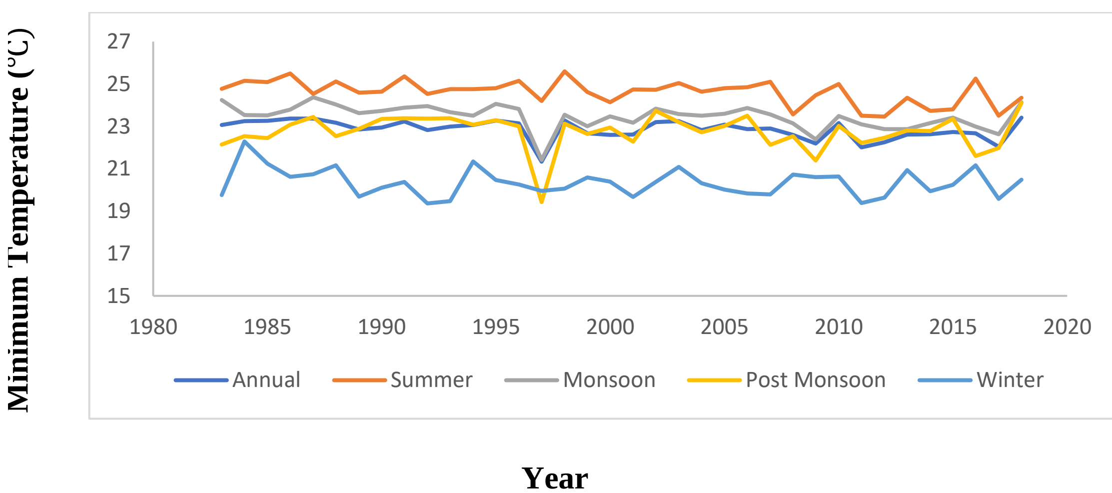

Figure 23. Trends in annual and seasonal Minimum Temperature vs Year at Pilicode

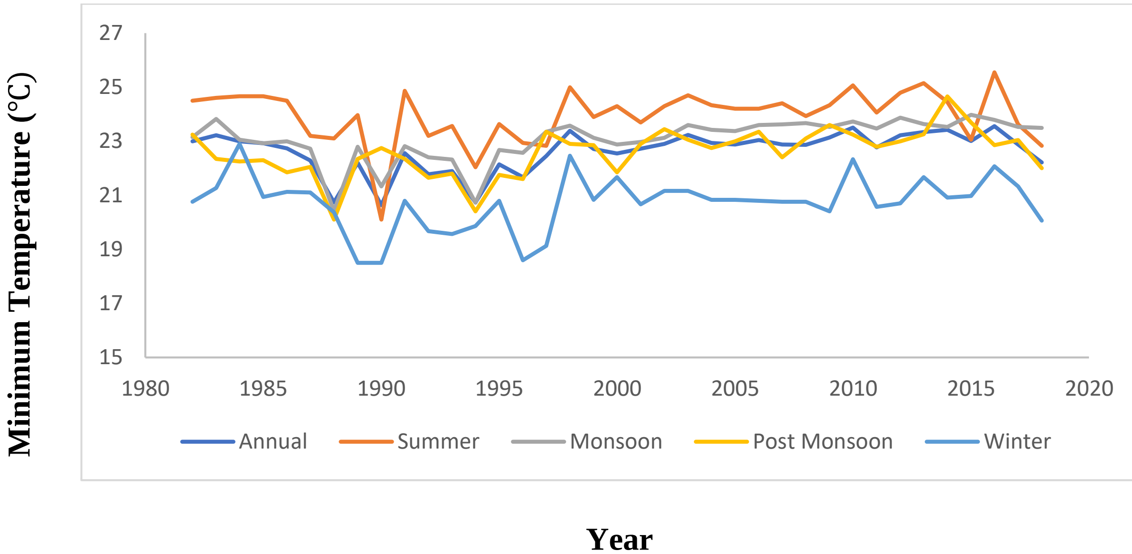

Figure 24. Trends in annual and seasonal Minimum Temperature vs Year at Pattambi

It is evident from Fig. 23 and Fig. 24 that the minimum temperature at Pilicode and Pattambi was showing almost similar behaviour ranged from 23 to 25^{0}C throughout the years with a decline in minimum temperature in the recent years. However, the winter season in Pattambi (17 to 23^{0}C) showed lower peaks as compared to Pilicode (19 to 23^{0}C).

4.3 MODELS FOR ESTIMATION OF CLIMATE CHANGE IN WEATHER PARAMETERS REGION WISE

4.3.1 Models for change in Weather Parameters for RARS Pilicode

The weather forecasting models are developed for rainfall, maximum temperature and minimum temperature based on monthly data for a period of 1983-2017 from RARS, Pilicode. The best model identification, estimation and diagnostic checking was done using an open source software Gretl. The development of a model would help in better understanding of weather parameters to predict the future values. Different types of time series models are available for better perceptive of the data and the time series model used in this study for modelling of rainfall, maximum temperature and minimum temperature was Seasonal ARIMA model.

4.3.1.1 Seasonal ARIMA models for Weather Parameters of RARS, Pilicode

The required time series data should be stationary before developing a model. Augmented Dickey Fuller (ADF) test is generally used for testing the stationarity of a time series data. The Seasonal ARIMA model can be represented by using its parameters as (p,d,q)(P,D,Q)m . The (p,d,q) stands for the non-seasonal part of the ARIMA model and (P,D,Q) stands for the seasonal part of the ARIMA model. If the model consists of only non-seasonal part then the model be ARIMA but if the model consists of both seasonal and non-seasonal parts, then the modal is said to be a Seasonal ARIMA (SARIMA).

The different stages in identifying the patterns in time series data for ARIMA and Seasonal ARIMA models are model identification, parameter estimation and diagnostic checking. The model identification was done by using the X12 ARIMA package inside the Gretl software tool. The X12 ARIMA automatically identifies the best model with its parameters. The parameter estimation of seasonal ARIMA model was also done by the usage of X12 ARIMA and later it was confirmed as the best model based on trial and error method.

The criteria for selection of a best model was based on the significance of the parameters in the model with least Akaike Information Criterion (AIC), least Bayesian Information Criterion (BIC) and least Hannan-Quinn criterion and the best models for weather parameters are given in Table 15. The diagnostic checking of the best model for autocorrelation was done using the Ljung-Box test. The non-significance of P value showed that residuals are not auto-correlated. The model which follows these criteria was said to be the best fit.

The results in Table 15 showed the results of the unit root test was conducted by the X12 ARIMA automatically and it detected that the minimum temperature and maximum temperature were stationary whereas the rainfall was non stationary for the non-seasonal part of the SARIMA model. The seasonal part of the SARIMA model needs differencing since the D value is 1 for all the weather parameters.

Weather Parameter	Unit Root Test		Automatic ARIMA Model
	Difference Order		
	Non-Seasonal	Seasonal	
Rainfall	1	1	(0,1,1)(0,1,1)
Maximum Temperature	0	1	(1,0,1)(0,1,1)
Minimum Temperature	0	1	(1,0,1)(0,1,1)

Table 15. The best selected model for weather parameters of Pilicode

It is reported that the best estimated model for rainfall, maximum temperature and minimum temperature was Seasonal ARIMA (0,1,1,)(0,1,1)12, (1,0,1)(0,1,1)12 and (1,0,1)(0,1,1)12 respectively. The parameters of best fitted models for rainfall, maximum temperature and minimum temperature along with model selection criteria are presented in Table 16.

Table 16. The parameters of the best model for the weather parameters of Pilicode

Weather Parameter		Coefficient	P-value	AIC	BIC	Hannan-Quinn
Rainfall	theta_1 Theta_1	-0.97 - 0.97	0.00 *** 2.27e-044 ***	5383.993	5400.029	5390.339
Maximum Temperature	phi_1 theta_1 Theta_1	0.82 -0.44 -1.00	7.95e-074 *** 7.80e-010 *** 5.56e-024 ***	718.809	738.866	726.746
Minimum Temperature	phi_1 theta_1 Theta_1	0.63 -0.28 -0.95	1.12e-014 *** 0.00 *** 1.61e-065 ***	940.232	960.288	948.168

*** P value significant at 1% level of significance

The results from table 16 showed the parameters of AR and MA terms are significant for the weather parameters rainfall, maximum temperature and minimum temperature at Pilicode. Similar type of results were reported by Nirmala and Sundaram

(2010) for modelling and forecasting rainfall in Tamilnadu using SARIMA (0,1,1)(0,1,1)12 model.

The X12 ARIMA had automatically selected the best Seasonal ARIMA model for all the weather parameters. In order to check the presence of any other best model with least AIC, BIC and Hennan-Quinn coefficient value could be determined using trial and error method. The results of the models identified and best model selected for different weather parameters are presented in the Table 17, Table 18 and Table 19.

Table 17. The best estimated model based on trial and error method for Rainfall at Pilicode

ARIMA Model		**Coefficient**	**P-value**	**AIC**	**BIC**	**Hannan-Quinn**
(0,0,0)(2,1,0)	Phi_1 Phi_2	-0.74 -0.30	5.00e-053 *** 3.26e-010 ***	5577.973	5594.134	5584.361
(1,0,1)(2,1,0)	phi_1 Phi_1 Phi_2 theta_1	-0.96 -0.73 -0.29 1.00	0.00 *** 2.93e-050 *** 1.45e-09 *** 0.00 ***	5576.393	5600.635	5585.974
(1,0,1)(1,1,0)	phi_1 Phi_1 theta_1	-0.94 -0.56 1.00	0.00 *** 1.04e-040 *** 0.00 ***	5608.749	5628.950	5616.733
(2,0,1)(1,1,0)	phi_1 phi_2 Phi_1 theta_1	-0.95 -0.00 -0.56 1.00	4.75e-085 *** 0.86 1.15e-040 *** 0.00 ***	5610.720	5634.961	5620.301
(0,1,1)(0,1,1)	theta_1 Theta_1	-0.97 -0.97	0.00 *** 2.27e-044 ***	5383.993	5400.029	5390.339
(1,1,1)(2,1,0)	phi_1 Phi_1 Phi_2 theta_1	0.01 -0.74 -0.30 -1.00	0.74 5.35e-052 *** 4.60e-010 *** 0.00 ***	5577.060	5601.287	5586.636
(0,1,1)(2,1,0)	Phi_1 Phi_2 theta_1	-0.74 -0.30 -1.00	1.42e-052 *** 4.51e-010 *** 0.00 ***	5575.168	5595.358	5583.149
(0,0,1)(2,1,0)	Phi_1 Phi_2 theta_1	-0.74 -0.30 0.01	1.91e-052 *** 3.33e-010 *** 0.77	5579.895	5600.096	5587.879
(1,0,0)(2,1,0)	phi_1 Phi_1 Phi_2	0.01 -0.74 -0.30	0.78 1.78e-052 *** 3.32e-010 ***	5579.896	5600.097	5587.880
(1,1,0)(2,1,0)	phi_1 Phi_1 Phi_2	-0.48 -0.75 -0.31	2.58e-030 *** 1.29e-053 *** 6.46e-011 ***	5737.931	5758.121	5745.912

*** P value significant at 1% level of significance

The results presented in Table 17 indicated that AIC (5383.993), BIC (5400.029) and Hannan- Quinn (5390.339) were lowest for the model SARIMA (0,1,1)(0,1,1)12. This implied that the rainfall at t^{th} period depends on rainfall at $(t-1)^{th}$, $(t-12)^{th}$ and $(t-13)^{th}$ period. The graph of the best model is shown in Fig. 25.

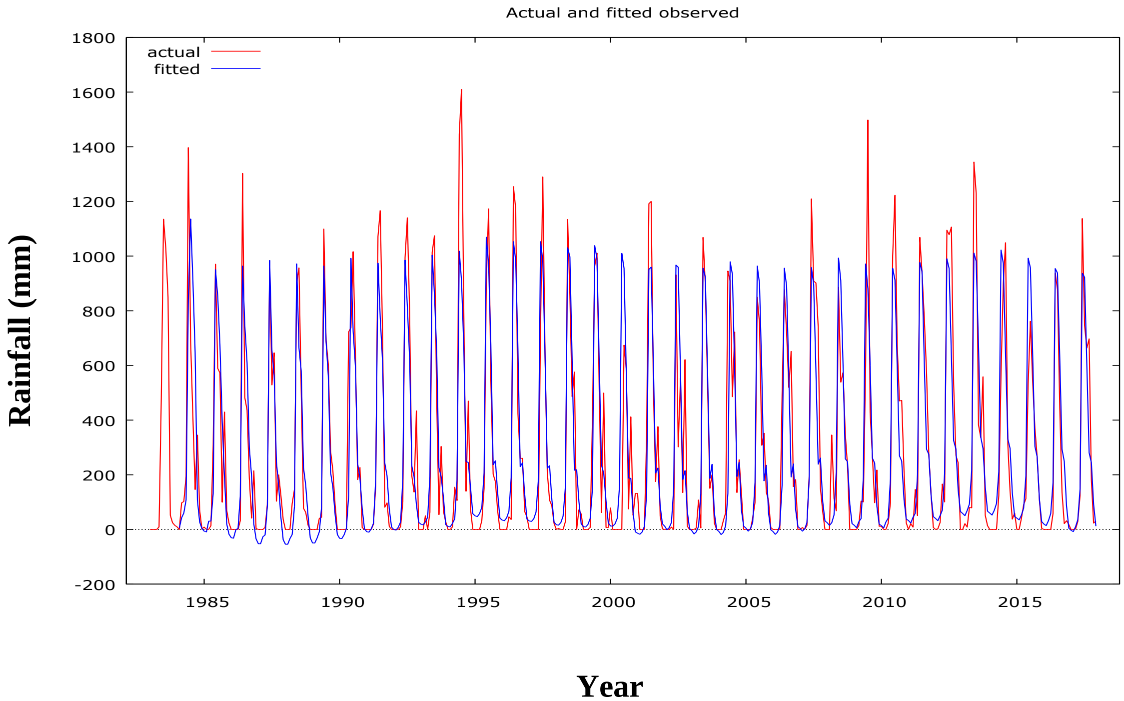

Figure 25. Actual and fitted trend plot for monthly Rainfall over the years at Pilicode

The Fig. 25 actual and fitted plot for rainfall showed that the fitted and actual value were similar with more fluctuations as compared to other weather parameters. It is a fact that in some years there will be heavy rainfall and in other years there will be very less rainfall which makes it difficult to fit the model. The fluctuations are higher for rainfall because the random variation was expected to be higher for rainfall. The observed fluctuations are less as compared to the expected which indicated that the model selected was the best model.

Table 18. The best estimated model based on trial and error method for Maximum Temperature at Pilicode

ARIMA Model		**Coefficient**	**P-value**	**AIC**	**BIC**	**Hannan-Quinn**
(0,0,1)(1,1,2)	Phi_1 theta_1 Theta_1 Theta_2	-0.85 0.39 -0.00 -0.76	9.76e-07 *** 4.01e-024 *** 0.96 2.02e-07 ***	802.171	826.413	811.753
(1,0,1)(1,1,2)	phi_1 Phi_1 theta_1 Theta_1 Theta_2	0.83 -0.41 -0.44 -0.63 -0.33	1.88e-066 *** 0.15 4.95e-08 *** 0.03 ** 0.26	737.399	765.681	748.578
(1,0,1)(1,1,1)	phi_1 Phi_1 theta_1 Theta_1	0.83 -0.06 -0.45 -0.97	3.21e-067 *** 0.22 2.79e-08 *** 3.09e-040 ***	736.181	760.423	745.7630
(1,0,1)(0,1,1)	phi_1 theta_1 Theta_1	0.82 -0.43 -1.00	2.10e-061 *** 9.84e-08 *** 3.00e-035 ***	735.729	755.930	743.713
(1,1,1)(0,1,1)	phi_1 theta_1 Theta_1	0.82 -0.44 -1.00	7.95e-074 *** 7.80e-010 *** 5.56e-024 ***	718.809	738.866	726.746
(1,0,0)(0,1,1)	phi_1 Theta_1	0.53 -0.96	2.62e-037 *** 1.63e-049 ***	754.549	770.710	760.9372
(1,0,1)(0,1,0)	phi_1 theta_1	0.60 -0.25	2.12e-010 *** 0.03 **	991.141	1007.303	997.529
(1,1,1)(1,1,2)	phi_1 Phi_1 theta_1 Theta_1 Theta_2	0.34 -0.37 -0.90 -0.70 -0.29	2.27e-08 *** 0.26 2.21e-158 *** 0.04 ** 0.39	741.005	769.270	752.178
(0,1,1)(1,1,2)	Phi_1 theta_1 Theta_1 Theta_2	-0.23 -0.64 -0.86 -0.13	0.59 9.16e-028 *** 0.05 * 0.76	759.429	783.657	769.006
(1,1,1)(1,1,1)	phi_1 Phi_1 theta_1 Theta_1	0.34 -0.08 -0.90 -0.99	3.73e-08 *** 0.10 3.40e-158 *** 6.04e-019 ***	739.435	763.662	749.011

*** P value significant at 1% level of significance
** P value significant at 5% level of significance
* P value significant at 10% level of significance

The results presented in Table 18 indicated that AIC (718.809), BIC (738.866) and Hannan- Quinn (726.746) were lowest for the model SARIMA (1,0,1)(0,1,1). This implied that the maximum temperature of t^{th} period depends on maximum temperature at $(t-1)^{th}, (t-12)^{th}$ and $(t-13)^{th}$ period. The graph of the best estimated model is presented in Fig.26.

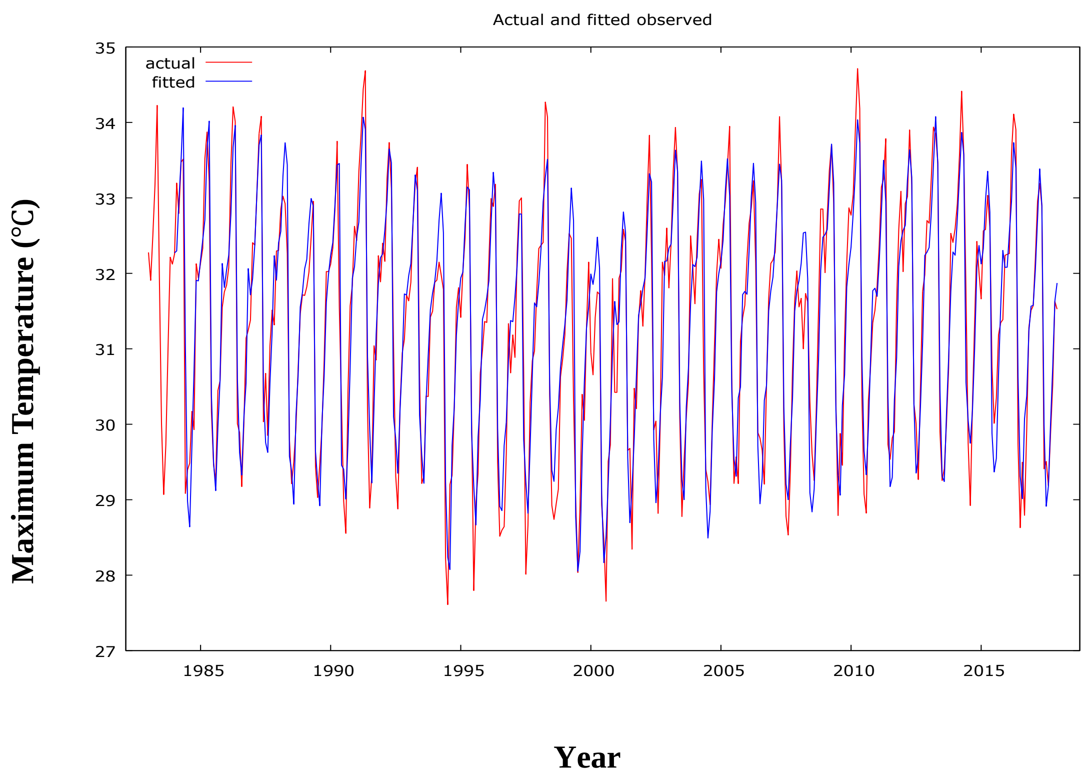

Figure 26. Actual and fitted trend plot for monthly Maximum Temperature over the years at Pilicode

The Fig. 26 indicated that the fitted and actual values highly coincide which indicates that the given model for maximum temperature was a good model. The fluctuations are very less for the fitted values from the observed values which indicated that the model estimated was the best model for maximum temperature.

Table 19. The best estimated model based on trial and error for Minimum Temperature at Pilicode

ARIMA Model		Coefficient	P-value	AIC	BIC	Hannan-Quinn
(1,0,0)(1,1,0)	phi_1 Phi_1	0.47 -0.49	5.35e-027 *** 1.75e-030 ***	1088.917	1105.078	1095.305
(1,0,1)(1,1,0)	phi_1 Phi_1 theta_1	0.68 -0.48 -0.27	1.83e-025 *** 6.08e-029 *** 0.00 ***	1081.640	1101.841	1089.624
(1,1,0)(1,1,0)	phi_1 Phi_1	-0.38 -0.48	1.40e-017 *** 3.49e-029 ***	1142.391	1158.542	1148.775
(1,1,1)(1,1,0)	phi_1 Phi_1 theta_1	0.47 -0.49 -1.00	4.60e-027 *** 3.00e-030 *** 0.00 ***	1094.807	1114.997	1102.788
(2,1,1)(1,1,0)	phi_1 phi_2 Phi_1 theta_1	0.40 0.16 -0.48 -1.00	1.63e-016 *** 0.00 *** 7.13e-029 *** 0.00 ***	1085.639	1109.866	1095.215
(1,1,1)(0,1,1)	phi_1 theta_1 Theta_1	0.42 -0.99 -0.94	5.18e-021 *** 0.00 *** 1.64e-097 ***	982.917	1003.107	990.8979
(1,1,1)(1,0,1)	phi_1 Phi_1 theta_1 Theta_1	0.43 0.99 -0.99 -0.95	0.00 *** 0.00 *** 0.00 *** 0.00 ***	1015.812	1040.209	1025.445
(1,1,1)(1,1,1)	phi_1 Phi_1 theta_1 Theta_1	0.42 0.02 -0.99 -0.95	4.53e-021 *** 0.61 0.00 *** 1.86e-070 ***	984.659	1008.886	994.235
(1,0,1)(0,1,1)	phi_1 theta_1 Theta_1	0.63 -0.28 -0.95	1.12e-014 *** 0.0035 *** 1.61e-065 ***	940.232	960.288	948.168
(1,0,1)(1,1,1)	phi_1 Phi_1 theta_1 Theta_1	0.67 0.04 -0.30 -0.95	7.50e-020 *** 0.47 0.00 *** 2.33e-078 ***	968.528	992.770	978.109

*** P value significant at 1% level of significance

The results presented in Table 19 indicated least AIC (940.232), BIC (960.288) and Hannan- Quinn (948.168) was reported for the model SARIMA (1,0,1)(0,1,1). This implied that the minimum temperature of t^{th} period depends on minimum temperature at $(t-1)^{th}$, $(t-12)^{th}$ and $(t-13)^{th}$ period. The best model identified by X12 ARIMA and trial and error method for rainfall, maximum temperature and minimum temperature are found to be the same. The graph of the best estimated model is presented in Fig.27.

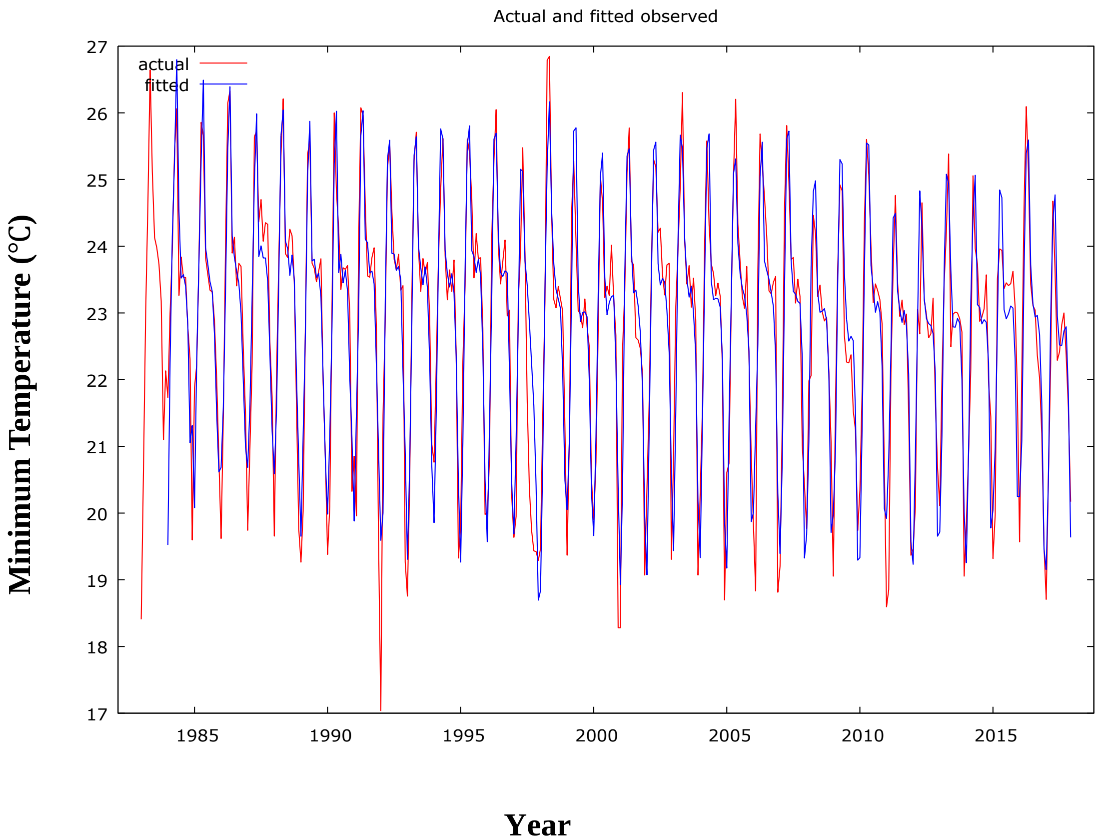

Figure 27. Actual and fitted trend plot for monthly Minimum Temperature over the years at Pilicode

The Fig. 27 indicated that the fitted and actual values highly coincide which indicates that the given model is the best model. There are some fluctuations in minimum temperature which are random. The fluctuation in minimum temperature was very low compared to the rainfall. The deviation from normal mean minimum temperature was low which indicated that the estimated model was the best model for minimum temperature.

The final stage of modelling is the diagnostic fitted model which was done by conducting the Ljung-Box test for autocorrelation. The Ljung-Box test was used to detect the presence of autocorrelation in the residuals is given in Table 20.

Table 20. Diagnostic checking of the best model at Pilicode

Weather Parameter	Automatic ARIMA Model	Ljung-Box Q'	P value
Rainfall	(0,1,1)(0,1,1)	29.68	0.63
Maximum Temperature	(1,0,1)(0,1,1)	34.39	0.15
Minimum Temperature	(1,0,1)(0,1,1)	22.91	0.96

The result from Table 20 showed that for rainfall, maximum temperature and minimum temperature the p value is greater than 0.05 which indicated the absence of autocorrelation between residuals. This indicated that the model determined for the different weather parameters are the best fit.

The best selected model in the equation form for the weather parameters are presented in Table 21.

Table 21. SARIMA model equation for weather parameters at Pilicode

Weather Parameter	SARIMA Model Equation
Rainfall	$Y_t = Y_{t-1} + Y_{t-12} - Y_{t-13} + e_t - 0.97e_{t-1} - 0.97e_{t-12} + 0.94e_{t-13}$
Maximum Temperature	$Y_t = Y_{t-12} + 0.82Y_{t-1} - 0.82Y_{t-13} + e_t - 0.44e_{t-1} - 1.00e_{t-12} + 0.44\,e_{t-13}$
Minimum Temperature	$Y_t = Y_{t-12} + 0.63Y_{t-1} - 0.63Y_{t-13} + e_t - 0.28e_{t-1} - 0.95e_{t-12} + 0.27e_{t-13}$

The next stage after the identification of the best model was the forecasting of the model. The forecasting was done for next one year using X12 ARIMA module of Gretl open source software. The estimated and forecasted rainfall, maximum temperature and minimum temperature are given in Table 22, Table 23 and Table 24.

Table 22. Forecasted monthly Rainfall using estimated model for 2018 at Pilicode

Month	**Forecasted Rainfall (mm)**	**Standard Error**	**Observed Rainfall (mm)**	**Variation from Predicted Value**
2018.Jan	7.49	170.53	0	7.49
2018.Feb	2.72	170.57	1.6	1.12
2018.Mar	20.08	170.62	36.9	-16.82
2018.Apr	46.03	170.67	10.1	35.93
2018.May	157.76	170.71	215.1	-57.34
2018.Jun	955.51	170.76	925.3	30.21
2018.Jul	924.14	170.81	898.2	25.94
2018.Aug	618.95	170.85	692.6	-73.65
2018.Sep	305.40	170.90	280.06	25.34
2018.Oct	243.06	170.94	155.3	87.76
2018.Nov	91.91	170.99	55.8	36.11
2018.Dec	16.76	170.04	18	-1.24

The results from Table 22 showed the forecasted rainfall for one year and it was compared with the observed rainfall in the same year. The results revealed that there was not much variation between the forecasted and observed rainfall. This result also indicated the fact that Kerala flood 2018 was not much affected in the Kasaragod district. The mean absolute error for rainfall was only 0.592 which confirmed that forecasted and observed were almost equal.

Table 23. Forecasted monthly Maximum Temperature using estimated model for 2018 at Pilicode

Month	**Forecasted Maximum Temperature (℃)**	**Standard Error**	**Observed Maximum Temperature (℃)**	**Variation from Predicted Value**
2018.Jan	31.79	0.51	30.97	0.82
2018.Feb	32.26	0.54	31.68	0.58
2018.Mar	32.87	0.56	32.41	0.46
2018.Apr	33.44	0.58	33.13	0.31
2018.May	33.17	0.59	32.35	0.82
2018.Jun	30.11	0.59	29.55	0.56
2018.Jul	29.27	0.60	29.99	-0.72
2018.Aug	29.26	0.60	29.33	-0.07
2018.Sep	30.09	0.60	30.57	-0.48
2018.Oct	30.90	0.60	31.00	-0.10
2018.Nov	31.86	0.61	31.82	0.04
2018.Dec	32.07	0.61	31.39	0.68

The results from Table 23 showed the forecasted maximum temperature for one year and it was compared with the observed minimum temperature in the same year. The results revealed that there was not much variation between the forecasted and observed maximum temperature. The mean absolute error for maximum temperature was only 0.015 which confirmed that forecasted and observed were almost equal.

Roy and Das (2012) conducted a research on the time series analysis of air temperature for a period of 30 years (1981–2010) in the Dibrugarh city of Assam. The results showed that the ARIMA (0, 0, 1) (0, 1, 1)12 model was found to be adequate for forecasting the monthly temperature.

Table 24. Forecasted monthly Minimum Temperature using estimated model for 2018 at Pilicode

Month	**Forecasted Minimum Temperature (℃)**	**Standard Error**	**Observed Minimum Temperature (℃)**	**Variation from Predicted Value**
2018.Jan	19.48	0.71	20.12	-0.64
2018.Feb	20.85	0.76	21.14	-0.29
2018.Mar	23.09	0.78	23.62	-0.53
2018.Apr	24.74	0.79	24.65	0.09
2018.May	24.81	0.79	24.79	0.02
2018.Jun	23.35	0.79	24.11	-0.76
2018.Jul	23.00	0.79	24.37	-1.37
2018.Aug	22.87	0.79	23.94	-1.07
2018.Sep	22.84	0.79	24.15	-1.31
2018.Oct	22.75	0.79	24.36	-1.61
2018.Nov	21.90	0.79	23.85	-1.95
2018.Dec	19.81	0.79	21.81	-2.00

The results from Table 24 showed the forecasted minimum temperature for one year ahead and it was compared with the observed minimum temperature in the same year. The results revealed that there was not much variation between the forecasted and observed minimum temperature. The mean absolute error for minimum temperature was only 0.041 which confirmed that forecasted and observed were almost equal.

The graph of forecasted and actual rainfall, maximum temperature and minimum temperature are depicted in Fig. 28, Fig. 29 and Fig. 30.

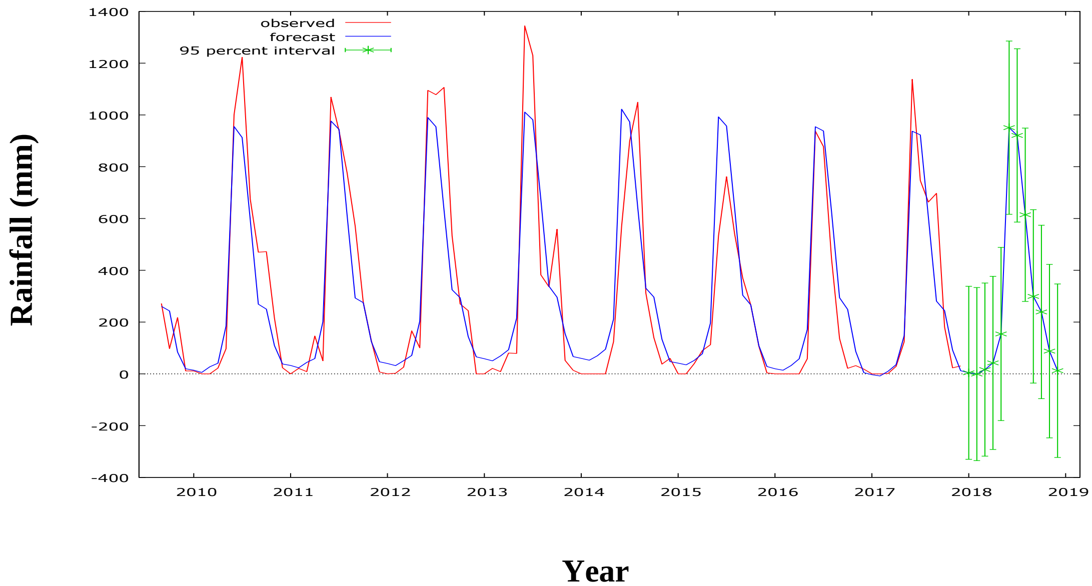

Figure 28. Forecasted plot for monthly Rainfall using estimated model at Pilicode

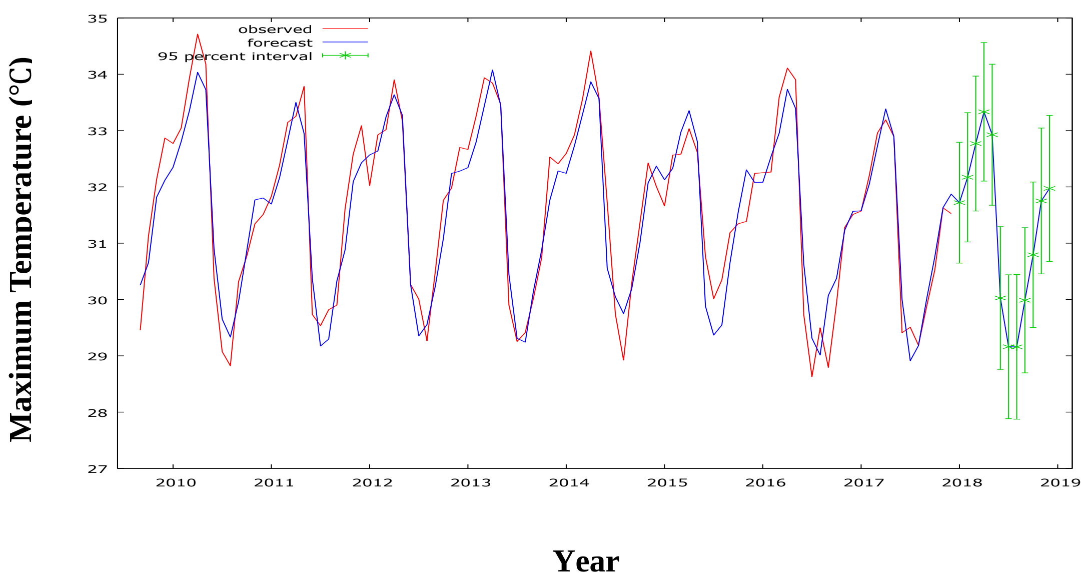

Figure 29. Forecasted plot for monthly Maximum Temperature using estimated model at Pilicode

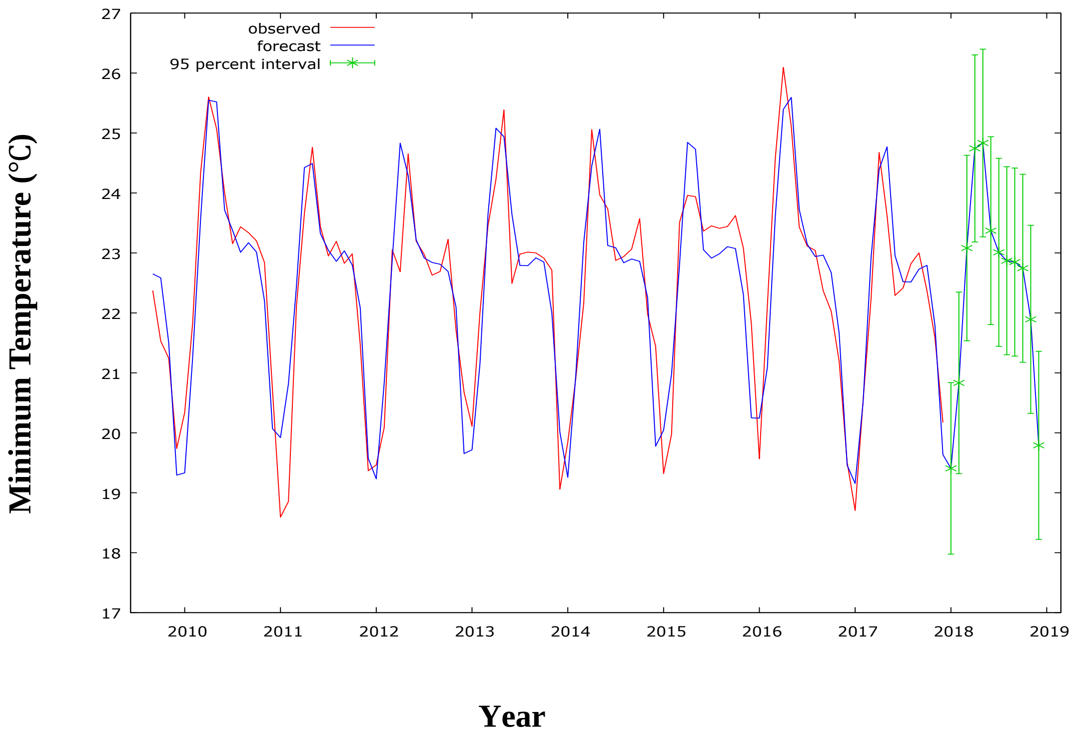

Figure 30. Forecasted plot for monthly Minimum Temperature using estimated Model at Pilicode

The Fig.28 provides the forecasted and observed plot for rainfall which showed that the forecasted and observed value are similar with more fluctuations as compared to other weather parameters. It is known that in some years there will be heavy rainfall and in other years there will be very less rainfall which makes it difficult to forecast the rainfall. Even though the fluctuations are higher it was expected since the weather parameter modelled and forecasted was rainfall. The observed fluctuations are less as compared to the expectation which indicated that the model selected was the best. The predicted values for 2018 had some fluctuations but it was almost the same as the original rainfall.

The Fig.29 indicated that the forecasted and observed values highly coincide which indicated that the given model for maximum temperature was the best model. The fluctuations are very less for the forecasted from the observed values which indicated that model estimated was the best model for maximum temperature. The predicted graph for 2018 has almost the same pattern of original maximum temperature.

The Fig.30 indicated that the forecasted and observed values highly coincide which indicates that the given model is the best model. There are some fluctuations in minimum temperature which are random. The fluctuation in minimum temperature was very low as compared to the rainfall. The predicted graph for 2018 was almost the same as the pattern of original minimum temperature.

4.3.2 Models for change in Weather Parameters for RARS Pattambi

The monthly weather data consist of rainfall, maximum temperature and minimum temperature for a period of 1982-2017 from RARS, Pattambi were used to developing of forecasting models. The R programming and an open source software Gretl was used for best model identification, estimation and diagnostic checking. The development of a model would help in better understanding of changes in weather parameters and to predict the future values. Different types of time series models are available for better perception of the data and the Seasonal ARIMA model was used in this study for modelling of rainfall, maximum temperature and minimum temperature.

4.3.2.1 Seasonal ARIMA models for Weather Parameters of RARS, Pattambi

Before the development of a model, the stationarity of the time series data used in the study should be verified. The stationarity of a time series data generally tested by using Augmented Dickey Fuller (ADF) test. The Seasonal ARIMA model can be represented by using its parameters as (p,d,q)(P,D,Q)m. The (p,d,q) stands for the non-seasonal part of the ARIMA model and (P,D,Q)m stands for the seasonal part of the ARIMA model (Goswami *et al.* 2017).

The model identification, parameter estimation and diagnostic checking are the different stages in identifying the patterns in time series data for ARIMA and Seasonal ARIMA models. Similar procedure explained in section 4.3.1 was adopted to model the changes in weather parameters at Pattambi and the results are presented in Table 26.

Table 25 provides the results of the unit root test conducted by the X12 ARIMA automatically and it detected that the rainfall and maximum temperature were stationary whereas the minimum temperature was non stationary for the non-seasonal part of the SARIMA model in the level form. The SARIMA model needs differencing for the seasonal part since the D value is 1 for all the weather parameters.

Table 25. The best selected model for weather parameters of Pattambi

Weather Parameter	**Unit Root Test**		**Automatic ARIMA Model**
	Difference Order		
	Non-Seasonal	**Seasonal**	
Rainfall	0	1	(0,0,0)(0,1,1)
Maximum Temperature	0	1	(1,0,1)(0,1,1)
Minimum Temperature	1	1	(0,1,1)(0,1,1)

It is reported that the best estimated model for rainfall, maximum temperature and minimum temperature was Seasonal ARIMA (0,1,1,)(0,1,1)12, (1,0,1)(0,1,1)12 and (1,0,1)(0,1,1)12 respectively. The parameters of best fitted models for rainfall, maximum temperature and minimum temperature along with model selection criteria are presented in Table 26.

Table 26. The estimation of model of the weather parameters of Pattambi

Weather Parameter		**Coefficient**	**P-value**	**AIC**	**BIC**	**Hannan-Quinn**
Rainfall	Theta_1	-0.96	1.11e-074 ***	5127.35	5141.73	5163.72
Maximum Temperature	phi_1 theta_1 Theta_1	0.72 -0.55 -0.87	5.00e-09 *** 0.00 *** 1.64e-203 ***	1011.36	1031.56	1019.35
Minimum Temperature	theta_1 Theta_1	-0.46 -0.96	1.18e-022 *** 5.52e-084 ***	1053.78	1069.93	1060.16

*** P value significant at 1% level of significance

The results from Table 26 showed the parameters of AR and MA terms are significant for the weather parameters rainfall, maximum temperature and minimum temperature at Pattambi.

Almost similar results were reported by Murthy *et al*., (2019) that SARIMA (1,0,0)(0,1,1)12 model fits best for modelling and forecasting the monthly maximum and minimum temperatures in the Indian geographical region.

The best Seasonal ARIMA model for all the weather parameters was automatically selected by the X12 ARIMA. The trial and error method is used in order to check the presence of any other best model with least AIC, BIC and Hennan-Quinn coefficient value. The results of the models identified and best model selected for different weather parameters are presented in Table 27, Table 28 and Table 29.

Table 27. The best estimated model based on trial and error method for Rainfall from 1982-2017 at Pattambi

ARIMA Model		**Coefficient**	**P-value**	**AIC**	**BIC**	**Hannan-Quinn**
(0,0,1)(1,1,0)	Phi_1 theta_1	-0.57 0.09	2.38e-048 *** 0.03 **	5512.61	5528.88	5519.04
(1,0,1)(1,1,0)	phi_1 Phi_1 theta_1	0.35 -0.58 -0.24	0.27 8.59e-049 *** 0.45	5513.70	5534.04	5521.73
(2,0,1)(1,1,0)	phi_1 phi_2 Phi_1 theta_1	-0.02 0.05 -0.58 0.13	0.96 0.53 8.30e-049 *** 0.85	5515.47	5539.88	5525.10
(0,0,0)(0,1,1)	Theta_1	-0.96	1.11e-074 ***	5127.35	5141.73	5163.72
(1,0,1)(0,1,0)	phi_1 theta_1	0.08 -0.04	0.89 0.94	5680.72	5696.99	5687.14
(1,0,1)(1,0,0)	phi_1 Phi_1 theta_1	0.23 0.72 -0.08	0.27 4.40e-086 *** 0.69	5789.40	5809.88	5797.47
(1,0,1)(0,0,1)	phi_1 theta_1 Theta_1	0.37 0.07 0.34	1.50e-05 *** 0.41 2.39e-022 ***	5926.80	5947.28	5934.88
(0,0,1)(0,0,1)	theta_1 Theta_1	0.36 0.36	2.30e-019 *** 4.22e-026 ***	5938.00	5954.38	5944.46
(0,0,1)(1,0,0)	Phi_1 theta_1	0.72 0.13	3.53e-094 *** 0.00 ***	5788.32	5804.71	5794.78
(2,0,1)(1,0,0)	phi_1 phi_2 Phi_1 theta_1	-0.29 0.10 0.72 0.44	0.56 0.21 1.52e-085 *** 0.39	5790.83	5815.40	5800.52

*** P value significant at 1% level of significance
** P value significant at 5% level of significance
* P value significant at 10% level of significance

The results recorded in Table 27 concluded that AIC (5127.35), BIC (5141.73) and Hannan- Quinn (5163.72) were lowest for the model SARIMA (0,0,0)(0,1,1)12. This implied that the rainfall of t^{th} period depends on rainfall at $(t-12)^{th}$ period. The graph of the best estimated model is presented in Fig.31.

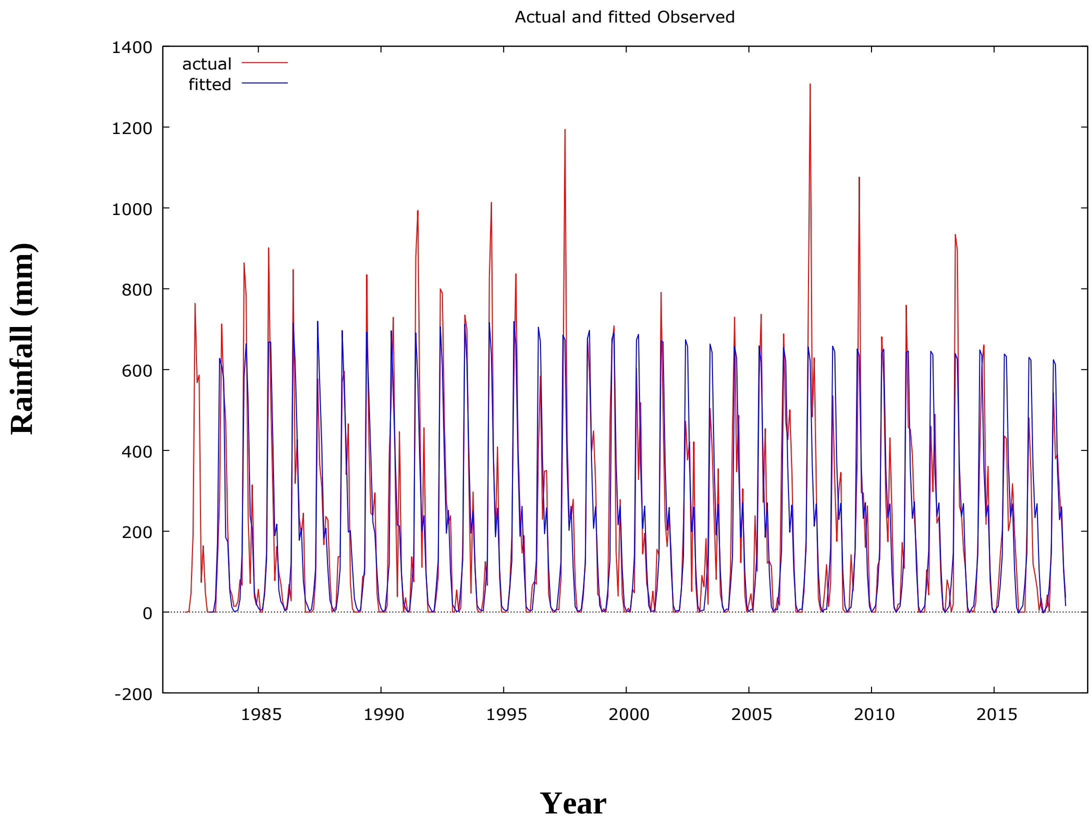

Figure 31. Actual and fitted trend plot for monthly Rainfall over the years at Pattambi

The (Fig.31) actual and fitted plot for rainfall showed that the fitted and actual value were similar with few variations contrast to other weather parameters. It was known that over the years there were some years with heavy rainfall and also years with very less rainfall which make it difficult for fitting the model. However the variations are higher but it was conventional since the weather modeled and fitted was rainfall. The model selected was the best since the observed fluctuations are less compared to the expected. The variations in rainfall for Pattambi was more compared to Pilicode.

Table 28. The best estimated model based on trial and error method for Maximum temperature at from 1982 to 2017 at Pattambi

ARIMA Model		Coefficient	P-value	AIC	BIC	Hannan-Quinn
(3,0,0)(0,1,1)	phi_1 phi_2 phi_3 Theta_1	0.18 0.04 0.14 -0.88	0.00 *** 0.33 0.00 *** 4.56 e-23 ***	1041.53	1065.94	1051.16
(1,0,0)(0,1,1)	phi_1 Theta_1	0.21 -0.90	7.08e-06 *** 6.07e-225 ***	1048.78	1065.05	1055.20
(1,0,1)(0,1,1)	phi_1 theta_1 Theta_1	0.72 -0.55 -0.87	5.00e-09 *** 0.00 *** 1.64e-203 ***	1011.36	1031.56	1019.35
(3,0,0)(1,0,1)	phi_1 phi_2 phi_3 Theta_1	0.20 0.04 0.13 -0.88	1.74e-05 *** 0.30 0.00 *** 2.53e-225 ***	1095.25	1123.92	1106.55
(3,0,0)(1,1,0)	phi_1 phi_2 phi_3 Phi_1	0.16 0.02 0.20 -0.49	0.00 *** 0.54 3.10e-05 *** 1.98e-032 ***	1172.45	1196.86	1182.08
(3,0,0)(0,0,0)	phi_1 phi_2 phi_3	0.92 -0.11 -0.32	1.44e-094 *** 0.06 * 2.63e-013 ***	1528.15	1548.63	1536.23
(2,0,0)(1,0,1)	phi_1 phi_2 Phi_1 Theta_1	0.21 0.07 0.99 -0.89	5.38e-06 *** 0.10 0.00 *** 2.15e-231 ***	1100.71	1125.29	1110.41
(3,0,0)(1,1,1)	phi_1 phi_2 phi_3 Phi_1 Theta_1	0.18 0.04 0.14 -0.05 -0.87	0.00 *** 0.32 0.00 *** 0.32 1.19e-150 ***	1042.58	1071.06	1053.82
(1,0,1)(1,0,1)	phi_1 Phi_1 theta_1 Theta_1	0.63 0.99 -0.42 -0.89	1.18e-06 *** 0.00 *** 0.00 *** 1.12e-232 ***	1098.43	1123.01	1108.12
(3,0,0)(0,1,2)	phi_1 phi_2 phi_3 Theta_1 Theta_2	0.18 0.04 0.14 -0.93 0.05	0.00 *** 0.32 0.00 *** 3.83e-070 *** 0.28	1042.37	1070.85	1053.61

*** P value significant at 1% level of significance
** P value significant at 5% level of significance
* P value significant at 10% level of significance

The results presented in Table 28 indicated that AIC (1011.36), BIC (1031.56) and Hannan- Quinn (1019.35) were lowest for the model SARIMA (1,0,1)(0,1,1)12. This implied that the maximum temperature of t^{th} period depends on maximum temperature at $(t-1)^{th}$, $(t-12)^{th}$ and $(t-13)^{th}$ period. The graph of the best estimated model is presented in Fig.32.

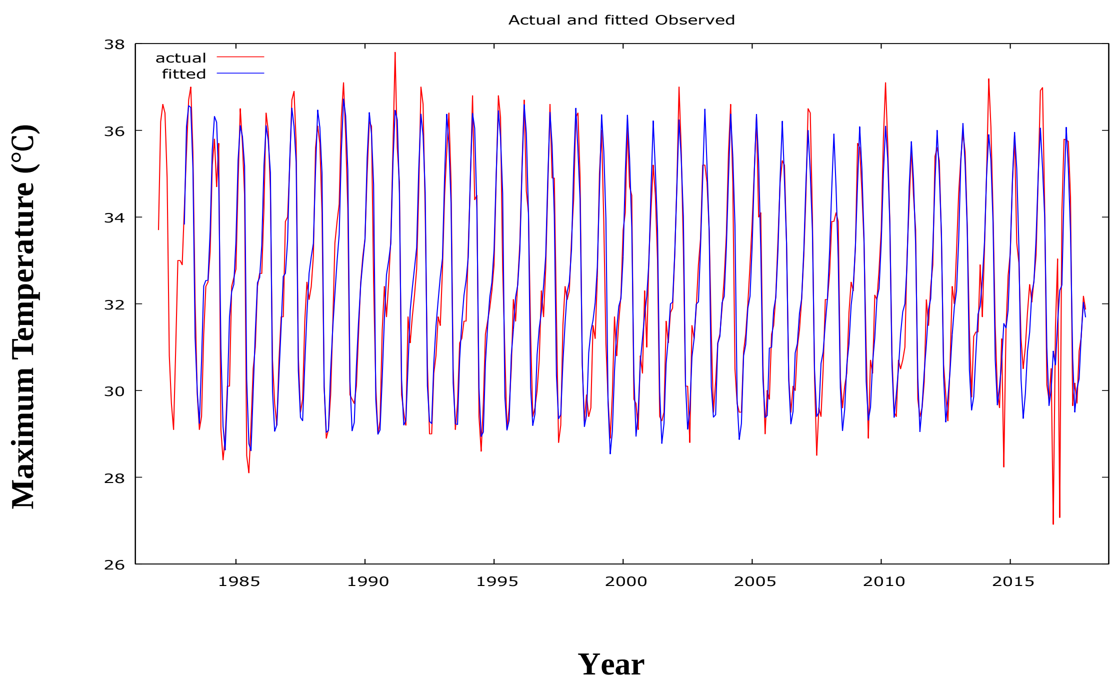

Figure 32. Actual and fitted trend plot for monthly Maximum Temperature over the years at Pattambi

The Fig. 32 revealed that the fitted and actual values highly coincide which showed that the given model for maximum temperature was the best model. The variations are very least for the fitted from the observed values which concluded that model estimated was the best model for maximum temperature.

Table 29. The best estimated model based on trial and error method for Minimum temperature at from 1982 to 2017 at Pattambi

ARIMA Model		**Coefficient**	**P-value**	**AIC**	**BIC**	**Hannan -Quinn**
(0,1,1)(0,0,0)	theta_1	0.09	0.03 **	1513.72	1526.00	1518.56
(0,1,1)(1,0,0)	Phi_1 theta_1	0.67 -0.41	5.90e-074 *** 7.10e-017 ***	1340.25	1356.63	1346.71
(0,1,1)(1,0,1)	Phi_1 theta_1 Theta_1	0.99 -0.49 -0.91	0.00 *** 1.05e-025 *** 2.55e-145 ***	1162.28	1182.75	1170.35
(1,0,1)(1,0,1)	phi_1 Phi_1 theta_1 Theta_1	0.82 0.99 -0.35 -0.88	3.93e-097 *** 0.00 *** 4.97e-09 *** 2.58e-114 ***	1133.88	1158.45	1143.57
(1,1,1)(1,0,1)	phi_1 Phi_1 theta_1 Theta_1	0.49 0.99 -0.94 -0.91	1.55e-021 *** 0.00 *** 0.00 *** 8.89e-126 ***	1150.35	1174.91	1160.03
(1,0,1)(1,1,1)	phi_1 Phi_1 theta_1 Theta_1	0.83 -0.05 -0.38 -0.87	2.23e-108 *** 0.40 1.62e-010 *** 5.20e-064 ***	1095.82	1120.23	1105.46
(1,1,1)(1,1,1)	phi_1 Phi_1 theta_1 Theta_1	0.45 -0.10 -0.92 -0.88	4.81e-014 *** 0.08 * 5.52e-182 *** 1.01e-086 ***	1115.79	1140.19	1125.43
(0,1,1)(0,1,1)	theta_1 Theta_1	-0.46 -0.96	1.18e-022 *** 5.52e-084 ***	1053.78	1069.93	1060.16
(1,1,1)(1,0,0)	phi_1 Phi_1 theta_1	0.57 0.56 -1.00	8.58e-048 *** 1.81e-042 *** 0.00 ***	1295.50	1315.97	1303.57
(1,0,1)(0,1,1)	phi_1 theta_1 Theta_1	0.83 -0.38 -0.90	4.33e-108 *** 1.17e-010 *** 5.47e-120 ***	1094.53	1114.88	1102.57

*** P value significant at 1% level of significance
** P value significant at 5% level of significance
* P value significant at 10% level of significance

The results presented in Table 29 indicated that AIC (1053.78), BIC (1069.93) and Hannan- Quinn (1060.16) were lowest for the model SARIMA (1,0,1)(0,1,1). This implied that the minimum temperature of t^{th} period depends on minimum temperature at $(t-1)^{th}$, $(t-12)^{th}$ and $(t-13)^{th}$ period. The graph of the best estimated model is presented in Fig.33.

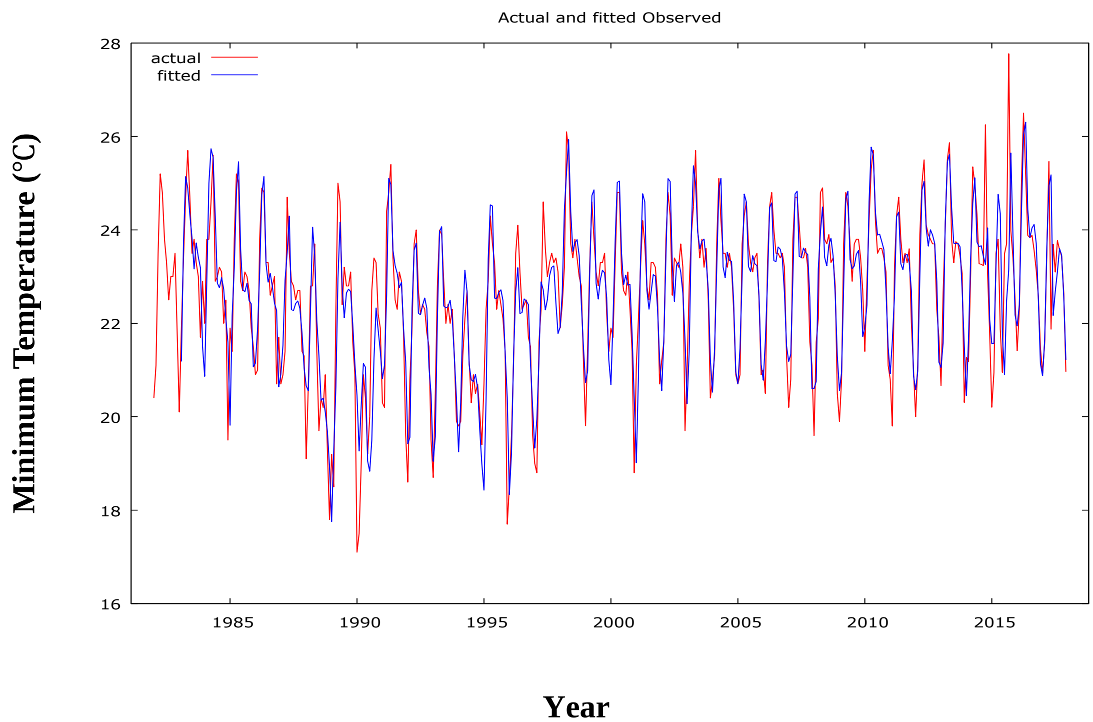

Figure 33. Actual and fitted trend plot for monthly Minimum Temperature over the years at Pattambi

The Fig. 33 indicated that the fitted and actual values highly coincide which indicates that the given model is the best model. There are some variations in minimum temperature which are random and very little compared to the rainfall. The deviation from observed minimum temperature was least which indicated that the estimated model was the best model.

The final stage of modelling is the diagnostic fitted model which was done by conducting the Ljung-Box test for autocorrelation of residuals (Murthy *et al.*, 2018). The Ljung-Box test was used to detect the presence of autocorrelation in the residuals which is given in Table 31. The result presented in Table 30 indicated that the p value is greater than 0.05 for rainfall, maximum temperature and minimum temperature which confirmed the absence of autocorrelation between residuals. This revealed that the model selected for the different weather parameters are the best fit.

Table 30. Diagnostic checking of weather parameter at Pattambi

Weather Parameter	**Automatic ARIMA Model**	**Ljung-Box Q'**	**P value**
Rainfall	(0,0,0)(0,1,1)	19.23	0.73
Maximum Temperature	(1,0,1)(0,1,1)	44.58	0.06
Minimum Temperature	(0,1,1)(0,1,1)	53.49	0.06

The best selected model in the equation form for the weather parameters are presented in Table 31.

Table 31. SARIMA model equation for weather parameters of Pattambi

Weather Parameter	**SARIMA Model Equation**
Rainfall	$Y_t = Y_{t-12} + e_t - 0.96e_{t-12}$
Maximum Temperature	$Y_t = Y_{t-12} + 0.72Y_{t-1} - 0.72Y_{t-13} + e_t - 0.55e_{t-1} - 0.87e_{t-12} + 0.48e_{t-13}$
Minimum Temperature	$Y_t = Y_{t-1} + Y_{t-12} - Y_{t-13} + e_t - 0.46e_{t-1} - 0.96e_{t-12} + 0.45e_{t-13}$

The next stage after the identification of the best model was the forecasting of the model. The forecasting was done for next one year using X12 ARIMA module of Gretl open source softwares. The estimated and forecasted rainfall, maximum temperature and minimum temperature are given in Table 32, Table 33 and Table 34.

Table 32. Forecasted monthly Rainfall using estimated model for 2018 at Pattambi

Month	**Forecasted Rainfall (mm)**	**Standard Error**	**Observed Rainfall**	**Variation from Predicted Value (mm)**
2018.Jan	1.27	103.58	0.00	1.27
2018.Feb	13.64	103.58	46.30	-32.66
2018.Mar	29.02	103.58	68.40	-39.38
2018.Apr	65.81	103.58	48.00	17.81
2018.May	154.68	103.58	407.10	-252.42
2018.Jun	587.59	103.58	790.20	-202.61
2018.Jul	465.63	104.01	713.00	-247.37
2018.Aug	347.04	103.58	670.50	-323.46
2018.Sep	248.87	103.58	38.30	210.57
2018.Oct	254.64	103.58	185.90	68.74
2018.Nov	108.29	103.58	10.60	97.69
2018.Dec	25.03	103.58	1.40	23.63

The results from Table 32 showed the forecasted rainfall for one year and it was compared with the observed rainfall observed in the same year. The results revealed that there was much variation between the forecasted and observed rainfall in the months of May, June, July, August and September which was due to the heavy rainfall occurred in the year of 2018 which led to the occurrence of Kerala flood 2018. The mean absolute error for rainfall was only 3.210 which confirmed that forecasted and observed were almost equal.

Table 33. Forecasted monthly Maximum Temperature using estimated model for 2018 at Pattambi

Month	**Forecasted Maximum Temperature (℃)**	**Standard Error**	**Observed Maximum Temperature**	**Variation from Predicted Value (℃)**
2018.Jan	33.31	0.64	32.77	0.54
2018.Feb	34.99	0.66	34.60	0.39
2018.Mar	36.05	0.67	35.58	0.47
2018.Apr	35.28	0.68	35.45	-0.17
2018.May	33.83	0.68	32.31	1.52
2018.Jun	30.49	0.68	29.69	0.80
2018.Jul	29.70	0.68	29.27	0.43
2018.Aug	30.01	0.68	28.63	1.38
2018.Sep	30.86	0.69	32.25	-1.39
2018.Oct	31.52	0.68	32.32	-0.80
2018.Nov	32.06	0.68	32.64	-0.58
2018.Dec	32.30	0.69	32.77	-0.47

The results from Table 33 showed the forecasted maximum temperature for one year and it was compared with the observed maximum temperature observed in the same year. The results revealed that there was not much variation between the forecasted and observed maximum temperature. The mean absolute error for maximum temperature was only 0.023 which confirmed that forecasted and observed were almost equal.

Table 34. Forecasted monthly Minimum Temperature using estimated model for 2018 at Pattambi

Month	**Forecasted Minimum Temperature (℃)**	**Standard Error**	**Observed Minimum Temperature**	**Variation from Predicted Value (℃)**
2018.Jan	20.73	0.61	19.67	1.06
2018.Feb	21.47	0.64	19.55	1.92
2018.Mar	23.46	0.67	22.40	1.06
2018.Apr	24.84	0.70	23.88	0.96
2018.May	24.83	0.73	22.22	2.61
2018.Jun	23.57	0.76	22.58	0.99
2018.Jul	23.12	0.78	22.16	0.96
2018.Aug	23.26	0.81	22.05	1.21
2018.Sep	23.24	0.83	24.16	-0.92
2018.Oct	23.15	0.86	22.15	1.00
2018.Nov	22.38	0.88	21.85	0.53
2018.Dec	20.96	0.90	20.89	0.07

The results from Table 34 showed the forecasted minimum temperature for one year and it was compared with the observed minimum temperature observed in the same year. The results revealed that there was not much variation between the forecasted and observed minimum temperature. The mean absolute error for minimum temperature was only 0.050 which confirmed that forecasted and observed were almost equal.

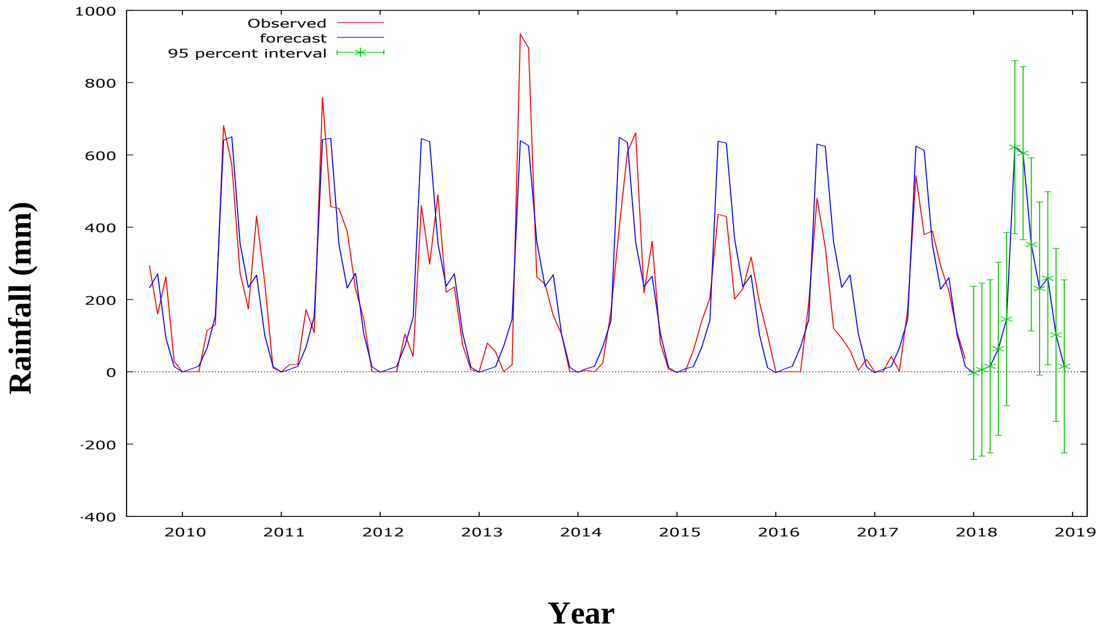

Figure 34. Forecasted plot for monthly rainfall using estimated model at Pattambi

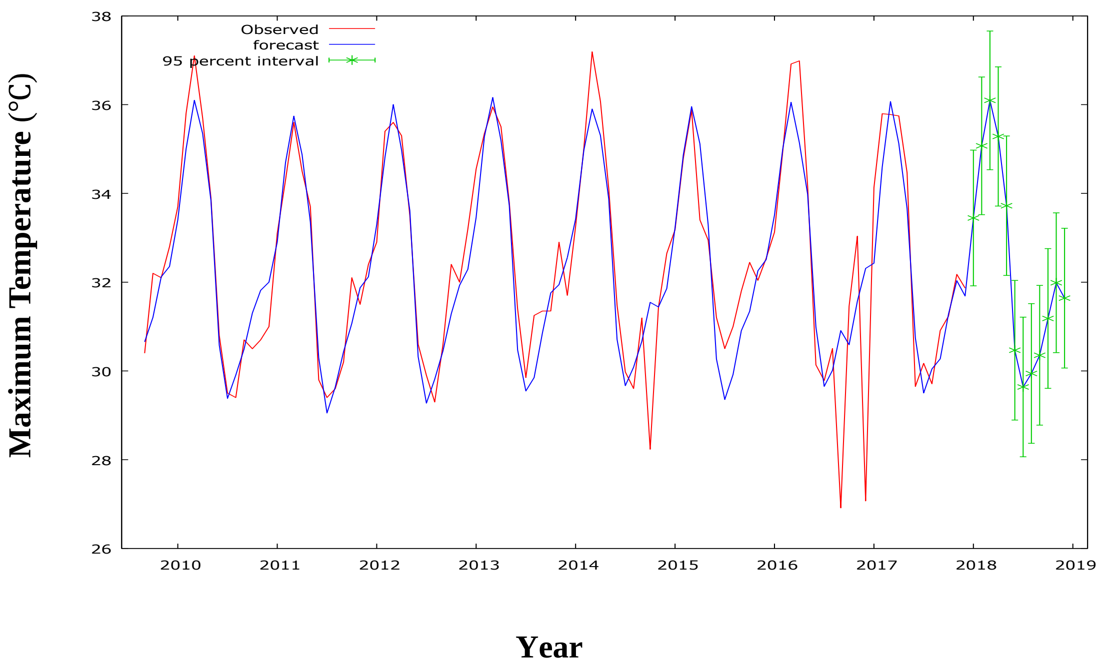

Figure 35. Forecasted plot for monthly Maximum Temperature using estimated model at Pattambi

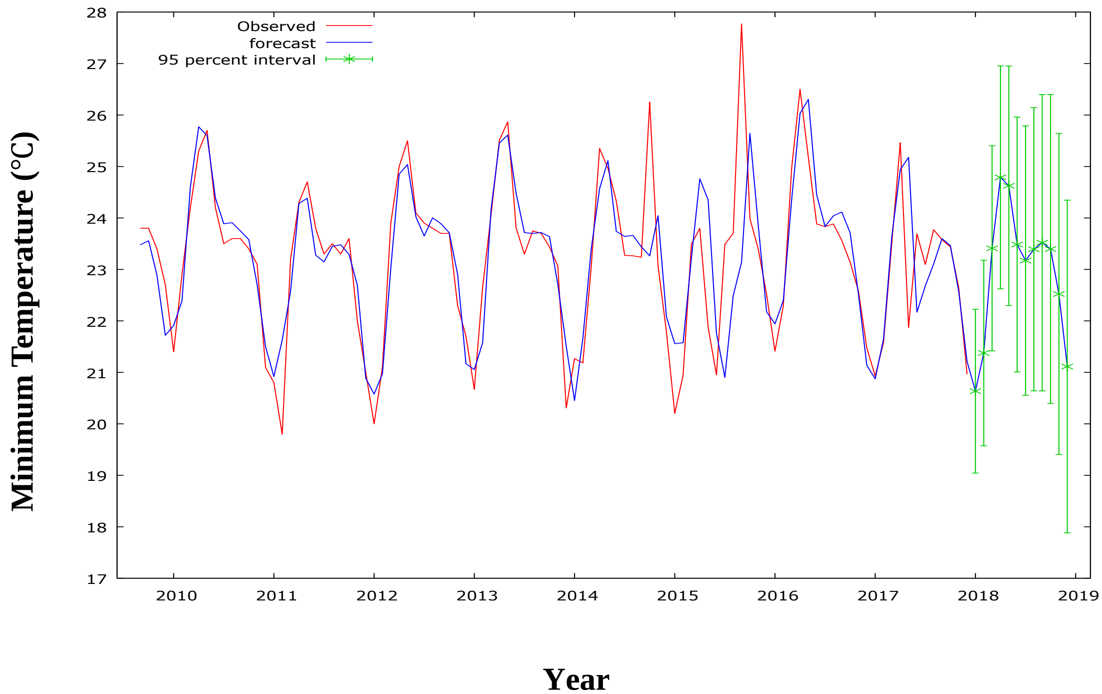

Figure 36. Forecasted plot for monthly Minimum Temperature using estimated model at Pattambi

The Fig. 34 forecasted and observed plot for rainfall showed that the forecasted and observed value are similar with more fluctuations compared to other weather parameters. It is clear that in some years there will be heavy rainfall and in other years there will be very less rainfall which makes it difficult to forecast the rainfall. Even though the fluctuations are higher it was expected since the weather parameter modeled and forecasted was rainfall. The observed fluctuations are less compared to the expectation which concluded that the model selected was the best. The predicted values for 2018 had some variations but it was almost the same as the original rainfall. The fluctuations for rainfall was more in Pattambi compared to Pilicode.

The Fig. 35 revealed that the forecasted and observed values highly coincide which indicated that the given model for maximum temperature was the best model. The fluctuations are very small for the forecasted from the observed values which indicated that the model estimated was the best model for maximum temperature. The predicted graph for 2018 was almost the same as the pattern of original maximum temperature.

The Fig. 36 indicated that the forecasted and observed values highly coincide which indicate that the given model was the best model. There are some fluctuations in minimum temperature which are random. The fluctuations in minimum temperature was very low compared to the rainfall. The predicted graph for 2018 was almost the same as the pattern of original minimum temperature. The fluctuation for minimum temperature was more in Pattambi as compared to Pilicode.

4.4 IMPACT OF WEATHER PARAMETERS ON PADDY YIELD

Paddy is an important food crop consumed by most of the population in the world. Studies have shown that paddy production is influenced by the parameters, rainfall (Rao *et al*., 2001), maximum temperature (Kumary, 2011) and minimum temperature (Subramanyam *et al.*, 2018) and the influence of these parameters varies across agro climatic zones or regions and seasons. This is an indication of the importance of weather parameters not only in the development of the paddy crop but also in the productivity and production of paddy. The influence of rainfall, maximum temperature and minimum temperature on the production of rice was determined by using the multiple linear regressions. Paddy production in Palakkad district is prominent mainly in two seasons viz; *virippu* and *mundakan* seasons. The *virippu* paddy cultivation starts from April- May and it gets over in September-October and it mainly depends on rainfall during that period. The *mundakan* paddy cultivation starts from September-October and get completed in December-January. In order to get a clear picture about the impact of climate change on paddy production over the study period in Palakkad, the unirrigated paddy production in *virippu* and *mundakan* season was taken.

The paddy production data of Palakkad district was collected from the Report of agriculture statistics GOK, for a period of 23 years (1995-2017). The paddy production data was regressed with the weather parameters during the seasons collected from RARS, Pattambi to obtain the influence of weather on production of paddy. The weather parameters considered as the independent variables and it consisted of rainfall, maximum temperature and minimum temperature in *virippu* and *mundakan* seasons. Regression analysis was performed to analyse the influence of weather parameters on production of paddy in *virippu* and *mundakan* season separately.

4.4.1 Impact of Weather Parameter on *virippu* Paddy Production

The *virippu* paddy cultivation at Palakkad would be started in the last week of April and ended in the first week of September. The duration of medium duration paddy crop was 135 days which is almost equal to three months. So the weather data for three months along was regressed with paddy production to obtain the influence of weather parameters and change in climate on paddy yield. The monthly total rainfall for May (R_1), June (R_2) and July (R_3), mean maximum temperature of May (Mx_1), June (Mx_2) and July (Mx_3) and the mean minimum temperature of May (Mn_1), June (Mn_2) and July (Mn_3) were taken as the independent variables in the regression with the dependent variable as production of paddy.

The Table 35 consisted of production of *virippu* paddy for a period of 23 years (1995-2017) and also the monthly rainfall, maximum temperature and minimum temperature of the months May, June and July are presented. Multiple linear regression equations were determined by considering production of paddy as the dependent variable and monthly rainfall, maximum temperature and minimum temperature of the months May, June and July as the independent variables. Cobb-Douglas production function was used to determine the interrelationship of weather parameters on production. The original values are transformed using logarithmic values and the parameters are estimated using the OLS method.

The impact of climate change on crop yield will be a balance between yield increases due to elevated CO2 concentrations (Drake *et al*., 1997), any negative effects due to warmer mean temperatures mediated through changes in phenology (Craufurd and Wheeler, 2009).

Table 35. Production, monthly rainfall, maximum and minimum temperature of *virippu* paddy

Year	Production (Tonnes)	R1 (mm)	R2 (mm)	R3 (mm)	Mx1 (℃)	Mx2 (℃)	Mx3 (℃)	Mn1 (℃)	Mn2 (℃)	Mn3 (℃)
1995	122995	185.9	583.2	836.8	32.8	30.9	29.1	23.7	23.3	22.3
1996	126117	69.2	402	584	34.1	31.3	29.4	24.1	23.1	22.3
1997	119374	80.7	510.1	1194.3	34.9	31.7	28.8	24.6	23.6	23
1998	91107	134.2	678.7	590.7	34.9	30.6	29.3	25.7	23.7	23.4
1999	71291	467.2	658	708.1	31.1	29.8	28.9	23.8	23.1	22.8
2000	83337	47.7	602.6	327.9	34.5	29.8	29.7	24.8	23.1	22.7
2001	96884	142	791.2	497.8	33	29.4	29.3	23.7	22.8	22.5
2002	99514	222.9	472	376.4	33.3	30.1	30.1	24.3	22.6	23.4
2003	113045	19.8	503.6	403.6	33.7	31.3	29.5	25.7	24	23.4
2004	111981	463.3	729.7	347.1	30.5	29.7	29.5	24.2	23.5	23.5
2005	108418	101.4	567.6	736.6	34.1	30.6	29	24.6	23.7	23.3
2006	99649	396.6	688.4	470.4	33.4	30.3	29.5	24.8	24	23.5
2007	103211	184.8	728.4	1307.5	34	30.3	28.5	24.7	24.1	23.4
2008	87316	73.2	535.1	322.7	33.9	30.3	29.6	24.9	23.8	23.7
2009	99507	158.6	378.9	1076.2	33.4	31	28.9	24.5	23.7	22.9
2010	81910	130.5	681.2	572.5	33.9	30.8	29.5	25.7	24.2	23.5
2011	83813	108.4	759	456.9	33.7	29.8	29.4	24.7	23.8	23.3
2012	88195	42.5	459.7	297.8	33.5	30.6	29.9	25.5	24.1	23.9
2013	88801	19.8	934.3	895.9	34.9	28.9	28.7	25.8	23.8	23.2
2014	84343	167.4	398.9	608.3	34.1	31.4	29.9	24.9	24.3	23.2
2015	83805	203.9	435.5	429.6	32.9	31.2	30.5	21.8	20.9	23.4
2016	88689	191.7	480.6	344.6	34.1	30.1	29.7	25.1	23.8	23.8
2017	82611	172.3	437.3	485.2	34.4	29.6	30.1	21.8	23.6	23.0

Table 36. Results of multiple linear regression analysis on production of *virippu* paddy

Particulars	Coefficient	Standard error	t-ratio	P value	VIF
Intercept	13.30	8.62	1.54	0.14	
R1	-0.01	0.05	-0.19	0.85	2.33
R2	0.02	0.22	0.11	0.91	3.21
R3	-0.20	0.20	-1.02	0.32	7.34
Mx1	0.15	1.57	0.09	0.92	2.60
Mx2	4.04	2.26	1.78	0.09 *	2.81
Mx3	-7.48	5.70	-1.31	0.21	9.30
Mn1	-1.00	1.52	-0.66	0.52	4.36
Mn2	0.20	1.54	0.13	0.89	2.31
Mn3	-1.41	2.16	-0.65	0.52	1.70
Number of Observations		23			
F(10,12)		1.00			
R^2		0.412			
P-value		0.477			
Durbin-Watson		1.823			

The result presented in Table 36 indicated that none of the weather parameters was not statistically significant at 5 percent level of significance, since all the estimated P value was greater than 0.05. The rainfall in June, maximum temperature in May and June and minimum temperature in June showed a positive non-significant (5%) influence on production of *virippu* paddy. However, maximum temperature in June was significant at 9%, indicating that temperature during June had a positive significant effect on the production of paddy at Palakkad in *virippu* season. It means that sunshine hours during June were favourable for production of paddy in *virippu* season. The maximum temperature recorded in June at Pattambi was from 28.9 to 31.7℃ and Samui (1999) suggested that it was the most favourable condition for maximum yield. Moreover, Takahashi *et al*., (1955) reported that weather parameters especially temperature influences the duration and production of tillers in paddy crops which ultimately decides the yield of the paddy crop.

Rainfall in May and July, maximum temperature in July and minimum temperature in May and July showed a decrease in rice production which was statistically not significant. The VIF test was done in order to identify the presence of multicollinearity and the result showed that all the values were less than 10 which indicated the absence of multicollinearity among the independent variables. The Durbin-Watson test was done in order to identify the presence of autocorrelation and the result showed that the Durbin-Watson d-statistic value was 1.823 which was nearly equal to 2 which indicated the absence of autocorrelation among the residuals. The estimated R^2 value was only 41.2 percent indicated that only 41 percent variation in the dependent variable was explained by the independent variable included in the study.

4.4.2 Impact of Weather Parameters on *mundakan* Paddy Production

The *mundakan* paddy cultivation at Palakkad would be started in the last week of April and ended in the first week of September. Similar to the *virippu* paddy, the weather data for three months along was regressed with paddy production to obtain the influence of weather parameters and change in climate on paddy yield in the *mundakan* season. The monthly total rainfall for October (R_1), November (R_2) and December (R_3), mean maximum temperature of October (Mx_1), November (Mx_2) and December (Mx_3) and mean minimum temperature of October (Mn_1), November (Mn_2) and December (Mn_3) were selected as the independent variables to assess its impact on production of paddy.

Saseendran (2000) conducted a study on effects of climate change on paddy production in the tropical humid climate of Kerala. The result showed that increase in temperature had a positive significant effect on yield of paddy. The result also revealed that increase in rainfall also led to the increase in yield of paddy.

Wang (2016) conducted a study on contribution of climatic and technological factors to crop yield of paddy in Hunan Province, China. The result showed that rise in temperature resulted in an increase in yield of paddy.

The Table 37 consisted of production of the *mundakan* paddy for a period of 23 years (1995-2017) and also the monthly rainfall, maximum temperature and minimum temperature of the months October, November and December were presented. Multiple linear regression equations were determined by considering production of paddy as the dependent variable and monthly rainfall, maximum temperature and minimum temperature of the months October, November and December were considered as the independent variables. The transformation of original values into logarithmic values was done for the estimation and the OLS method was used for the estimation of the parameters.

Mathews *et al*., (1997) conducted a study on impact of change in temperature on paddy yield. The increase in maximum temperature showed a significant reduction in paddy yield due to spikelet sterility. The rise in maximum temperature above 35°C led to reduction in pollen viability and spikelet sterility which resulted in a decrease in yield.

Rao *et al*., (2001) conducted a study on impact of change in climate on yield of paddy. The results revealed that excess rainfall had a negative impact on paddy yield even though paddy is a water loving crop. The important phases of growth of paddy crops which need high amounts of water are the reproductive and ripening stage. The lack of rainfall during these important stages of growth of paddy plants could reduce the yield. The absence or lack of standing water after transplantation of paddy can also result in decrease in yield.

Table 37. Production, monthly rainfall, maximum and minimum temperature for *mundakan* paddy

Year	**Production (Tonnes)**	**R1 (mm)**	**R2 (mm)**	**R3 (mm)**	**Mx1 (℃)**	**Mx2 (℃)**	**Mx3 (℃)**	**Mn1 (℃)**	**Mn2 (℃)**	**Mn3 (℃)**
1995	22370	146	189.2	0	32.1	31.6	32.5	22.1	21.4	17.7
1996	20139	350.4	43	14.2	30.7	32.3	31.7	21.7	21.5	19.6
1997	19534	230.9	279.1	72	32.4	32.1	32.3	23.3	23.4	23.1
1998	19307	316.8	44.1	37.3	29.6	31.5	31.2	23	22.8	21.2
1999	17561	278.3	42.7	0.8	30.8	31.6	32.2	23.5	22.2	21.4
2000	17531	194.9	70.1	42	30.4	32.3	31	22.3	21.4	18.8
2001	19756	239.8	143.9	0	31.1	31.8	31.9	23.2	22.6	20.7
2002	17105	421.3	70.8	0	31.2	31.9	32.9	23.7	23.2	19.7
2003	9528	354.6	44.8	19.2	31.3	31.9	32.6	23.6	22.5	20.4
2004	3763	305.2	42.8	0	31.3	32	32.9	23.2	22.3	20.9
2005	40612	121.1	126.2	112.9	31.3	31.5	32.2	23.5	22.5	20.9
2006	15515	352.9	133.9	0	31	31.4	32.1	23.5	23.2	21.3
2007	9346	297.4	34.4	6	30.5	32.1	32.1	23.2	21.6	21.1
2008	2635	345.7	7.6	0	31.8	32.5	32.3	23.4	22.8	20.5
2009	3480.8	160	262.8	28.8	32.2	32.1	32.8	23.8	23.4	22.7
2010	3752.7	430.9	245.1	10.5	30.5	30.7	31	23.4	23.1	21.1
2011	3566	229.7	147	0	32.1	31.5	32.4	23.6	22	21
2012	990	234.9	74.6	6.2	32.4	32	33.2	23.7	22.3	21.7
2013	635	155.2	104.6	0.2	30.9	32.3	31.9	23.4	23.0	20.3
2014	731	360.7	78.3	6.3	28.2	31.4	32.6	26.2	23.0	21.7
2015	291	317.8	194.2	101.5	32.4	32.0	32.5	23.9	23.3	22.5
2016	13	59.6	4.1	34.3	31.4	33.0	27.0	23.1	22.5	21.4
2017	75.7	229.5	109	35.4	31.2	32.1	31.8	23.4	22.6	20.9

Table 38. Results of multiple linear regressions on production of *mundakan* paddy (unirrigated)

Particulars	**Coefficient**	**Standard error**	**t-ratio**	**P value**	**VIF**
Intercept	23.84	13.75	1.73	0.10	
R1	-0.22	0.13	-1.65	0.12	3.05
R2	0.05	0.06	0.78	0.45	3.37
R3	-0.03	0.05	0.56	0.58	1.58
Mx1	-5.28	1.75	-3.01	0.01*	2.34
Mx2	-2.67	3.96	-0.67	0.51	2.64
Mx3	6.60	1.79	3.67	0.00***	3.93
Mn1	-5.33	2.04	-2.61	0.02**	3.75
Mn2	2.06	2.12	0.97	0.34	2.79
Mn3	1.27	1.02	1.24	0.23	2.70
Number of Observations		23			
F(9,13)		4.93			
R^2		0.773			
Adj. R^2		0.616			
P-value		0.005***			
Durbin-Watson		1.724			

*** P value significant at 1% level of significance
** P value significant at 5% level of significance
* P value significant at 10% level of significance

The result observed in Table 38 showed that the independent variables monthly maximum temperature and minimum temperature in October showed decrease in production of paddy whereas maximum temperature December showed increase in production and all of them are statistically significant since the P-value was less than 0.05. The rainfall in November, minimum temperature of November and December showed an increase in production of *mundakan* paddy but it was statistically not significant. The rainfall in October and December and the maximum temperature in November showed a decrease in paddy production which was statistically not significant. The regression coefficient measures change in dependent variable due to unit change in independent variable. The increase in maximum and minimum temperature can negatively affect paddy production since the increasing temperature can affect the spikelet quality and it can also led to pollen sterility. The rise in minimum and maximum temperature lead to an increase of water requirement for paddy (Surendran *et al*., 2014).

The VIF test was done in order to identify the presence of multicollinearity and the result showed that all the values were less than 10 and the highest value was 3.98 which indicated the absence of multicollinearity among the independent variables. The Durbin-Watson test was performed in order to identify the presence of autocorrelation and the result showed that the Durbin-Watson d-statistic value was 1.724 which was nearly equal to 2 which indicated the absence of autocorrelation among the residuals. The adjusted R^2 value was 0.616 which indicated that 61.6% variation in the dependent variable was explained by the independent variable selected for the multiple linear regression.

Li *et al*., (2015) reported a significant yield loss of 5.3% per °C for paddy yield. The decrease in paddy yield increases up to 8.3 % per °C for 3–6 °C of warming. The study conducted by IRRI revealed that an increase in temperature by 1°C can reduce the yield of paddy up to 10%. The pointe estimates of impact of increase in temperature over paddy production do show some evidence of more negative impacts from statistical studies at higher temperatures (4–5℃), the effect is not precisely estimated and error bars are large. (Moore *et al*., 2017)

Table 39. Results of multiple linear regressions on production of *mundakan* paddy (unirrigated) excluding December rainfall.

Particulars	Coefficient	Standard error	t-ratio	P value	VIF
Intercept	311.84	114.72	2.72	0.01	
R1	-1.23	1.14	-1.08	0.29	3.00
R2	-0.54	0.51	-1.06	0.30	3.06
Mx1	-24.59	14.47	-1.70	0.11	2.27
Mx2	-71.52	32.48	-2.20	0.04**	2.53
Mx3	42.87	14.91	2.88	0.01**	3.87
Mn1	-53.69	16.77	-3.20	0.00***	3.62
Mn2	14.17	17.72	0.80	0.43	2.79
Mn3	4.73	7.93	0.60	0.56	2.32
Number of Observations		23			
F(9,13)		3.83			
R^2		0.686			
Adj. R^2		0.507			
P-value		0.013**			
Durbin-Watson		1.805			

*** P value significant at 1% level of significance
** P value significant at 5% level of significance

The result observed from Table 39 revealed that maximum temperature in November and minimum temperature of October showed a decrease in production whereas maximum temperature in December showed an increase in unirrigated *mundakan* paddy production in which all of them are statistically significant. The minimum temperature in November and December showed an increase in paddy production which was statistically not significant. The rainfall in October and November, the maximum temperature in October expressed a decrease in *mundakan* unirrigated paddy production which is statistically not significant. The increase in temperature can affect the paddy production since it affects spikelet development and also reduces the pollen viability.

Beena *et al.*, (2018) concluded that the spikelet fertility percentage and photosynthetic rate get reduced with increase in temperature for all genotypes except N-22. Similar experiments were carried out by Pillai and Rajasree (2015) and results revealed that the vulnerability for the paddy production from climate change can be controlled with the help of suitable adaptation strategies consisting of developing high yielding varieties tolerant to high temperature, flood and drought and also by modifying the planting dates according to the climatic conditions.

The results of VIF test concluded that there was an absence of multicollinearity in the independent variables since all the VIF values were less than 10. The highest value of VIF value was 3.87 in the maximum temperature of December. The Durbin-Watson test was conducted in order to detect the existence of autocorrelation between the residuals of independent variables. The Durbin-Watson d statistic value was 1.805 and it was almost equal to 2 which determined the absence of autocorrelation. The adjusted R^2 value was 0.51 which expressed that 51 percentage of variation of the dependent variable was explained by the independent variables.

The Table 40 consisted of total production of mundakan paddy for a period of 23 years (1995-2017) and also the monthly rainfall, maximum temperature and minimum temperature of the months October, November and December were presented. Multiple linear regression equation was determined by considering total production of paddy (both irrigated and unirrigated) as the dependent variable and monthly rainfall, maximum temperature and minimum temperature of the months October, November and December were considered as the independent variables. The transformation of original values into logarithmic values was done for the estimation and the OLS method was used for the estimation of the parameters.

Table 40. Total production, monthly rainfall, maximum and minimum temperature for *mundakan* paddy

Year	Total Production (Tonnes)	R1 (mm)	R2 (mm)	Mx1 (℃)	Mx2 (℃)	Mx3 (℃)	Mn1 (℃)	Mn2 (℃)	Mn3 (℃)
1995	130735	146	189.2	32.1	31.6	32.5	22.1	21.4	17.7
1996	132556	350.4	43	30.7	32.3	31.7	21.7	21.5	19.6
1997	123149	230.9	279.1	32.4	32.1	32.3	23.3	23.4	23.1
1998	123214	316.8	44.1	29.6	31.5	31.2	23	22.8	21.2
1999	123292	278.3	42.7	30.8	31.6	32.2	23.5	22.2	21.4
2000	112598	194.9	70.1	30.4	32.3	31	22.3	21.4	18.8
2001	119346	239.8	143.9	31.1	31.8	31.9	23.2	22.6	20.7
2002	112229	421.3	70.8	31.2	31.9	32.9	23.7	23.2	19.7
2003	68413	354.6	44.8	31.3	31.9	32.6	23.6	22.5	20.4
2004	132403	305.2	42.8	31.3	32	32.9	23.2	22.3	20.9
2005	153728	121.1	126.2	31.3	31.5	32.2	23.5	22.5	20.9
2006	151829	352.9	133.9	31	31.4	32.1	23.5	23.2	21.3
2007	118856	297.4	34.4	30.5	32.1	32.1	23.2	21.6	21.1
2008	105044	345.7	7.6	31.8	32.5	32.3	23.4	22.8	20.5
2009	128426	160	262.8	32.2	32.1	32.8	23.8	23.4	22.7
2010	106824	430.9	245.1	30.5	30.7	31	23.4	23.1	21.1
2011	121202	229.7	147	32.1	31.5	32.4	23.6	22	21
2012	94531	234.9	74.6	32.4	32	33.2	23.7	22.3	21.7
2013	127876	155.2	104.6	30.9	32.3	31.9	23.4	23.0	20.3
2014	132295	360.7	78.3	28.2	31.4	32.6	26.2	23.0	21.7
2015	122157	317.8	194.2	32.4	32.0	32.5	23.9	23.3	22.5
2016	40730	59.6	4.1	31.4	33.0	27.0	23.1	22.5	21.4
2017	100979	229.5	109	31.2	32.1	31.8	23.4	22.6	20.9

Table 41. Results of multiple linear regressions on production of *mundakan* paddy (Total-irrigated and unirrigated) excluding December rainfall.

Particulars	**Coefficient**	**Standard error**	**t-ratio**	**P value**	**VIF**
Intercept	24.31	13.39	1.82	0.09	
R1	-0.21	0.13	-1.63	0.12	3.00
R2	-0.03	0.05	0.65	0.52	3.06
Mx1	-5.12	1.95	-3.03	0.00***	2.27
Mx2	-3.12	3.79	-0.82	0.42	2.53
Mx3	6.73	1.74	3.87	0.00***	3.87
Mn1	-5.12	1.95	-2.62	0.02**	3.62
Mn2	2.05	2.06	0.99	0.33	2.79
Mn3	1.05	0.92	1.14	0.27	2.32
Number of Observations		23			
F(8,14)		5.78			
R^2		0.767			
Adj. R^2		0.635			
P-value		0.002***			
Durbin-Watson		2.097			

*** P value significant at 1% level of significance
** P value significant at 5% level of significance

The result recorded in table 41 showed that maximum and minimum temperature in the month of October showed a significant negative impact on paddy production in Palakkad whereas the maximum temperature in December showed a significant positive influence on total paddy production in the *mundakan* season. The minimum temperature in November and December expressed a negative impact on total paddy production in *mundakan* season which was statistically not significant. The low minimum temperature for paddy led to increase the duration of vegetative and ripening phases (Sreedharan and

Vamadevan, 1977). The rainfall in October and November and the maximum temperature in November indicated a negative influence on the *mundakan* total paddy production in Palakkad district. The high temperature in tropical environments is one of the major environmental stresses limiting paddy productivity, with decline in grain weight and quality (Krishnan *et al*., 2011).

The multicollinearity was absent and it was the same as that of the *mundakan* unirrigated paddy production (excluding rainfall in December) since the independent variables used for the both the regression are the same. The Durbin-Watson d statistic value was 2.097 which indicated the absence of autocorrelation between the residuals. The adjusted R^2 value was 0.635 which concluded that 63.5 percent of variation in dependent variables was interpreted by the independent variables.

Srivastava *et al*., (2009) concluded that for high climate sensitive regions, development of high temperature tolerant varieties are needed in order to maintain the paddy production.

SUMMARY

5. Summary

Agriculture is the science and art of growing plants and livestock which has started in this world thousands of years ago and it provides employment for most of the people in our country. Agriculture is acting as the backbone of our country over the years and it also played a crucial role in development of human society. The green revolution also had a significant impact on agriculture. The application of cultivation techniques has a significant influence on the development of agriculture all over the world. The use of high yielding varieties (HYV) seeds, machinery and chemicals led to an increase in production of agricultural goods in India and also all over the world (Tripathy and Khan, 2020). The effects of famine present during the early 1960's got reduced with the help of green revolution in agriculture (Parayil, 1992). But at present the biggest problem faced by agriculture is the unexpected climate changes occur in different parts of the world.

Climate change is an important phenomenon which occurs over the years and it is also one of the main problems faced recently in the world. Climate change is defined as the significant and long lasting variation in distribution of the weather parameters over the period which may include decades or millions of years. The climate changes are happening mainly due to the factors which include variation in solar radiation, oceanic process, volcanic eruption, plate tectonic abnormal movements, biotic process and also due to the human made changes in the environment. The greenhouse gases present in the atmosphere also play a crucial role in global warming. Global warming was also due to the result of human made changes in the environment. The release of a high amount of Chlorofluorocarbon (CFC) resulted in the depletion of the ozone layer. The destruction of forest land and transformation of paddy fields for building constructions led to huge adverse effects to the environment. The research about climate change has been summarized and recorded by the Intergovernmental Panel on Climate Change (IPCC). Scientists from all over the world have tried to model climate change over the years in order to forecast or predict the variation in the future time period.

The climate changes have shown significant impacts on various parts of India over the years. The different climatic disasters like flood, drought and cyclone were happening all over India throughout the last century. The minimum and maximum temperature in different parts of India has increased over the last 100 years. The fluctuations in precipitation is also recorded in various parts of India. The south west monsoon blows from sea to land and north east monsoon blows from land to sea and these two winds bring most of the rainfall all over the country. The south west monsoon gives more rainfall as compared to north east rainfall. The fluctuations in these winds led to a series of climatic deviations all over the country. Many cyclones have hit in various parts of our country and caused severe damages for both human life and infrastructure. The flood occurred in different states over the years and also destroyed many houses and buildings and livelihood of many people. The drought is also seen in different parts of India. The lack of rainfall or absence of normal rainfall more than 40 percent can be considered as drought (Mishra and Liu, 2014). The water is an important source for all basic needs of human beings, plants and animals. The absence of pure water can affect the life of all living things in the world. Severe drought has been observed in different parts of the country. In order to prevent the sudden changes in climate, the humans should stop the practices they are following over the years which disturbs the ecosystem and biodiversity of the environment.

The effect of climate change in the state of Kerala was very adverse in the last few years. In the year 2018 and 2019, the state of Kerala has been affected by the flood which destroyed many human lives and infrastructures. The landslides occurred in highly sensitive areas led to the death of many people in Kerala. It also led to the destruction of the home and livelihood of many people in Kerala. The rainfall was varying in different parts of Kerala. Even though there was very high rainfall in 2018 at Kerala, the lakes got dried soon after this rainfall. The Bharathapuzha river basin was completely filled with water in the 2018 Kerala flood but it was only for a short period of time. After this heavy rain the river dried up within a few months. Many districts are getting less total annual rainfall than before. The temperature all over Kerala is increasing over the years. Global warming is happening in all the districts of Kerala. The minimum and maximum temperature over the years is increasing in various parts of Kerala. The summer of all the districts of Kerala is becoming extremely hot and the temperature is rising over the years. The days and nights are becoming warmer in all the parts of Kerala. Even in hilly regions of Kerala, the temperature has been increasing over the years. The different climatic changes observed in Kerala is mainly due to the human made disturbances in the environment. Humans should try to stop the practices which affect the balance in the ecosystem. The government of Kerala should impose strict rules against conversion of paddy cultivated land for construction of building purposes which affect the natural drainage system and it indirectly increase the effects of flood

Climate change also affects the cultivation of food crops in the world. Rice is the stable crop of India consumed by more than half of the population. Rice is the major food crop and the change in climatic factors influence different growth stages of rice. In Kerala rice is mainly cultivated in Palakkad district and Kuttanad region. The different climatic changes showed significant impacts on rice production. The increase in minimum and maximum temperature affect the spikelet development of the rice crop. The duration of the reproductive stage gets increased due to the increase in temperature. The temperature variation can also lead to pollen sterility in rice crop. The heavy rainfall can also increase the salinity of the soil which may cause harmful impacts for the rice crop. Even though rice is a water loving crop, the presence of excess water can affect the development of the rice crop at the last stages. The absence of sufficient water leads to destruction of the crop. The lack of water at tillering, heading, booting, panicle initiation and reproductive stages results in crop failure. An understanding of the changes in weather parameters and its impact led to the present study.

The research work entitled “Statistical models for climate change in northern and central Kerala” was carried out at College of Agriculture, Vellayani during 2018-2020. The objective of the study was to develop statistical models to evaluate climate change over time across northern and central Kerala and to determine the effect of climate change on paddy production.

The rainfall, maximum temperature and minimum temperature of RARS Pilicode (from 1983-2018) and RARS Pattambi (1982-2018) was collected in order to determine climate change over the years. The detection and estimation of the trend was done to determine the climate change over the years by using Mann-Kendall test and Sen's slope estimator. Suitable model was selected for weather parameters of Pilicode and Pattambi respectively based on least AIC, BIC and Hannan-Quinn criterion which helped to understand the pattern and also to determine the future values. It also helped to determine the climate change over the years in both northern and central Kerala on a comparative basis. The impact of climate change on paddy production was analyzed by taking the unirrigated rice production of Palakkad district from the report of agriculture statistics of GOK for a period of 23 years (1995-2017). The paddy production was taken as dependent variable and rainfall, maximum temperature and minimum temperature of respective months are taken as independent variables. The paddy production in virippu and mundakan season was taken and regressed with respective weather parameters in order to determine the effect of climate change over the years.

5.1 Salient Findings of the Study

1. The descriptive statistics of monthly rainfall in Pilicode revealed that the highest mean (537mm in August), standard deviation (381mm in June) and CV (378.46 in January) recorded respectively. The mean rainfall indicated that over the years the highest amount of rainfall was observed in the month of August. The standard deviation was highest in the month June which expressed that over the years there was more deviation for rainfall. The CV was highest in the month of January which concluded that over the years there was very little or absence of rainfall.

2. The descriptive statistics of monthly rainfall in Pilicode also revealed the lowest mean (2mm in February), standard deviation (5mm in February) and CV (34.44 in August) observed respectively. The lowest mean and standard deviation of rainfall

was recorded in the month of February which indicated that over the years there was very less rainfall or absence of rainfall. The less CV was observed in the month of August which declared that most of the years there was a very high rainfall with less deviation as compared to all other months.

3. The skewness for rainfall in Pilicode expressed that most of the months are positively skewed. The kurtosis indicated that most of the months are leptokurtic or platykurtic. The results of both skewness and kurtosis indicated that rainfall didn't follow normal distribution.

4. Similarly the monthly rainfall in Pattambi showed the highest mean (638.26mm in June), standard deviation (258.06mm in July) and CV (289.3 in January) obtained respectively. The mean rainfall indicated that over the years the largest amount of rainfall was recorded in the month of June. The standard deviation was largest in the month July which concluded that there was more variation for rainfall. The CV was highest in the month of January which indicated that over the years, a small amount of rainfall was received.

5. Moreover the smallest mean (4.05mm in January), standard deviation 11.72mm in January) and CV (26.96 in June) expressed respectively for the rainfall in Pattambi. The least mean and standard deviation for rainfall was observed in the month of January which indicated that over the years there was very less rainfall or absence of rainfall. The less CV was observed in the month of June which suggested that over the years there was a very high rainfall with less deviation compared to all other months.

6. However the kurtosis and skewness for rainfall in Pattambi showed that they are positively skewed for every months except month of June and the curve was platykurtic or leptokurtic for all months which indicated that monthly rainfall in Pattambi also didn't follow normal distribution.

7. The maximum and minimum temperature in Pilicode revealed that both of them showed higher mean values in summer season (March to May) and lower

temperature in winter months (December to February) and also in some of the monsoon months due to heavy rainfall. The CV and standard deviation for both maximum and minimum temperature was very low as compared to rainfall. The skewness and kurtosis for both minimum and maximum temperature indicated that both didn't follow normal distribution.

8. Similarly in Pattambi, the minimum and maximum temperature had the greater mean values in the months from March to May (summer) and smaller mean values in the months from December to February (winter) respectively. In comparison with the rainfall, the CV and standard deviation for maximum and minimum temperature was very less. The skewness and kurtosis suggested that distribution of both minimum and maximum temperature was not normal.

9. The results of Mann-Kendall test and Sen's slope estimator for annual rainfall, maximum temperature and minimum temperature at Pilicode showed a statistically significant negative trend only for minimum temperature. The deseasonalized annual rainfall and minimum temperature also indicated statistical significant trends.

10. The seasonal classification of weather parameters at Pilicode showed the absence of significant trend for both rainfall and maximum temperature. The seasonal classification of minimum temperature revealed that summer and monsoon showed a significant negative trend at Pilicode.

11. Similarly at Pattambi, the annual rainfall and maximum didn't show any statistically significant trend whereas the minimum temperature indicated the presence of statistically significant positive trend over the years. The deseasonalized rainfall and maximum temperature showed absence of significant trend whereas deseasonalized minimum temperature showed a significant positive trend.

12. The classification of annual data into different seasons revealed that maximum and minimum temperature during summer had a significant negative trend. The

rainfall in summer showed significant positive trend. All other seasons didn't show any statistically significant trend at Pattambi.

13. The comparison between Pilicode and Pattambi suggested the rainfall in Pilicode was much higher than Pattambi. The maximum temperature in Pattambi was high as compared to Pilicode whereas minimum temperature was almost similar for both places. The temperature in Pattambi showed a significant increasing trend whereas Pilicode has recorded a significant declining trend.

14. The best seasonal ARIMA model selected for weather parameters of Pilicode are SARIMA ((0,1,1,)(0,1,1)12) for rainfall, SARIMA ((1,0,1)(0,1,1)12) for maximum temperature and SARIMA ((1,0,1)(0,1,1)12) for minimum temperature respectively. The mean absolute error (MAE) for forecasting based on the best selected model was rainfall (0.592), maximum temperature (0.015) and minimum temperature (0.041) respectively.

15. However, for the weather parameters at Pattambi, the best seasonal ARIMA model selected for rainfall ((0,0,0,)(0,1,1)12), maximum temperature ((1,0,1)(0,1,1)12) and minimum temperature ((0,1,1)(0,1,1)12) respectively. The forecast based on the best model for maximum (0.023) and minimum temperature (0.05) showed a low MAE as compared to the rainfall (3.21). The fluctuation in rainfall is always expected and forecasting of rainfall is a difficult process.

16. The regression of unirrigated paddy production at Palakkad district with the weather parameters showed that the *virippu* season rice was not affected by the weather parameters with an explanatory power of 41 percent. .

17. While the regression of unirrigated rice production in the *mundakan* season showed that the weather parameters had a significant impact on production of paddy. The maximum temperature in October and minimum temperature for October showed significant negative impact whereas the maximum temperature in December recorded a significant positive impact on paddy production. The results

of regression analysis on total of irrigated and unirrigated paddy production in *mundakan* showed almost similar result with a higher explanatory power R^2 value.

18. The maximum and minimum temperature in October showed a negative influence on paddy production. The negative impact of rise in temperature on production of paddy is because the increase in temperature led to pollen sterility and disturbs the development of spikelet formation.

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STATISTICAL MODELS FOR CLIMATE CHANGE IN NORTHERN AND CENTRAL KERALA

by

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ABSTRACT

STATISTICAL MODELS FOR CLIMATE CHANGE IN NORTHERN KERALA

The research work entitled "Statistical models for climate change in northern Kerala" was carried out at college of agriculture, Vellayani during 2018-2020. The objective was to develop statistical models to evaluate climate change over time across different regions of northern Kerala and to determine the effect of climate change on paddy production. The secondary data of rainfall, maximum temperature and minimum temperature was collected from RARS Pattambi for a period of 37 years (1982-2018) and from RARS Pilicode for a period of 36 years (1983-2018). The secondary data on paddy production from Palakkad district of Kerala was collected from the report of agricultural statistics, GOK for a period of 23 years (1995-2017).

The descriptive statistics for the monthly data of weather parameters include mean, range, coefficient of variation, skewness and kurtosis. The analysis of weather data was done with the help of R programming and open software Gretl. The results of descriptive statistics and box plot of weather parameters showed that heavy rains was received in some months during several years at Pilicode as compared to Pattambi. Moreover, the Skewness for all the weather parameters of both Pilicode and Pattambi showed positive and negative skewness which indicated the absence of normal distribution among the weather data.

The climate change over the years of different weather parameters was analysed in terms of trends and its presence and direction was determined. Shapiro-wilks test was initially conducted for the weather parameters which showed that all the parameters didn't follow normal distribution for both Pilicode and Pattambi. The trend was detected using non parametric Mann-Kendall (MK) test and trend was estimated using Sen's slope estimator. The results of MK test and Sen's slope estimator revealed positive nonsignificant trend for annual, summer and monsoon rainfall and maximum temperature

in all the seasons at Pilicode suggests a nonsignificant increase in both parameters overtime. However a significant increase in summer rainfall and significant decrease in annual maximum temperature was recorded in Pattambi. Moreover the annual rainfall of Pilicode was more as compared to Pattambi with low maximum temperature in Pilicode. The deseasonalized rainfall (Z value is 2.00, P value is 0.04) of Pilicode also showed a significant positive trend. The classification of weather data in to different seasons also helped to identify season wise significant trend in different weather parameters

Modeling of weather parameters was done in order to develop best model which is suitable for determining the climate change. Seasonal ARIMA model was selected for modelling the weather data since the weather data consist of seasonality. The best model was estimated with the help of X12 ARIMA in Gretl open source software. The best model was selected on the basis of least AIC value, BIC value and Hannan-Quinn criterion value. The X12 ARIMA automatically detect the best model and then the best model was confirmed by trial and error method that no other models have the least value for the criterion. The best estimated models were respectively SARIMA ((0,1,1)(0,1,1)12) for rainfall, SARIMA ((1,0,1)(0,1,1)12) for Maximum Temperature and SARIMA ((1,0,1)(0,1,1)12) for minimum temperature for Pilicode. Similarly the best models identified for rainfall, maximum temperature and minimum temperature were respectively SARIMA ((0,0,0)(0,1,1)12), SARIMA ((1,0,1)(0,1,1)12) and SARIMA ((0,1,1)(0,1,1)12) for Pattambi. The validation of the model was done with the help of forecasting and comparing for 2018 and mean absolute error for forecasted was calculated. The mean absolute error was low for forecasted maximum temperature and minimum temperature in both Pilicode and Pattambi but the rainfall had high standard error and mean absolute error which was due to the fluctuations in rainfall at both Pilicode and Pattambi respectively.

The multiple linear regression was done to analyse the impact of weather parameters on the production of Paddy uder unirrigated area in *virippu* and *mundakan* season from 1995 to 2017 at Palakkad district. The results of the analysis reported no significant influence of weather parameters on *virippu* season but maximum and minimum temperature in October and maximum temperature in November had significant negative influence on *mundakan* Paddy production. While an increase in maximum temperature during December was favourable for *mundakan* Paddy production.

The results of the analysis on climate change indicated an increase in rainfall and decrease in maximum temperature over time at Pilicode as compared to Pattambi. SARIMA models were found to be the best model for weather parameters for prediction or forecasting. An increase in maximum temperature during December was favourable while increase in maximum and minimum temperature during October was unfavourable to Paddy production under unirrigated area in *mundakan* season.