WATER AVAILABILITY AND CLIMATIC WATER BALANCE FOR A SELECTED CROPPED AREA

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Dedication

This thesis is dedicated to my Mother, Father and Brother, who sacrificed much to bring me up to this level and to my guide, friends and their families for the devotion they made to make my life successful.

DECLARATION

I hereby declare that this thesis entitled **"Water availability and climatic water balance for a selected cropped area"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associate ship, fellowship or other similar title of any other University or Society.

Place: Tavanur **K. VENKATA SAI**

Date: **(2016-18-015)**

CERTIFICATE

Certified that this thesis entitled **"Water availability and climatic water balance for a selected cropped area"** is a record of research work done independently by **K. VENKATA SAI (2016-18-015)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship to him.

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We, the undersigned members of the advisory committee of **Mr. K. VENKATA SAI,** a candidate for the degree of Master of Technology in Agricultural Engineering with major in Irrigation and Drainage Engineering, agree that the thesis entitled **"Water availability and climatic water balance for a selected cropped area"** may be submitted by **Mr. K. VENKATA SAI** in partial fulfillment of the requirement for the degree.

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K. VENKATA SAI

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SYMBOLS AND ABBREVIATIONS

%	:	Percentage
>	:	Greater than
<	:	Less than
=	:	Equal to
&	:	And
”	:	Second
“	:	Minute
°	:	Degree
°C	:	Degree Celsius
χ^2	:	Chi-Square test
Acc.	:	Accumulated
AD	:	Anderson Darling test
AER	:	Agro ecological region
AESR	:	Agro ecological sub region
AET	:	Actual evapotranspiration
AWC	:	Available water holding capacity
CDF	:	Cumulative Distribution Function
cm	:	Centimeter
CV	:	Coefficient of Variation
Dept.	:	Department
DEF	:	Deficit

ET_o	:	Reference or Potential evapotranspiration
ET	:	Evapotranspiration
et al.	:	and others
ET_c	:	Crop evapotranspiration
etc.	:	Etcetera
exp	:	Exponential
FAO	:	Food and Agricultural Organization
Fig.	:	Figure
I_m	:	Moisture Index
IPCC	:	Intergovernmental Panel on Climate Change
J.	:	Journal
KAU	:	Kerala Agricultural University
K_c	:	Crop Coefficient
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
K-S	:	Kolmogorov–Smirnov test
km^2	:	Square kilometer
km/hr	:	Kilometer per hour
m	:	Meter
MAI	:	Moisture Adequacy Index
Mha	:	Million hectares
M-K	:	Mann-Kendall Test

mm	:	Millimeter
NE	:	North-East
PDF	:	Probability Density Function
R^2	:	Coefficient of determination
RARS	:	Regional Agricultural Research Station
RH	:	Relative humidity
RMSD	:	Root Mean Square Deviation
Sci.	:	Science
SD	:	Standard Deviation
SMS	:	Soil Moisture Storage
SMW	:	Standard Meteorological Week
SUR	:	Surplus
SW	:	South-West
viz.	:	Namely

INTRODUCTION

CHAPTER – I
INTRODUCTION

Water is the most important and limiting natural resource in the world. The economic development of any country depends on many factors in which water is one of the most important factors. It is the main requirement for the survival of any living organism and also plays an important role in agriculture and industry. Rainfall is the main source available for water in the design of water catchment structures, river basin management strategies and crop planning. In particular, the nature and state of agriculture in a region depend strongly on the total annual rainfall, its intensity and distribution. The distribution of rain varies greatly in time and space. The magnitude, frequency and intensity are the three main characteristics of rain that vary from place to place, day to day, month to month and also from year to year. The detailed knowledge of these characteristics is crucial for the planning of crops in a region and the full use of rainwater.

A proper analysis of the precipitation pattern of a region for several years is very useful for making decisions regarding efficient crop planning. In particular, the annual and monthly rainfall of a region is very useful for farmers to decide when and where to plant and harvest for a successful cultivation with the appropriate use of available water and irrigation resources. Recent abnormalities in the magnitude and distribution of rainfall have made the crop more risky. The lack of water supply has a huge negative impact on agricultural and industrial production. Knowledge of the spatial and temporal variation of the precipitation pattern is necessary for agricultural planning and is very essential for the management of water resources. In order to have a sustainable development of water resources and better planning of development operations in a given area, it is important to know the distribution of rainfall during the individual months, seasons and years.

Rainfall is an important phenomenon that differs in space and time, the distribution of rain is very uneven and varies not only from one place to another, but also varies from year to year. Most of the country's water requirements during the calendar year correspond to the rains that occurred especially during the Monsoon period. The variation in monsoon rainfall has a social and economic impact, since agriculture depends heavily on rainfall in India. The observed monsoon rainfall in India does not show any significant trend but regional monsoon variations have been recorded. Intergovernmental Panel on Climate Change (IPCC, 2007) has reported that future climate change is likely to affect agriculture, increase of risk of hunger and water scarcity and may lead to rapid melting of glaciers. Kumar and Jain (2010) reported that a higher or lower or changes in rainfall distribution would influence the spatial and temporal distribution of runoff, soil moisture, groundwater reserves and would alter the frequency of droughts and floods. A trend of increasing monsoon seasonal rainfall has been found along the west coast, northern Andhra Pradesh and north-western India, while a trend of decreasing monsoon rainfall has been observed over eastern Madhya Pradesh, north-eastern India, and some parts of Gujarat and Kerala. This indicates that a study of rainfall trend patterns is essential for planning and adapting to extreme events. The trend can be roughly defined as "long-term average change", but there is no complete mathematical definition. However, trend analysis helps in forecasts. Trend analysis was conducted to explore trends in long-term rainfall. The tendency to rain is very important for the economic development and hydrological planning of the country.

The trend analysis will show the systemic concentrations, which increase and decrease during a certain period of time. In addition, the evaluation of the scale of the trend can help to conclude that a statistically significant trend is of particular importance. Due to the impact of climate change and/or human action on a large scale in water resources systems, the hydrological time series of many regions confirm a significant change or trend. Trend free mean indicates that there is no significant correlation between observed time series and time. A statistically significant trend is only shown if the changes are strong enough and the time series is long enough. A comprehensive knowledge of the trend and persistence in rainfall of the area is of great importance because of economic implications of rain sensitive operations. Keeping this points in view trend analysis of historical rainfall should be done by using different approaches.

The concept of estimating probabilities with respect to a given amount of rainfall is extremely helpful for crop and water resources planning. Probability analysis can be used to forecast the occurrence of future rainfall based on historical rainfall record. Probability analysis of rainfall can be done by using different probability distribution functions. There is a generalized application of the probability distribution in the understanding of the precipitation pattern. It is equally important to establish a probability distribution that provides a good fit for the rainfall data of a region. There are several studies on rainfall analysis and the most appropriate probability distributions for crop planning are normal, log-normal, Weibull and log-Pearson III. In a growing season of a given crop, decisions should be made many times on the basis of probability of receiving certain amount of rainfall and ET demands of the given crop during a given period. So, comparing the rainfall availability with the evapotranspiration demands of rice crop for the selected region gives the appropriate result.

Kerala state receives an average annual rainfall of about 3107 mm which is quite enough for effective rice crop production. Though, the average annual rainfall is good enough for raising the rice crop but its distribution is not uniform during the entire crop growth period, particularly during critical growth stages. Thus, terminal droughts will occur more often. The success or failure of the off season rice crop is fully dependent up on the rainfall conditions, which are not in one’s control. It is however, possible to get higher crop production by adjusting crop plans, agronomic practices and land-water management options according to the probable rainfall availability and crop-water demands. The quantity of rainfall received over a period of time at any location provides a general picture of its sufficiency or inadequacy to meet the crop demands. Analysis of monthly rainfall data is not usually considered appropriate from the crop planning point of view. Thus it has been suggested to consider the week as the unit of time, where the rainfall is showery and highly abnormal in intensity, amount and distribution (Pali *et al.*, 2016).

Crop production in an area has a direct relation with amount and distribution of rainfall. Correct evaluation of water availability, water deficiency are very important for crop planning. The climatic water balance is a widely used method for this (Thornthwaite and Mather, 1955, 1957). A climatic water balance technique asses the water availability, water deficiencies and length of growing period for agricultural planning. Based on weekly climatic water balance it is possible to identify the suitable crops and cropping pattern for the area. It also asses the effective rainfall water surplus and deficit during different growth phases.

The estimation of the components of the water balance, that is, the actual evapotranspiration (AET), the surplus of water (SUR) and the water deficit (DEF) over an area are extremely important in the field of Hydrology, Agriculture, Ecology, etc. in identifying the eligible regions for different crops. The calculation of the water balance is one of the most important tools in applied climatology, which has innumerable applications namely, climate classification, crop planning, the potential for water collection and studies of climate change.

Water deficit is a complex and nonlinear phenomenon, since it depends on several interacting climatological parameters such as precipitation, temperature, humidity, wind speed, bright sunshine hours etc. Choice of crop varieties withstanding moisture stress, adoption of appropriate conservation measures and lifesaving irrigation through recycling surplus water are the viable measures for combating moisture stress. Climatic shifts, though temporary are of significance in the assessment of the climatological potentialities of a region for development. Thus to address the above issues, one can go with climatic water balance procedure (Srinivasa Reddy *et al.*, 2008).

In the view of all the above facts, a study entitled "**Water availability and climatic water balance for a selected cropped area**" was undertaken with the following objectives:

1. To analyse the variability and trend of rainfall.
2. To assess the expected rainfall amount at different probability levels of exceedance.
3. To compare the rainfall availability with evapotranspiration demands of the selected cropping pattern.
4. To assess the climatic water balance and water availability period.

REVIEW OF LITERATURE

CHAPTER- II
REVIEW OF LITERARTURE

Water is the most precious and limiting natural resource in the world. The main source of the water is rainfall which plays an important role in designing of water harvesting structures, water management practices and crop planning. The changes in rainfall and its distribution, probability and trends would influence the spatial and temporal distribution of runoff, soil moisture and groundwater reserves and also may affect the agricultural productivity. Crop production in an area has a direct relation with the amount and distribution of rainfall. So correct evaluation of water availability period is an important pre-requisite for crop planning. Climatic water balance is widely used for determining water availability. Hence, in this chapter, a review of the literature referring to the analysis of rainfall carried out by many researchers in India and in other countries on different features like variability of rainfall and its trend, probability, climatic water balance were briefly explained.

The review has been organized objective wise under the following sub heads:

1. Variability of rainfall.
2. Trends of rainfall.
3. Rainfall probability distribution.
4. Climatic water balance.

2.1 Variability of rainfall

Sharma *et al.* (1979) studied the rainfall analysis for Pantnagar with 17 years (1961-1977) of daily rainfall data. They found that weekly rainfall was more useful for the cropping pattern as well as water management practices as compared to the monthly, seasonal and annual data.

Ramachandran and Benarjee (1983) anlaysed the daily rainfall data of monsoon season for 7 years (1970-1976) in the entire Western Ghats. They found that weekly mean rainfall of the meteorological sub-divisions on the either side of Ghats showed a negative correlation with the southern sector and positive correlation with central and northern sectors.

Ghadekar and Thakare (1991) analysed description of rainfall of Nagpur region for crop production and cropping patterns. They concluded that during the Kharif season the mean rainfall was observed as 831.5 mm with 52.3 rainy days and with 20.8% and 17.3% coefficient of variation respectively.

Subramaniam and Rao (1984) studied the variability of rainfall over the Prakasam district of Andhra Pradesh. The study revealed that it had the non-homogeneous rainfall variability in different parts of the district and during June-November the district received the monsoon rainfall. The drought was a very common phenomenon in the interior parts of the district. The intensity of rainfall was more at coastal areas and decreasing towards the western parts of the district.

Subramaniam and Rao (1989) studied the variability of rainfall over Prakasam and Nellore districts of Andhra Pradesh. The result indicated that the coastal regions had the higher annual rainfall variation while the interior parts had the lower rainfall variation. The highest coefficient of variation occured in Kandukur region (33%) and the lower coefficient of variation occured in Giddalur region (23.5%). Further they found that the coastal stations received higher rainfall as compared to the inland station which received the lowest rainfall.

Gaikwad *et al.* (1996) made a rainfall analysis for daily rainfall data of 30 years during 1963-1992 recorded at Dry Farming Research Station, Solapur, Maharashtra. Annual, seasonal, monthly and weekly rainfall analysis and weekly rainfall probability analysis which was less than or equal to 20 mm rainfall/week were worked out. They found that mean annual rainfall was 723 mm, in which the rainfall received 76% during south-west monsoon and 15% during north east monsoon season. The trend showed that there was 40% chance of getting more than normal rainfall. The water availability period consisted of 140 days. They also found that medium to long duration dry spells were occurring common during monsoon seasons.

Chaudhary (1999) analysed the variations in rainfall and rainy days for understanding and adopting the suitable cropping system and scope for the application of the modern techniques for increased cropping intensity and crop productivity. He observed that the rice production was more sustainable in the regions of Sukma, Bijapur and Jagadalpur because of the less coefficient of variation of monsoon rainfall. The high unstable region for rice production was observed in Dantewara region because of high values of coefficient of variation.

Reddy *et al.* (2001) explored the drought zones in Andhra Pradesh using weekly data on long-term rainfall. Seasonal variations in rainfall and percentage of deviation, drought periods during the vegetation season and the frequency of drought have been studied. Based on the length of growth period, rainfall variability, drought frequency, number of dry periods and drought-prone areas have been identified and classified as areas subject to moderate, severe and chronic agricultural drought prone areas. The study revealed that about 11.57 Mha, covering 13 zones and 64 talukas, are exposed to various degrees of agricultural drought, entirely or moderately. A reasonable distribution of an area called a drought-prone area was observed in the Rayalaseema region (85%), followed by Telangana (33%) and the lowest observed in the coastal region (21%).

Hundal and Kaur (2002) analysed annual and seasonal variabilities in maximum and minimum, rainfall and temperature collected from historical daily meteorological data for Amritsar (1970-1998), Patiala (1970-1998), Ludhiana (1970-1999) and Bathinda (1977-1998). For the characterization of seasonal trends, two distinct crop growth season of Kharif and Rabi were selected. The small standard deviation and coefficient of variation were observed at all stations for both annual and seasonal, maximum and minimum temperatures. Both the annual and seasonal rainfall showed the high standard deviation and coefficient of variation indicating the large variation in rainfall at all stations.

Subash (2009) studied the impact of onset of monsoon and also variability and its distribution during the monsoon month on rice production over India. It was found that Kharif being the main rice growing season with 84% of the country's rice crop production during the season. The mean monsoon rainfall over India during June-September was observed as 840 mm with 10% coefficient of variation to the total of 85% of the annual rainfall i.e, 1081 mm. The regressions between Normalized yield index and the Normalized monthly rainfall indices during the monsoon months showed that rainfall in July and September were most important to rice yield variability.

Singh *et al.* (2013) identified that rainfall variability has a major impact on crop production and productivity. Therefore, rainfall patterns should be taken into account during crop planning and water management as this is the main aspect of harvesting of a crop in rainfed condition.

2.2 Trends of rainfall

Kothyari *et al.* (1996) analyzed rainfall data of three stations in Agra, Dehradun and Delhi to assess changes in precipitation and temperatures in the upper and middle parts of the Ganga basin in Northern India. The analysis included long-term seasonal rainfall, the number of rainy days during the season and the maximum annual temperature at these stations. The nonparametric test was used for the analysis. The results showed a falling trend in monsoon rainfall and the number of rainy days whereas a rising trend in the annual maximum temperature. The results showed a possible differences in the climate regime in the Ganga basin, which has intense recommendations for the Indian economy.

Githui *et al.* (2004) analysed trends of rainfall and river discharge of Yala river basin, Kenya over a period of 1963-1998. Trend analysis was performed using seasonal Kendall test and it showed that there was an average decreasing trend of rainfall. River discharge was observed as decreasing trend in upstream station and an increasing trend in downstream station.

Jayawardene *et al.* (2005) analysed the trends of annual rainfall depth in Srilanka over the last century. The meterological data of more than 100 years were collected from 15 meterological stations. The result revealed that there was a significant increasing trend in Colombo and decreasing trends were observed in Nuwara Eliya and Kandy respectively. Most recent data discovered a decreasing trends in 13 out of 15 stations. The largest downward trend of 11.16 mm/year was detected at Batticaloa.

Singh *et al.* (2008) explored the changes in the last century's rainfall over nine river basins in North-West and central India. The percentage change in rainfall in each of the 43 stations was estimated by the slope of trend line and these points are interpolated to obtain a spatial distribution of rainfall in the area surveyed. They identified a rising trend in annual rainfall over eight river basins.

Krishnakumar *et al.* (2009) examined the temporal variation of monthly, seasonal and annual rainfall of Kerala for the period 1871-2005. The results discovered a significant falling trend in the SW monsoon and a rising trend in the post monsoon season. The rainfall in winter and summer showed an insignificant rising trend.

Longobardi and Villani (2009) investigated time series of rainfall, identified potential trends and evaluated their importance over a large area of approximately 25,000 km^2 in the Campania region of southern Italy over a period of 1918-1999. The statistical analysis of the database showed that the trend seems to be mostly negative, both on annual basis and seasonal basis, with the exception of summer season where it appeared positive.

Kumar *et al.* (2010) examined the trend of rainfall data over 135 years (1871-2005), which showed no significant trend in annual, seasonal and monthly rainfall across India. Annual and monsoon rainfall had decreased and pre monsoon, post monsoon and winter rainfall had increased over the years. The monsoon months of June, July and September observed a falling rainfall trend while August revealed a rising trend on all India basis.

Jain and Kumar (2012) analysed trends in temperature and rainfall data for India. Sen's non-parametric slope estimator is used for the valuation of the magnitude of the trend and the statistical significance was analysed by the Mann-Kendall test. The outcome showed that the different units which may had a non-zero slope value and few values were statistically impact. The study on basin wise trend analysis revealed that there was decreasing trend in 15 basins of annual rainfall and only one basin revealed the trend decreasing at 95% confidence level. With regard to temperature trends, the average maximum temperature series showed an increasing trend in most stations and a decreasing trend in some stations. The average minimum temperature indicated an increasing and a decreasing trends.

Chakraborthy *et al.* (2013) studied the spatial and temporal variability of rainfall at Seonath sub basin in Chhattisgarh state for 49 years (1960-2008). To detect the trend, non-parametric tests such as Mann-Kendall or Modified Mann-Kendall and parametric test such as Spearman's rho test was used and to detect the magnitude Sen's slope was used. The results revealed that there was decreasing trend in annual and seasonal rainfall by both the trend methods. For the whole river basin by the both tests it was observed that there is decreasing trend for annual and seasonal rainfall.

Duhan and Pandey (2013) studied the spatial and temporal variability of rainfall of 45 districts of Madhya Pradesh (MP) for the period of 102 years (1901-2002). The trend and magnitude of the rainfall data on annual and seasonal basis were detected by using the non-parametric tests such as Mann-Kendall and Sen's slope estimator. To detect the possible change points, the Pettit-Mann-Whitney test and cumulative deviations were used. The change in percentage of mean of 1901-1978 period over 1979-2002 period showed that there was a decrease in rainfall in almost all the stations. The decrease in annual rainfall over total Madhya Pradesh in 102 years was observed as 2.59%.

Gocic and Trajkovic (2013) analysed changes in meterological values using statistical Mann-Kendall and Sen's slope estimator tests for 12 weather stations in Serbia from 1980 to 2010. The existence of sudden variations was detected using cumulative sum charts and bootstrapping. The results confirmed the good agreement of performance in finding of the trend for meteorological variables.

Krishan *et al.* (2015) analysed annual, seasonal and monthly variations of rainfall trend in Punjab, India by using rainfall data for 102 years (1901 – 2002). Statistical non- parametric tests like modified Mann-Kendall (MMK) test and Sens's slope were used to do the analysis. The results of the study given the rising trend or falling trend in rainfall in all districts. The annual rainfall resulted a decreasing trend whereas the monthly and seasonal rainfall observed increasing and decreasing trends.

Meena *et al.* (2015) investigated the monthly rainfall data (1901-2011) of 17 mega cities located in the range 25°18'00''N to 34°5'24"N in India. Out of 17 mega cities, 10 recorded a significant rising trend of rainfall whereas 6 cities identified a significant falling trend. Only one mega city of Northern India observed a null trend.

Randhawa *et al.* (2015) analysed the trends of monsoon in Himachal Pradesh by using the rainfall data of 101 years from the year 1901-2002. Seasonal and monthly analysis were carried out by using rainfall data for the 11 districts. The monthly analysis revealed that there was decreasing trend in December and January months and the rest of the months indicated an increasing trend. The seasonal analysis revealed that there was observed an increasing trend during all the four seasons. They also found that there was a sharp increasing trend in pre monsoon period and normal trend in the remaining seasons.

Roy (2015) analysed the spatial and temporal difference of seasonal maximum and minimum, temperatures and rainfall conditions with an assemblage of monthly data for the years 1901-2002 in Rajasthan. During pre-monsoon months the Bashara, Dungarpur, Udaipur, Rajsamand and Sirohi districts had experienced a declining rainfall. The remaining districts in the northern part of the state had experienced the rising trend in rainfall but the significance level varies.

Swain *et al.* (2015) analysed trends of monthly rainfall data for Raipur district of Chhattisgarh for the period of 102 years (1901 – 2002). The results revealed that was a significant decrease trends for the months of Southwest monsoon and a consequent decrease in annual rainfall.

Chattopadhyay and Edwards (2016) studied the long-term rainfall and temperature trends in Kentucky, USA for a period of 61 years (1950-2010). Non-parametric statistical tests were applied for the homogeneous and necessary annual series of rainfall and temperature. The significant trends in annual rainfall were identified (both positive, averaging 4.1 mm/year) for only two of the 60 rainfall similar weather stations (Calloway and Carlisle counties in rural western Kentucky). Only three of the 42 temperature similar stations confirmed trends (all positive, averaging 0.01 °C/year) in mean annual temperature.

Nain *et al.* (2016) studied the spatial and temporal variation of monthly rainfall in Haryana for the period of 1970-2011 which was covered about 27 rain guage stations. To examine the trend detection Mann-Kendall and Sen's slope estimator were used. The result revealed that an increasing and decreasing trends were observed at different rain guage stations. The results also revealed that in annual rainfall there was an increasing trend in Sirsa and the decreasing trend was observed in Ballabgarh and Thanesar. The seasonal rainfall detected an increasing trend in Sirsa and decreasing trend in Thanesar and Narnaul stations respectively.

Singh and Kumar (2016) analysed the trends in historical rainfall of Sagar district using parametric and non-parametric approaches. The analysis was carried out using 45 years data (1960-2004) of four rain gauge stations located in different places namely Sagar, Khurai, Rehli and Banda. Mann-Kendall analysis, Sen's slope method and linear regression method were used for the trend analysis. The trend of summer season at the Khurai station observed a significant rising trend in rainfall while summer season at the Rehli station observed a significant falling trend. There was no significant rising or falling trend at any other station.

Thenmozi and Kottiswaran (2016) studied the annual and seasonal rainfall trends over the region of Udumalpet in Tamilnadu for 33 years (1981-2013) at 4 rain-guage stations. Mann-Kendall test and Sen's slope estimator were used to detect the trends of rainfall. The results indicated that there was an increasing trend in Thirumurthy nagar station and Nallar station and decreasing trend in Amaravathy nagar and Udumalpet respectively.

Zelenacova *et al.* (2016) determined trends in 487 guaging stations during the period 1981-2013 in Slovakia. Monthly rainfall trends were detected by using non-parametric Mann-Kendall test. The rainfall trends observed a high variability. The gauging stations indicated an increasing trend especially in the month of July.

Hayelom *et al.* (2017) determined trends variation in climatic elements of temperature and precipitation in the southern zone of Tigray regional state, Ethiopia.

The daily, monthly and annual precipitation totals and temperature during the period 1981-2013 observed at Korem meteorological station were used. Mann Kendall test method and descriptive statistics were used to demonstrate any existence of possible trends. The result revealed that the mean and maximum temperature had a general increasing trend and minimum temperature showed a decreasing trend whereas the annual temperature showed a warming trend. The annual precipitation data showed a coefficient of variation ranging from 33.77–233%. This indicated that the precipitation dissemination is not normal with large year to year variances.

Saranya and Payal (2017) studied the temporal variation of meterological parameters such as rainfall and temperature to execute the trends using the statistical tests for the data of 21 years (1994-2014) for Marathwada region of Maharashtra. Trend analysis was performed by Mann-Kendall test. The result outcome in the study displayed that for the last 21 years (1994-2014) there was an increase in trend of monthly rainfall in Kavitkheda and Shahagad stations during July, Awadshirpur station in August and Manoor station in October. The decreasing trend was observed in the month of June for Manoor station, July and October for Sapli dam station, June and August for Sundgi station, October for Awadshirpur, Potanandgaon and Takli station. Annual rainfall detected a decreasing trend in 6 out of 8 stations and increasing trend in 2 stations. Annual maximum temperature showed a decreasing trend in Awadshirpur station and increasing trend in Manoor station. Annual minimum temperature showed a decreasing trend in Sundgi station and increasing trend in Awadshirpur, Manoor and Shahagad stations.

2.3 Rainfall Probability Distribution

Kulandaivelu *et al.* (1984) analysed the daily rainfall data for a period of 70 years over Coimbatore region by fitting incomplete gamma distribution model. The analysis indicated that there was likely commencement of rains, period of drought, length of growing season and end of the growing season.

Senapati *et al.* (1985) analysed rainfall pattern of Bhubaneswar based on past 30 year records. Frequency analysis for maximum annual rainfall data had been done by gumbel distribution. The drainage coefficient values for different design periods have been found on the basis of rainfall analysis.

Rao *et al.* (1988) studied daily rainfall data for Anantapur, Nandyal and Lam to evaluate the probability of getting satisfactory rain for successful crop. The 10 day periods in which accumulated rainfall reached 200 mm were calculated for each year, together with the probabilities of 2 successively 10 day periods occurring. The suggestions for crop production were discussed and the probability of receiving a mimimum, monthly rainfall of 57, 70 or 100 mm at each location was calculated.

Ghadekar and Thakare (1991) analysed description of rainfall of Nagpur region for crop production and cropping patterns. They found that the cropping seasons of 13 weeks from 25th to 36th Standard Meteorological Week (SMW) with dependent rainfall at 75, 80, 85 and 95% probability levels were most guaranteed and risk free.

Gare *et al.* (2000) examined the daily rainfall data for 28 years from 1969 to 1996 logged at Agricultural Research Station Gadhinglaj, Maharashtra. Annual, seasonal, monthly and weekly rainfall and weekly rainfall probabilities were analysed. It was observed that mean annual rainfall was 931.1 mm in which 75% received from the south west monsoon and 14% received from north east monsoon. Initial probabilities showed that less than 75% probability rainfall could be predictable from 28th to 31st SMWs during the Kharif season and 39th SMW during the Rabi season. The rainfall probabilities of less than 50% from 34th to 37th SMWs specified that there was a chance of dry spells during the Kharif season. Conditional probabilities exceeding 80% in SMW 29 showed the suitability of the 29th SMW for dry sowing.

Singh *et al.* (2002) analysed the monthly and yearly rainfall data for 50 years (1946-1995) to estimate the drought occurrence at Jhansi. They found that 18% of the years were drought, 14% surplus and 68% normal years, suggesting that there was a probability of one drought year in every five year plan. 24% of total monsoon season months were drought months in total 50 years period. The probability analysis of the drought months indicated that there was a chance of occurring 5 drought months with 80% probability and also found that August month was the wetted month with 304.7 mm rainfall followed by July with 278.8 mm rainfall.

Gupta *et al.* (2005) determined the probability and frequency analysis of rainfall data to define the expected rainfall at different probability levels. The result indicated that the rainfall at 80% probability can be safely taken as guarantee rainfall, while 50% chance can be considered as the extreme limit for taking any risk.

Bhakar *et al.* (2008) made a detailed statistical analysis of weekly and monthly rainfall for Kota, Rajasthan using 35 years (1970-2004) daily rainfall data collected from Central Soil and Water Conservation Centre, Kota. The result revealed that the variation in weekly and monthly rainfall pattern was found to be more consistent during monsoon season. The maximum mean rainfall varied from 0.18 mm in 1st SMW to 81.15 mm in 34th SMW. For forecasting the weekly and monthly rainfall Weibull, Normal, Log-normal, Gumbel probability distributions were fitted. They found that gumbel distribution was fitted well for prediction of weekly and monthly rainfall.

Chakraborty and Mandai (2008) analyzed the rainfall data for the period (1990-2001) recorded at meteorological observatory, Rudranagar, Sagar Block. They found that at 61.53% probability there were no rains. They also found that the reliable rainfall at 76.92% probability was anticipated to occur in the area in every year. The monthly dependable rainfall (P=76.92%) was estimated to occur in every year during the month of May to October with major concentration during June to September.

Jat *et al.* (2010) analysed daily rainfall data for 81 years (1921-2001) of Udaipur, Rajasthan. The weekly rainfall probability revealed that 10 mm rainfall in Monsoon was expected to occur at 50% probability during 24th SMW in Udaipur region when seedbed preparation and sowing of maize might be initiated. The average rainfall was observed between 25 to 50% probability. The probability of receiving minimum assured weekly rainfall was very low during 40th week and onwards. Hence, a short duration maize variety may be selected for Kharif.

Baweja (2011) analyzed 38 years daily rainfall data (1971-2008) to calculate the long-term average of weekly, monthly, annual and seasonal rainfall and its variability of Solan, Himachal Pradesh. The result revealed that the regular rainfall period was 14 weeks, spread between 24th and the 37th SMWs, which could be considered as a guarantee period for crop growth. As the rainfall in winter season was uncertain and unstable, residual moisture could be recharged and is essential for the preparation of tree basins, the application of manure to moderate fruits and the early cultivation of the Kharif season crops under rainfed conditions.

Probability analysis of monthly and seasonal rainfall at Solapur, Maharashtra was analysed by Bhakar *et al.* (2011) with the daily rainfall data of 22 years (1987-2008) collected from Dry Farming Research Station, Solapur. The annual rainfall of the region was observed as 732.4 mm. Normal, surplus and drought seasons had presented which could be useful for agricultural planning and irrigation schemes. The percentage probability of Zaid and Kharif seasons found to be normal is 81.82% and 77.27% respectively. The probability percentage for Kharif season found to be drought is 4.55% while that of Zaid season is 9.09%.

Barman *et al.* (2012) analysed historical rainfall data for the period of 2001-2010 observed from meteorological observatory at CRIJAF, Barrackpore. The probability analysis of the rainfall data revealed that the onset of monsoon was on 23rd week which extended between 4th to 10th June in standard meteorological week. The probability distribution of seasonal rainfall indicated that the occurrence of 80% rainfall in Kharif, Zaid and Rabi season are 751.8, 419.4 and 22.2 mm respectively, whereas the annual rainfall was observed as 1193.4 mm. It was also forecasted that the occurrence of rainy days (>2.5 mm rainfall per day) were 69 days per annum.

Singh *et al.* (2012) analysed rainfall data of 39 years (1973-2011) to find the probability of annual one day maximum rainfall of Jhalarapatan area of Rajasthan, India. Based on the probability distribution, the minimum rainfall of 44.74 mm in one day could be expected to occur with 99% probability and one year return period. A maximum of 252.98 mm rainfall could be received with one percent probability and 100 year return period.

Bhagat and Patil (2014) studied weekly reference evapotranspiration values of Solapur for the period (1977-2007) which were computed by the Penman-Monteith FAO-56 in the semi-arid zone of Maharashtra. The probability distributions that were fitted to ET_o values are log normal, gumbel and Weibull probability distribution functions and found best fit by Chi-Square test. ET_o values at 10% to 90% probability levels were estimated. They found that lognormal distribution (34) is the best fit for most of the weeks followed by gumbel (12) and Weibull (6).

Manikandan *et al.* (2014) analyzed the daily rainfall data of 30 years (1981-2010) of Coimbatore for weekly variability and the probability of occurrence. The study revealed that the chance of getting 25 mm weekly rainfall with 50 percent probability was observed from 39th to 46th SMWs. Drought resistant short duration pulses and sorghum could be grown within the growing period from 39th to 46th SMWs.

Rai *et al.* (2014) studied annual rainfall data for 62 years (1949-2010) in Sagar and 65 years (1945-2010) in Damoh District, Bundelhand Region, central India. They found that initial and conditional rain probability analysis in Damoh showed that initial probabilities of receiving 10 mm of rainfall per week was observed as 76% for the 25th SMW. Therefore, the preparation of the seed bed could initiate in this week. Initial and conditional probability followed by wet week of receiving 20 mm rainfall was more than 80% during 27th SMW in Sagar district. Therefore this week was best suited for sowing operation in this area.

Asim and Nath (2015) analyzed the probable rainfall of Allahabad district using 34 years data (1980-2013). The annual rainfall values were calculated on the basis of the proposed forecast models, Gumbel and Log Normal. The rainfall data in the previous distribution and their corresponding rainfall are calculated at a different probability levels. The goodness of the fit was tested by the chi-square test. They found that the Gumbel distribution is the best model for predicting annual rainfall (mm) and the Log Normal distribution is quite close to the observed annual rainfall (mm).

John and Ajithkumar (2015) analysed fitting of probability distribution of rainfall data in Thrissur for about 31 years from 1980 to 2010, recorded at Vellanikkara, Kerala. They found that the exponential distribution was appropriate for 16 SMWs, normal distribution for 10 SMWs and log-normal for 8 SMWs. The probabilities of more than 10, 20, 30 and 40 mm of rainfall at different weeks of standard time were estimated based on these distributions. They found that the heavy rainfall was acquired from 23rd to 31st SMWs during 4th June to 5th August as showed by the probabilities.

Mandal *et al.* (2015) analyzed 16 years of rainfall (1995-2010) of the Daspalla region, Odisha. In June a rainfall of 105.9 mm was observed at 90% probability level. As a result, rainy seasonal crops could be planted and rice nurseries could be prepared in June month with the start of southwest monsoon. In July, at 90% probability level the observed rainfall was 181.9 mm. Therefore, rice transplantation could be done using this high amount of rainfall in this month.

Pegu and Malik (2015) analysed the rainfall data of Dhemaji region, Assam for a period of 35 years (1980-2014) by using the probability distribution methods viz. Normal, Log normal, Log pearson-III and Gumbel distribution. These probability distribution methods were applied to estimate the expected monthly, seasonal and annual rainfall for the period of 1980-2014. Weibull`s plotting position was used for computation of observed monthly, seasonal and annual rainfall separately in different return periods. The observed and expected values were compared using Chi-Square Test (χ^2) test. The result indicated that gumbel distribution method was the best fit to predict annual rainfall for different return periods. In case of seasonal analysis, log-pearson-III was found to be the best fit. However, the best fit probability distribution of monthly data was found to be different for different months. Log-pearson-III was determined as the best fit probability distribution for the months of June and July. For the month of August, the lowest Chi-Square value (10.24) obtained by Log normal distribution and for the month of September; the best probability distribution selected by Chi-square test was Normal distribution. As per gumbel distribution, annual rainfall of 2437.76 mm can be expected with 90% probability in 1.11 year return period while annual rainfall of 4796.47 mm could be expected with 1% probability in return period of 100 years. The magnitude of 2960.18 mm annual rainfall with 50% probability could be expected in every 2 years which was approaching to mean annual of 3050 mm. In monsoon season, the expected rainfall during July was higher as compared to other monsoon months. On this month, precipitation of 295.22 mm was expected with 90% probability in 1.11 years. The developed regression model also indicated the best fitted curve of each monsoon months, seasonal and annual scattered observed rainfalls with R^2 value more than 0.90, except in case of July (0.78).

Asim *et al.* (2016) studied rainfall probability using 114 years data (1901-2014) to forecast the yearly rainfall of India. The annual rainfall values were estimated by gumbel and log normal distributions. The goodness of fit were estimated by Root Mean Square Deviation (RMSD) test. They found that Gumbel distribution was the best model for forecasting yearly rainfall (mm), whereas log normal distribution was fairly close to the observed annual rainfall of previous 114 years (mm).

Pali *et al.* (2016) analyzed rainfall and evaporation data and expected rainfall availability at assumed probability levels and ET demands of the crop at various growth stages were assessed between 1994 and 2013 of Durg, Dhamdha and Patan blocks of Durg district, Chhattisgarh. The analysis indicated that the annual rainfall for the three blocks was 1067.9 mm, 1088.8 mm and 908.7 mm respectively and 98% of the annual rainfall obtained during the monsoon season. The probability analysis for weekly and seasonal precipitation showed that weekly rainfall for 23-28 and 37-43 SMWs followed an exponential distribution and 29-36 SMW followed normal distribution and seasonal precipitation followed the normal distribution at the three blocks. The expected ET demand of rice in the three blocks was estimated as 738 mm for medium period rice variety. When they looked at the whole crop period, they found that seasonal rainfall was able to meet the ET demands of crop.

Ray (2016) analysed rainfall data of 36 years (1980-2015) of Keonjahar district, Odisha to find weekly, monthly and seasonal probabilities. The annual average rainfall of the area was about 892.53 mm with 52 number of rainy days. The probability for receiving more than 100 mm of rainfall could be expected only at 25% probability. It was also found that 75% assured probability level rainfall of more than 250 mm could be expected only in July and August months. He also found that, on seasonal basis, rainfall at assured probability level of 75% is not sufficient.

Barkotulla (2017) analyzed rainfall data during 1971 to 2009 of Naogaon rainfall station in Bangladesh to determine the annual one day maximum rainfall. The values of the return period were assessed from the position of the Weibull plot and the values were calculated using a probability distribution for the best fit. The three statistical goodness of fit tests were used (Kolmogorov-Smirnov test (KS) Anderson Darling (AD) and Chi-square test (χ^2)) to choose the best probability distribution model. The five probability distribution functions (Gamma, normal, lognormal, Log-Pearson type III and Gumbel distribution) were examined with the observed values. The result revealed that the Log Pearson Type III distribution was the best fit distribution of probabilities for calculating the annual one day maximum rainfall for different return periods.

2.4 Climatic water balance

Subrahmanyam (1982) studied the aridity and droughts with special reference to India by using water balance approach. The principles and procedures of drought climatology employing the water balance concepts were given and discussed the climatology of aridity and droughts of the Indian region. Identification and categorization of drought years have been made using Thronthwaite's index of aridity. Year to year water balance fluctuations revealed shifts in normal climatic types of situations and changes in their moisture regimes. A proposed index of drought severity in terms of intensity and duration of droughts in different years is expected to be of immense practical use in assessing the impact of droughts on agricultural economy.

Kar and Verma (2004) attempted a study on spatial variation of climatic water balance, probabilistic monthly monsoon rainfall and mapping of cold periods in agro-ecological region (AER) 12.0 of India using GIS and models. They found that as per climatic water balance, large to moderate water surplus (520–70 mm) was available in Agro ecological sub region (AESR) 12.1. The rainfall surplus of 220–370 mm was computed in AESR 12.2 and 370–520 mm in AESR 12.3. Since winter rainfall is insufficient and unpredictable, this amount of rainfall might be harvested and utilized for providing supplemental irrigation to winter crops or rainy season crops during dry spells. This study also revealed that at 80% probability level (highly assured) rainfall of 98-156 mm occurred June in AESR 12.1, 103–144 mm in AESR 12.2 and 93–132 mm in AESR 12.3. During the 1st month of South-West monsoon these amounts of rainfall were sufficient to prepare land and sowing of direct seeded crops like maize, groundnut, black gram, green gram, pigeon pea, cowpea, etc. that might done from 24th standard week onwards (11th-7th June) after onset of southwest monsoon in the region.

Kothari *et al.* (2007) studied water balance based crop planning for Bhilwara district of Rajasthan using daily meteorological data of 45 years (1960-2004). The study revealed that on annual basis, the region require 1691.3 mm water, whereas the rainfall was only 669.1 mm. The actual evapotranspiration in the region was 476.6 mm and water deficit was 1214.7 mm. The water surplus was 189.6 mm during 31st to 36th week and water deficit was observed in remaining weeks. The surplus water was available even in driest year, which could be harvested and utilized during the period of soil moisture deficit.

Reddy *et al.* (2008) noted that agricultural drought occurs when soil moisture and rainfall are insufficient during the growing season of crop. The result revealed that the weekly water deficit during the Kharif season varied from 1.18 to 13.04 mm and that excess water ranged from 1.03 to 48.83 mm, representing a total excess of 260.8 mm of water. The excess water during the Kharif season allowed the harvesting, storage and recycling of rainwater during the stress period. The years of drought had been identified and their intensities have been estimated using departure of annual aridity indices on land.

Sattar and Khan (2016) conducted a study at Pusa, Samastipur region of Bihar using the rainfall data of 45 years (1968-2012) to evaluate water balance and length of growing period for effective crop planning in rainfed condition. The average annual rainfall calculated was 1226.7±388.9 mm. They found that, more than 30 mm rainfall per week was detected during 24-39 SMWs and more than 50 mm rainfall per week was observed during 25-39 SMWs except in 38th SMW. The total water surplus was estimated as 487.3 mm during 24-43 SMWs whereas the total annual water deficit was 75.4 mm during the corresponding period. Under average rainfall condition, actual evapotranspiration (AET) was more than 0.25 of potential evapotranspiration (PET) during the period from 18-50 SMWs, whereas it was more than 50% of PET during 24-44 SMWs. Out of annual average rainfall of 1227 mm, the surplus and effective rainfall were observed as 39.7% and 60.3% respectively. The average effective rainfall was found to be 739.4±89 mm.

Thakural *et al.* (2017) explored the assessment of water balance components with Thornthwaite and Mather method (FAO-56) for the Dhasan River basin in Sagar district, Madhya Pradesh. The daily rainfall and temperature are used to assess the various components of the water balance such as water surplus, water scarcity, runoff, etc. The study showed that under normal conditions, the basin had an annual water requirement of 1770 mm, while the rainfall was 1149 mm and the actual evapotranspiration was 821 mm. The analysis revealed a water surplus of 327 mm in the months of July, August and September, while the water deficit was 948 mm for the remaining months. The water deficit indeed begins in October and usually increases with the beginning of the summer season. As wheat is the main crop planted during the Rabi season in the catchment, irrigation should be planned for crops respectively. The annual water deficit was much higher than the annual surplus of water. As a result, the basin could be considered an area that is threatened by drought.

MATERIALS AND METHODS

CHAPTER-III
MATERIALS AND METHODS

This chapter explains the various methods used in the study, description of the study area and collection of data. The methods pertaining to various statistical analysis like variability, trend and probability distribution of rainfall were explained in detail. A comparison was made between probable evapotranspiration demands and probable rainwater availability. A climatic water balance was conducted for evaluating the water surplus and water deficits. Each of these parts were detailed in the following subheads.

3.1 STUDY AREA, CLIMATE, SOIL TYPE AND MAJOR CROPS

3.1.1 Study Area

The Pattambi region coming under the agroclimatic zone AEZ 10 was selected for the study. Pattambi is located in Palakkad district of Kerala state in India which is located in range of 10.76° N latitude and 76.57° E longitude. The entire region is at an elevation of 63 m above the mean sea level. This area was selected due to the availability of all the parameters needed for this study.

3.1.2 Climate

The average minimum and maximum temperature of the Pattambi region is 22.8 °C and 32.4 °C respectively. The region falls under the humid tropical climate. The average annual rainfall of the region is about 2749 mm. The rainy season in this area begins in late May and it ends in the month of November. Summer season is hot with a maximum temperature of 36 °C during late April and May. The relative humidity is low in summer with 35% and it goes up to 85% during the monsoon season. The wind speed in the region is about 3-6 km/hr.

Plate 3.1. A field view of rice, banana and tomato in Pattambi region

3.1.3 Soil Type

The major part of the study area contains Laterite soils in which clay content is more. These soils falls under the category of the soil group Ultisols (Jose *et al.*, 2012).

3.1.4 Major Crops

Rice is the major crop in the region. The other crops grown in the region are Banana, Mango species and Vegetables. A view of the crops in the region is shown in Plate 1.

3.2 DATA AVAILABILITY

The daily rainfall and all other weather parameters were collected from the meteorological station of RARS, Pattambi, KAU for the period of 35 years from 1983-2017. The daily rainfall data were converted into weekly, monthly, annual, South-West, North-East, summer and winter values (Appendix I (a), (b), (c), (d)). The mean monthly values of the weather parameters during the period 1983-2017 are given in Table 3.1.

For seasonal analysis of rainfall, the daily rainfall data were converted into seasonal data as follows:

1. South-West monsoon season (June-September)
2. North-East monsoon season (October-November)
3. Summer season (March-May)
4. Winter season (December-February)

For weekly analysis of rainfall, daily rainfall data were converted into weekly values based on the Standard Meteorological Weeks (SMW). The total no. of days in a year is divided into 52 SMWs with 7 days in a week. In this study the first 7 days in January was taken as 1st SMW, next 7 days was taken as 2nd SMW and so on up to the 52nd SMW.

Table 3.1 Mean monthly values of weather parameters during the period 1983-2017.

S.No	Month	Max. Temp (°C)	Min. Temp (°C)	RH (%)	Wind speed (km/hr)	Sunshine (hr)	Evaporation (mm)
1.	January	33.30	20.48	58.50	5.81	8.61	5.48
2.	February	35.28	21.05	61.00	4.81	8.86	5.63
3.	March	36.11	23.36	62.50	4.00	8.50	5.48
4.	April	35.28	24.53	71.85	3.22	7.90	5.00
5.	May	33.75	24.71	76.75	3.08	7.25	4.10
6.	June	30.20	23.43	84.75	2.64	4.47	2.45
7.	July	29.44	22.88	83.50	3.13	3.35	2.57
8.	August	29.61	23.09	83.00	3.49	4.44	2.63
9.	September	30.47	23.61	80.25	3.13	5.76	3.13
10.	October	31.20	23.26	79.00	2.08	5.62	2.57
11.	November	32.20	22.22	73.50	2.83	6.65	3.13
12.	December	32.12	21.04	69.25	5.17	7.85	3.60

3.3 RAINFALL ANALYSIS

3.3.1 Variability of Rainfall

In order to study the variability of rainfall, the statistical parameters like maximum, minimum, mean, standard deviation and coefficient of variation were computed for the rainfall data.

Mean

The mean is a mathematical representation of the typical value of a series of numbers, computed as the sum of all the numbers in the series divided by the count of all numbers in the series. The arithmetic mean is sometimes referred to as the average or simply as the mean. Some mathematicians and scientists prefer to use the term "arithmetic mean" to distinguish it from other measures of averaging, such as the geometric mean and the harmonic mean. The arithmetic mean is calculated by using the formula

$$\mu = \frac{\sum X}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where,

μ - Sample mean,

X - Variable of the sample,

n - Number of variables in sample

Maximum

Maximum is the highest value in the given values.

Minimum

Minimum is the lowest value in the given values.

Standard Deviation

Standard deviation is the positive square root of the arithmetic mean of the squares of the deviations of the given values from arithmetic mean. The standard deviation is calculated by using the formula

$$\sigma = \sqrt{\frac{\sum (X-\mu)^2}{N}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where,

σ - Standard deviation,

x - The variable of the sample,

N- Number of variables in a sample and

μ − Sample mean

Coefficient of Variation (CV)

The coefficient of variation (CV) is the statistical measure of how individual data points vary about the mean value. The coefficient of variation is calculated by using the formula

$$CV = \frac{\sigma}{\mu} \times 100 \text{ ………………………….. } (3.3)$$

Where,

CV - Coefficient of variation,

σ- Standard Deviation and

μ − Sample mean

Skewness

The skewness is used to find out the negatively or positively skewed distribution. The mean, mode and median can be used to find out negatively or positively skewed distribution. The positive values indicates the positively skewed distribution and the negative values indicates the negative skewed distribution.

Kurtosis

The measure of kurtosis is defined as the peakness of frequency curve. Kurtosis is measured by the moment coefficient which is defined by the following formula.

$$\beta_2 = \mu_4 / \mu_2 \text{ ………………… } (3.4)$$

Where, $\mu_r = \frac{1}{N} \sum f(x_i - \bar{X})^r$

The mean values of weekly, seasonal and annual rainfall for the area were formulated. By using this data the excess, normal and deficit rainfall years were identified. If the rainfall in an individual year is equal to or more than the summation of mean annual rainfall and standard deviation, then the year is considered as excess rainfall year. Similarly, the years receiving less than the difference between mean annual rainfall and standard deviation are considered as the deficit years and the years that receive annual rainfall approximately equal to the annual rainfall are considered as the normal rainfall years (Bhakar *et al.*, 2011).

3.4 TREND ANALYSIS

Trend analysis is the practice of collecting information and attempting to spot a pattern or trend in the information. It is the method of time series data (information in sequence over time) analysis involving comparison of some item over a significantly long period to detect general pattern of a relationship between associated factors or variables and project the future direction of this pattern.

Trend analysis of all the independent weather parameters was statistically examined in two phases. Firstly, the non-parametric Mann-Kendall test was used. The presence of a rising or falling trend was tested based on the normalized test statistics (Z) value. In the second phase, the rate of increase or decrease in trend was estimated by using nonparametric Sen's slope estimator. The trend analysis is to detect the presence of raising and falling trends in a monthly, seasonal and annual rainfall series were performed using following methods.

3.4.1 Mann-Kendall Test (M-K)

The M-K test is a non-parametric test for detecting trends and the non-linear trend derived from Kendall test statistics. The Mann-Kendall test was used for trend analysis of time series data. Monotonic trend (increasing or decreasing) in the time series of annual and seasonal rainfall was tested based on the normalized Z statistics value. Negative value of the Z statistics represents the falling trend and positive value of Z statistics shows the rising trend of rainfall. It has been found to be an excellent tool for trend detection and many researchers have used this test to assess the significance of trends in hydro-climatic time series such as water quality, stream flow, temperature and precipitation.

Mann-Kendall test compares the relative magnitudes of data rather than data values themselves. In this test, each data value in the time series is compared with all subsequent values. Initially the Mann-Kendall statistics (S) is assumed to be zero, and if a data value in subsequent time periods is higher than a data value in previous time period, S is incremented by 1, and vice-versa. The net result of all such increments and decrements gives the final value of S.

The Mann-Kendall statistics (S) is given in equation 3.5.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_j - x_i) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.5)$$

Where,

$sign(x_j - x_i)$ = 1, if $(x_j - x_i) > 0$

$sign(x_j - x_i)$ = 0, if $(x_j - x_i) = 0$

$sign(x_j - x_i)$ = -1, if $(x_j - x_i) < 0$

A positive value of S indicates a rising trend, and a negative value indicates a falling trend. However, it is necessary to perform the statistical analysis for the significance of the trend. The test procedure using the normal approximation test is described by Kendall (1975). This test assumes that there are not many tied values within the dataset. The variance (S) is calculated by the following equation 3.6.

$$Var\ (S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5)\right] \qquad \ldots\ldots\ldots\ldots \ (3.6)$$

Where,

n- Number of data points,

g- Number of tied groups and

t_p- Number of data points in the pth group.

The normal Z-statistics is computed as follows:

$$\left.\begin{aligned} Z &= \frac{S-1}{\sqrt{Var\ (S)}}, \text{ if } S > 0 \\ Z &= 0, \text{ if } S = 0 \\ Z &= \frac{S+1}{\sqrt{Var\ (S)}}, \text{ if } S < 0 \end{aligned}\right\} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.7)$$

The trend is said to be falling if Z is negative and the computed Z-statistics is greater than the Z-value corresponding to the 5% level of significance. The trend is said to be rising if Z is positive and the computed Z-statistics is greater than the Z-value corresponding to the 5% level of significance. If the computed Z-statistics is less than the Z-value corresponding to the 5% level of significance, there is no trend.

- Z-value at 10% level of significance is 1.645.
- Z-value at 5% level of significance is 1.96.
- Z-value at 1% level of significance is 2.33.

3.4.2 Sen's slope Estimator

Simple linear regression is one of the most widely used model to detect the linear trend. However, this method requires the assumption of normality of residuals. Sen's slope has the advantage over the regression slope in the sense that it is not much affected by gross data errors and outliers. The Sen's slope is estimated as the median of all pair wise slopes between each pair of points in the dataset. Each individual slope (m_{ij}) is estimated using the following equation:

$$m_{ij} = \frac{(Y_j - Y_i)}{(j-i)} \qquad \text{........................} \quad (3.8)$$

Where,

i=1 to n-1 and j= 2 to n,

Y_j and Y_i are data values at time j and i (j > i), respectively.

If there are n values of Y_j in the time series, there will be N= n (n-1)/2 slope estimates. The Sen's slope is the median slope of these N values of slopes.

The Sen's slope is:

$m = m_{(\frac{N+1}{2})}$, if n is odd

$m = \frac{1}{2}(m_{(\frac{N}{2})} + m_{(\frac{N+1}{2})})$, if n is even

Positive Sen's slope indicates rising trend while the negative Sen's slope indicates the falling trend.

3.5 RAINFALL PROBABILITY AT DIFFERENT LEVELS OF EXCEEDANCE

The probability of rainfall enables us to determine the expected rainfall at various chances. Thirty five years of rainfall data of Pattambi were used to find out annual, seasonal, monthly and weekly rainfall probability of exceedance. It was estimated using WEATHER COCK software which was developed at CRIDA, Hyderabad for weather data analysis. Weather Cock contain 26 numbers of modules which are related to agro-climatic parameters, out of which 8 to 10 modules were used in this study for weather data analysis. Some attention is to be given before going for weather data analysis using Weather Cock software and they were as follows:

1. Never rename the Weather Cock folder.
2. All Data files should be either created in Notepad or as csv file (comma separated values) of excel.
3. Kindly examine the data file structure in the 'Sample Data' folder for any analysis before creating the new data file.
4. While analysing data with .csv file, if any error occurs then open the .csv file in Notepad and delete all the last commas in every data line.
5. Data for every day Date structure- mm/dd/yyyy.
6. The possible errors in data are like 12.8.0 or 12..8 or 12.8.instead of 12.8. Data may be typed as a non-numeric symbols (space, _, +).

The example showing the correct data file and incorrect data file is as follows:

Correct Data File

Pattambi

Year, Week, RF (MM)

2016, 1, 0

2016, 2, 0

In Correct Data File

Pattambi

Year, Week, RF (MM) ,,,

1971, 1, 0 ,,

The main window of the Weather cock software is shown in Fig.3.1.

Fig 3.1 Main window of "Weather cock" software

3.5.1 Analysis of Weekly, Monthly, Seasonal and Annual Rainfall Probability of Exceedance

Weekly, monthly, seasonal and annual rainfall probabilities of exceedance were calculated through the module named as "Incomplete Gamma Probabilities.exe" of the weather cock software. The daily rainfall data were used in the software to calculate rainfall probability at levels of 90%, 75%, 50%, 25% and 10% in each case. The exceedance probability at different levels were computed by fitting Incomplete Gamma Distribution.

3.6 EVALUATION OF PROBABILITY DISTRIBUTION MODELS

Analysis of rainfall data strongly depends on its distribution pattern. It has long been a topic of interest in the fields of meteorology in establishing a probability distribution that provides a good fit to rainfall. Several studies have been conducted in India and abroad on rainfall analysis and best fit probability distribution function such as Normal, Lognormal, Gumbel max, Weibull and Pearson type distribution were identified. Hence in this study the probability distributions viz. Normal, Lognormal, Gumbel max, Weibull and Log Pearson III were evaluated to identify the best fit probability distribution model for the rainfall of this region. The mathematical software " Easy Fit" was used to test the probability distribution of weekly, monthly and annual rainfall.

The Key Features of the software includes:

i) Support for over 55 continuous & discrete distributions,

ii) Automated & manual distribution fitting,

iii) Advanced Excel integration,

iv) Interactive graphs,

v) Goodness of fit tests,

vi) Distribution viewer & probability calculator,

vii) Descriptive statistics calculation,

viii) Random number generation,

ix) Excel-like spreadsheet,

x) Data import (Excel, ASCII),

xi) Easy to use interface and

xii) Built-in and online help.

The probability distributions that were used in this study are explained in the following subheads:

3.6.1 Normal Distribution

The normal distribution is the most useful continuous distribution of all the distributions. The probability density function (PDF) and cumulative distribution function (CDF) of the normal distribution are calculated using equations (3.9) and (3.10) respectively:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \qquad \ldots\ldots\ldots\ldots\ldots (3.9)$$

$$F(x) = \frac{1}{2}\left[1 + \text{erf}\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right] \qquad \ldots\ldots\ldots\ldots\ldots (3.10)$$

Where, μ- location parameter and σ – scale parameter.

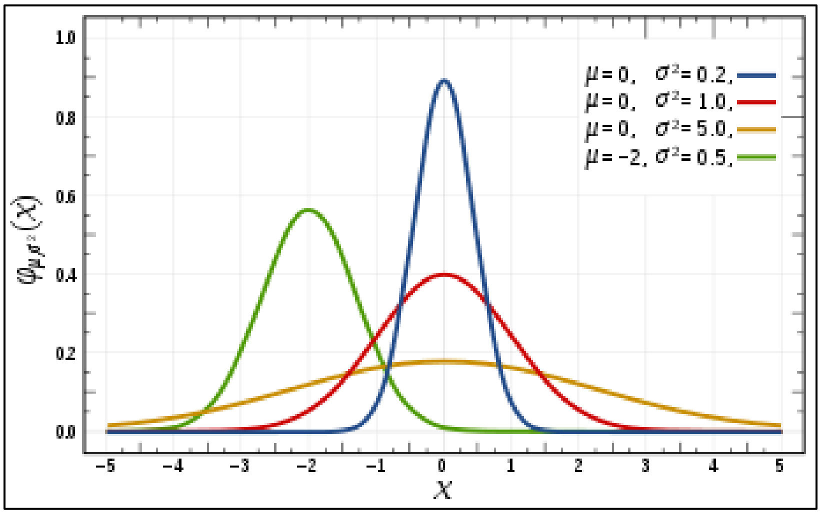

Fig 3.2 Graph for Normal Probability Distribution function

3.6.2 Log normal Distribution

The log-normal distribution is a distribution of random variables with a normally distributed logarithm. The lognormal distribution model includes a random variable Y, and Log(Y) is normally distributed. The probability density function (PDF) and cumulative distribution function (CDF) of the log-normal distribution were calculated using equations (3.11) and (3.12), respectively:

$$f(x) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}} \quad \text{……………..} \quad (3.11)$$

$$F(x) = \frac{1}{2} + \frac{1}{2}\left[1 + \operatorname{erf}\left(\frac{ln\ x-\mu}{\sigma\sqrt{2}}\right)\right] \quad \text{……………} \quad (3.12)$$

Where,

μ - shape parameter and σ - Scale parameter

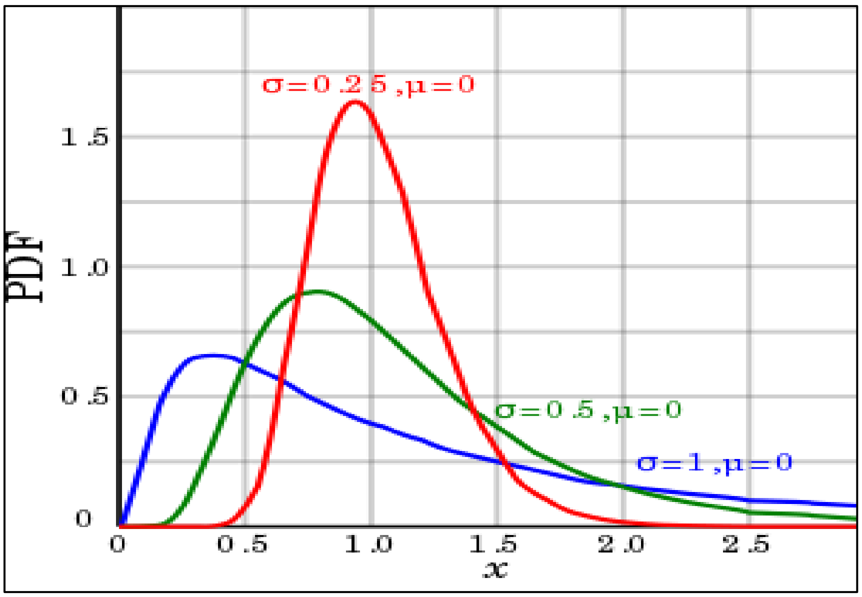

Fig 3.3 Graph for Lognormal probability distribution function

3.6.3 Log-Pearson type III Distribution

The log-Pearson type-III distribution has been widely and frequently used in hydrology and for hydrologic frequency analyses. The probability density function (PDF) and cumulative distribution function (CDF) of the log-Pearson type-III distribution are calculated using equations (3.13) and (3.14), respectively:

$$f(x) = \frac{1}{x|\beta|\tau(\alpha)} (\frac{\ln(x)-y}{\beta})^{\alpha-1} e^{-\frac{\ln(x)-y}{\beta}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.13)$$

$$F(x) = \frac{\tau_{\frac{\ln(x)-y}{\beta}}(\alpha)}{\tau(\alpha)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.14)$$

Where, α, β and γ are shape, scale and location parameters, respectively.

3.6.4 Gumbel Max Distribution

The Gumbel max distribution named in honor of Emil Gumbel, and also known as the Extreme Value Type I distribution, is a continuous probability distribution. This distribution can be applied to model maximum or minimum values (extreme values) of a random variable. The probability density function (PDF) and cumulative distribution function (CDF) of the Gumbel distribution were calculated using equations (3.15) and (3.16), respectively.

$$f(x) = \frac{1}{\sigma} e^{(-\frac{x-\mu}{\sigma} - e^{\left(-\frac{x-\mu}{\sigma}\right)})} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.15)$$

$$F(x) = e^{\left(-e^{\left(-\frac{x-\mu}{\sigma}\right)}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.16)$$

Where σ and μ are the scale and location parameters, respectively.

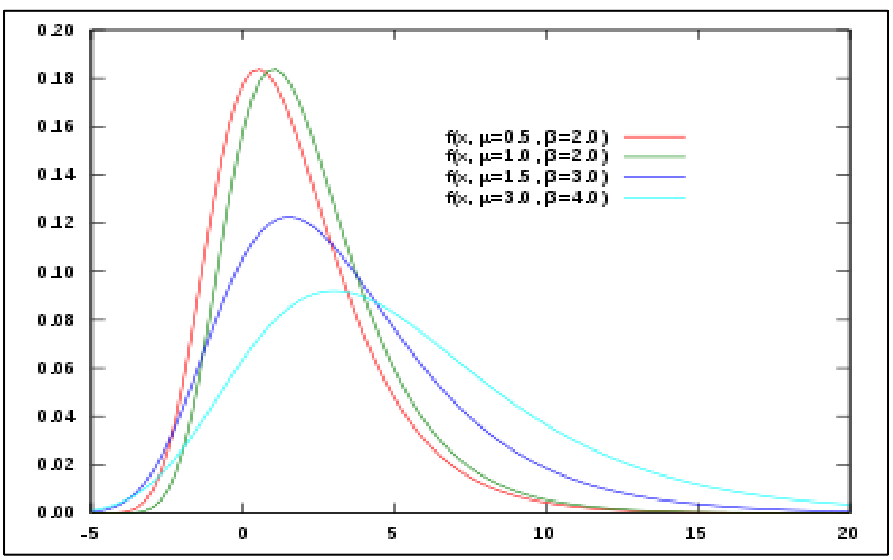

Fig 3.4 Graph for Gumbel max probability distribution function

3.6.5 Weibull Distribution

The Weibull distribution is a continuous probability distribution. It is named after Swedish mathematician Waloddi Weibull. The probability density function (PDF) and cumulative distribution function (CDF) of the Weibull distribution were calculated using equations (3.17) and (3.18), respectively:

$$f(x) = \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{\lambda}{k}\right)^{k}}, \; x \geq 0$$

$$= 0, \; x < 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (3.17)$$

$$F(x) = 1 - e^{-\left(\frac{x}{\lambda}\right)^{k}}, \; x \geq 0$$

$$= 0, \; x < 0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (3.18)$$

Where, k and λ are shape and scale parameter, respectively.

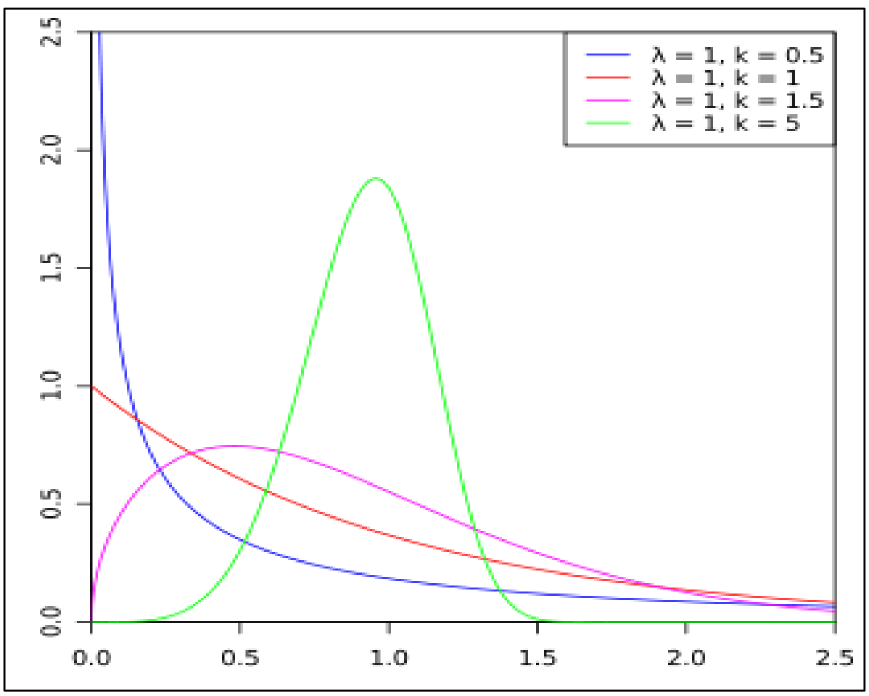

Fig 3.5 Graph for Weibull probability distribution function

3.7 TESTING OF GOODNESS OF FIT OF PROBABILITY DISTRIBUTION MODELS

The goodness of fit test measures the compatibility of random sample with the theoretical probability distribution. The goodness of fit tests is applied for testing the following null hypothesis:

H_0: The rainfall data follows the specified distribution

H_A: The rainfall data does not follow the specified distribution

The following goodness of fit tests viz. Kolmogorov-Smirnov test, Anderson-Darling test were used along with the Chi-Square test at 5% level of significance for the selection of best fit probability distribution.

3.7.1 Kolmogorov-Smirnov Test (KS)

The Kolmogorov-Smirnov statistic (D) is defined as the largest vertical difference between the theoretical and the empirical cumulative distribution function (ECDF):

$$D = \max \left(F(X_i) - \frac{i-1}{n}, \frac{i}{n} - F(X_i)\right), 1 \leq i \leq n \qquad \text{……………………….. (3.19)}$$

Where,

X_i = random sample,

i = 1, 2, 3… n.

$$CDF = F_n(x) = \frac{1}{n} \times (Number\ of\ observations \leq X) \qquad \text{…………………… (3.20)}$$

This test was used to decide if a sample comes from a hypothesized continuous distribution.

3.7.2 Anderson-Darling Test (AD)

The Anderson-Darling test was used to compare the fit of an observed cumulative distribution function to an expected cumulative distribution function. This test gives more weight to the tails than the Kolmogorov-Smirnov test. The Anderson-Darling statistic (A^2) is defined as follows.

$$A^2 = -n - \frac{1}{n}\sum(2i-1).\left[\ln F(Xi) + \ln(1 - F(Xn - i + 1))\right] \qquad \text{……….. (3.21)}$$

Where i=1, 2, 3… n

3.7.3 Chi-Square (χ^2) Test

The Chi-Square test is the most commonly used procedure for the testing of goodness of fit. It is used to test if a sample of data came from a population with a specific distribution. The Chi-Square test of goodness of fit is expressed by the following equation.

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i} \qquad \text{……………… (3.22)}$$

Where,

O_i – Observed frequency and

E_i – Expected frequency of rainfall.

3.8 IDENTIFICATION OF BEST FIT PROBABILITY DISTRIBUTION MODEL

The three goodness of fit tests mentioned above were tested for the rainfall data by using the “Easyfit” software. The test statistic of each test were computed at 5% level of significance. First of all the input values were given in the new worksheet of the software. Then analyzed the data by using the fitting distribution column in the tool bar. After analyzing all the data, the software would produce the best fitting curves for each distribution and their parameters values as outputs. The goodness of fit could be given based on the test statistic value. The rank of the distribution was given according to the statistic value. The less statistic value would get the first rank and more statistic value would get the last rank. The distribution with the less statistic value would be the best fit for the goodness of fit. Same procedure would be applied for different types of goodness of fit tests. After identifying the best fit probability distribution for the region, it was compared with exceedance probability at 75% level of incomplete gamma distribution.

3.9 COMPARISON OF PROBABLE RAINWATER AVAILABILITY WITH PROBABLE EVAPOTRANSPIRATION DEMAND OF THE CROPS

3.9.1 Probable Rainwater Availability

Among the different probability distribution, the one which was best fit to the region for weekly rainfall data was used to find the probable rainwater availability. The rainfall obtained at 75% probability level was considered as the probable rainfall (Pali *et al.,* 2016).

3.9.2 Estimation of Weekly Reference or Potential Evapotranspiration (ET_o) by FAO-56 Penman-Monteith model

Direct measurement of evapotranspiration under field conditions is a very difficult task. Based on the meteorological data available, the weekly potential or reference evapotranspiration was estimated by using FAO-56 Penman-Montetith model which is most widely used all over India. The measurement of reference or potential evapotranspiration (ET_o) by FAO-56 Penman-Monteith model is given by the following formula:

$$ET_o = \frac{0.408\Delta\,(Rn - G) + \Upsilon \frac{900}{T+273} U2\,(ea - ed)}{\Delta + \Upsilon\,(1 + 0.34U2)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.23)$$

Where,

ET_o = Reference crop evapotranspiration (mm/day),

R_n = Net radiation at crop surface (MJ m^{-2} day^{-1}),

G = Soil heat flux (MJ m^{-2} day^{-1}),

T = Average temperature at 2 m height (^oC),

U_2 = Wind speed measured at 2 m height (m s^{-1}),

(e_a-e_d) = Vapour pressure deficit for measurement at 2 m height (K Pa),

Δ = Slope vapour pressure curve (K Pa $^oC^{-1}$),

Υ = Psychrometric constant (K Pa $^oC^{-1}$),

900 = Coefficient for the reference crop (1 j^{-1} Kg K d^{-1}) and

0.34 = Wind coefficient for the reference crop (s m^{-1}).

The various components of the above relation are derived as

i) When solar radiation is available

$$R_n = 0.77\ R_s - (a_c\frac{Rs}{Rso} + b_c)\ (a_1 + b_1\sqrt{ed})\ \sigma\ \frac{(T_{Kx}^4 + T_{Kn}^4)}{2}$$

Where, T_{kx} and T_{kn} is both set equal to mean hourly air temperature for hourly calculations. This is not employed in the present study as very few stations have the data on solar radiation.

ii) When only sunshine data is available

$$R_n = 0.77\ (0.25 + 0.50\ \frac{n}{N} + R_s) - 2.45 \times 10^{-9}\ (0.9\ \frac{n}{N} + 0.1)\ (0.34 - 0.14\sqrt{e_d})\ (T_{Kx}^4 + T_{Kn}^4)$$

$$G = 0.38\ (T_{day\ i} - T_{day\ i-1})$$

Where, $T_{day\ i}$ = Mean daily air temperature and $T_{day\ i-1}$ = Mean daily air temperature of preceding day.

iii) Vapour Pressure Deficit (VPD)

$$VPD = (e_a - e_d) = \frac{e^o(T_{max}) + e^o\ (T_{min})}{2} - e_d$$

Where,

VPD = Vapour Pressure Deficit (K Pa),

$e^o\ (T_{max})$ = Saturation vapour pressure at T_{max} (K Pa),

e^o (T_{min}) = Saturation vapour pressure at T_{min} (K Pa),

e_d = Actual vapour pressure (K Pa) and

$e_a = e^o$ (T) = 0.611 exp $\left(\frac{17.27T}{T+237.3}\right)$.

Where, e_a = Saturation vapour pressure (K Pa),

e^o (T) = Saturation vapour pressure function (K Pa),

T = Air temperature (^oC) and

$e_d = e^o\ (T_{min})\frac{RH_{max}}{100}$.

iv) Δ is slope of vapour pressure, computed as

$$\Delta = \left(\frac{e_a}{T_m+273}\right)\left(\frac{6791}{T_m+273} - 5.03\right)$$

3.9.3 Probable Evapotranspiration Demand

The probable weekly ET_o values at 50% probability level was estimated by fitting normal distribution (Sahu, 2000). The reason for using ET_o values at 50% probability level was that Senapathi *et al.* (1996) used ET_o values at 20% probability level and found that if this ET_o value is used for computing the actual ET_c, then ET_{rice} would be overestimated as compared to the long term measured values by lysimeter and drum culture technique. Hence, the expected weekly ET_o values at 50% probability level were used to estimate the actual ET_c values for the corresponding week. Then the actual evapotranspiration (ET_c) of the crops were estimated by multiplying probable ET_o with the corresponding crop coefficient values as follows.

$$ET_c = K_c \times ET_o \text{ (Probable)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.24)$$

Where,

K_c = Crop coefficient value

The K_c values of the different crops grown in this area is given in Table 3.2.

Table 3.2 K_C values of different crops according to stage of crops

S.No	Crop	Initial stage	Development	Mid stage	Late stage	Harvest stage
1.	Rice	0.85	0.9	1.01	1.05	1
2.	Banana	0.45	0.78	1.05	0.95	0.8
3.	Vegetable (Tomato)	0.45	0.75	1.15	0.875	0.625

(FAO-56, Guidelines for Computing Crop Water Requirements)

3.9.4 Rainwater Surplus/Deficit

The surplus/deficit of rainfall for the different weeks at 75% probability of rainfall was compared to the ET_c demands of the major crops for the corresponding weeks. Then the surplus/deficit values were worked out to know whether supplemental irrigation is needed during the weeks of major crop growth or not. It is stated that when there was surplus rainwater availability, the excess rainwater could be harvested/stored and could be used at the times of deficiency.

3.11 CLIMATIC WATER BALANCE

Estimation of climatic water balance components, viz., actual evapotranspiration (AET), water surplus (SUR) and water deficit (DEF) over a region are extremely important in the field of Hydrology, Agriculture, Ecology, etc. in identifying the regions suitable for growing different crops. Water balance computation is one of the important tools in applied climatology that has innumerable applications, viz., climatic classification, agricultural crop planning, water harvesting potentials, and climate change studies. The climatic water balance components calculated were soil moisture storage (SMS), actual evapotranspiration (AET), water surplus (SUR) and water deficit (DEF). Thronthwaite (1948) developed the procedure to compute the water balance by considering the monthly rainfall and potential evapotranspiration

(ET_o). Later Thronthwiate and Mather (1955) developed a water balance technique as explained below which is used in this study to estimate the climatic water balance.

3.11.1 Computation of Weekly Climatic Water Balance by Thronthwaite and Mather's Method (1955)

To compute the weekly climatic water balance according to Thronthwaite and Mather's method (1955), following information at a place were collected.

- Weekly rainfall in mm.
  (The weekly rainfall of Pattambi region is given in Appendix I).
- Weekly potential evapotranspiration in mm.
  (The weekly potential evapotranspiration is given in Appendix III).
- Available water holding capacity of the soil.
  (The available water holding capacity of the soil in the study area is about 140 mm. Research Report: RARS, Pattambi)

Procedure to calculate weekly water balance

The different steps involved in the calculation of weekly water balance were given below:

Step-1: Reference evapotranspiration (ET_o) was computed on weekly basis by using Penman-Monteith FAO-56 method.

Step-2: Computation of accumulated values of P-ET_o for each week.

Step-3: Computation of actual storage of soil moisture for each week by using the following equation:

$$STOR = AWC \times e^{\left(\frac{Acc(P-ET_O)}{AWC}\right)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (3.25)$$

Where,

STOR – Actual Storage of soil moisture, mm,

AWC – Available soil water content, mm,

P – Rainfall, mm,

Acc (P-ET_o) – Accumulated values of (P-ET_o),

ET_o - Reference evapotranspiration, mm.

Step-4: Computation of change of actual storage from week to week (ΔSTOR). When the storage remains at capacity level, the ΔSTOR = 0. When the STOR reaches values of less than the capacity, STOR is calculated as the subtraction of STOR of present week from the previous week.

Step-5: Weekly actual evapotranspiration (AET) was computed as given below:

a) When ΔSTOR is negative,
   AET = P + abs (ΔSTOR) …………….. (3.26)

b) When ΔSTOR is positive,
   AET = ET_o ……………. (3.27)

Step-6: Weekly water deficit (DEF) values were determined by using the following expression:

$$DEF = ET_o - AET \qquad (3.28)$$

Step-7: Weekly surplus water (SUR) were computed using the following expression:

$$SUR = P - AET \qquad (3.29)$$

SUR is the amount of water percolating to the water table and becoming as runoff to the underground system. It occurs only when (P-ET_o) is positive and when storage has reached the capacity level.

Step-8: Climatological Indices:

The climatological indices such as Humidity Index (I_h), Aridity Index (I_a), Moisture Index (I_m) and Moisture Adequacy Index (MAI) are the output of the water balance analysis. The indices viz. aridity index, humidity index and moisture index are useful in climate classification and to find the type of climate of a particular place. Moisture Adequacy Index (MAI) provides a good indication of the moisture status of the soil in relation to the water need, high values of the index signifying good moisture availability and vice-versa. Aridity Index (I_a) was considered to evaluate the drought condition in terms of the drought intensity. Based on Moisture Index (I_m) the type of the climate in the region was determined (Subramanyam, 1982).

Table 3.3 Type of climate on basis of Moisture Index (I_m)

S. No	Moisture Index (I_m)	Type of climate
1.	> 100	A – Per humid
2.	80 – 100	B4 – Humid
3.	60 – 80	B3 – Humid
4.	40 – 60	B2 – Humid
5.	20 – 40	B1 – Humid
6.	0 – 20	C2 – Moist sub humid
7.	-33.3 – 0	C1 – Dry sub humid
8.	-66.7 - -33.3	D – Semi arid
9.	-100 - -66.7	E - Arid

The climatological indices were computed using the following expressions:

$$Humidity\ Index\ (I_h) = \frac{Water\ Surplus\ (SUR)}{ET_o} \times 100 \quad \text{.....................} \ (3.30)$$

$$Aridity\ Index\ (I_a) = \frac{Water\ Deficit\ (DEF)}{ET_o} \times 100 \quad \text{.....................} \ (3.31)$$

$$Moisture\ Index\ (I_m) = I_h - I_a \quad \text{.....................} \ (3.32)$$

$$Moisture\ Adequacy\ Index\ (MAI) = \frac{AET}{ET_o} \quad \text{.....................} \ (3.33)$$

3.11.2 Determination of Water availability period (Length of Growing Period)

a) Based on MAI

The ability to provide so much water for the irrigation area during each irrigation period depends mainly on the availability of water. To determine the water availability period, the Moisture Adequacy Index (MAI) which is the ratio between actual evapotranspiration and potential evapotranspiration has been considered. Since the region falls under humid tropical condition, the growing season considered as a week when MAI was greater than or equal to 0.75 (Gupta *et al.,* 2010), which was considered as a minimum moisture level for starting the sowing of crops. The termination of a growing period was taken at a week from where MAI is less than 0.25 (Krishnan *et al.,* 1980).

b) Based on Surplus/Deficit

Water Surplus

Under the average rainfall condition the water availability period would be high (surplus water is observed in the weeks) if AET greater than the 50% of ET_o. Under such conditions we can say that there is a surplus water available during that period.

Water Deficit

Under the average rainfall condition the water availability period would be less (deficit water is observed in the weeks) if AET less than the 50% of ET_o. Under such conditions we can say that there is a deficiency of water during that period.

RESULT S AND DISCUSSION

CHAPTER IV
RESULTS AND DISCUSSION

Rainfall is the main source available for water, which plays an important role in the design of water catchment structures, river basin management strategies and crop planning. The knowledge of the rainfall variability is crucial for crop planning in a region. Trend analysis show the systematic concentrations which increase and decrease during a certain period of time. A complete knowledge of the trend and persistence in rainfall of the area is of great importance because of economic implications of rain sensitive operations. Keeping this points in view trend analysis of historical rainfall was done by using different approaches. The concept of estimating probabilities with respect to a given amount of rainfall is extremely helpful for crop and water resources planning. In a growing season of a crop, decisions should be made many times on the basis of probability of receiving certain amount of rainfall and ET demands of the crop. So, a comparison was made between rainfall availability and the evapotranspiration demands of the crop. Crop production in an area have a direct relation with amount and distribution of rainfall. A correct evaluation of water availability period is an important pre-requisite for crop planning. Hence, climatic water balance was done to assess the water surplus, water deficiencies and water availability period for agricultural planning. The results and discussion pertaining to all these aspects were discussed in the following subheads.

4.1 VARIABILITY OF RAINFALL

The variability of rainfall in Pattambi region during the period 1983-2017 was studied using the statistical parameters Mean, Standard Deviation (SD), Coefficient of Variation (CV), Skewness and Kurtosis and the results are given in Table 4.1.

Table 4.1 Annual, monthly and seasonal characteristics of rainfall in Pattambi region (1983-2017)

S. No	Month/Seasonal/ Annual	Mean (mm)	SD (mm)	CV (%)	Skewness	Kurtosis	75% probability (mm)	% contribution to annual rainfall (mm)
1.	January	10.76	32.28	300.00	4.66	24.09	3.1	0.45
2.	February	8.69	16.22	186.65	2.04	3.00	3.2	0.37
3.	March	14.18	31.84	224.54	3.01	9.16	4.8	0.60
4.	April	66.28	58.76	88.65	0.86	0.41	27.5	2.79
5.	May	152.18	98.23	64.55	1.54	2.89	87.3	6.40
6.	June	603.73	200.89	33.27	-0.83	0.97	471.1	25.39
7.	July	572.1	246.3	43.05	0.77	0.96	409.5	24.06
8.	August	349.85	119.27	34.09	0.10	-0.67	271.1	14.71
9.	September	236.25	151.6	64.17	0.60	-0.16	136.2	9.93
10.	October	255.07	116.89	45.83	-0.33	0.01	177.9	10.73
11.	November	89.54	59.56	66.52	0.75	0.44	50.2	3.77
12.	December	19.32	29.48	152.59	2.14	4.45	9.5	0.81
13.	Annual	2377.96	458.8	19.29	0.21	1.48	2051.6	100.00
14.	South-West	1761.93	447.84	25.42	0.45	1.63	1466.4	74.09
15.	North-East	344.62	134.24	38.95	-0.97	0.94	256.0	14.49
16.	Summer	232.63	112.27	48.26	0.55	0.39	158.5	9.78
17.	Winter	39.91	44.05	110.37	1.90	5.07	10.8	1.68

The annual rainfall over the Pattambi region during the period 1983-2017 was found to be 2377.96 mm with a standard deviation of 458.8 mm and coefficient of variation of 19.29%, indicating that the rainfall is highly stable. The seasonal rainfall of the region was observed as 1761.93 mm for South-West monsoon, 344.62 mm for North-East monsoon, 232.63 mm for summer season and 39.91 mm for winter season with standard deviations 447.84 mm, 134.24 mm, 112.27 mm and 44.05 mm respectively.

The dependable rainfall at 75% probability level for the corresponding seasons were observed as 1466.4 mm, 256.0 mm, 158.5 mm and 10.8 mm respectively. June (25.39%) and July (24.06%) were the months that contributed the highest percentage of rainfall whereas the months that contributed the least amount of rainfall were in January (0.4%) and February (0.37%). The South-West monsoon season contributed the highest amount of rainfall (74.09%) followed by North-East, summer and winter with 14.49%, 9.78% and 1.68% respectively.

The CV of the seasonal rainfall indicated that the rainfall was highly stable in South-West monsoon season followed by North-East, summer and winter seasons with a coefficient of variation of 25.42% 38.95%, 48.26% and 110.37% respectively. The winter season experienced undependable rainfall because of its high CV. The rainfall was highly stable in the month of June with CV of 33.27% followed by August with 34.09%. A high variability of rainfall was found in the month of January with CV 300% followed by March (224.54%).

The skewness of all the data series was found between -0.97 to 4.66. The North-East monsoon season showed a negatively skewed distribution whereas South-West monsoon, summer and winter seasons showed a positively skewed distribution. The months of June and October showed a negatively skewed distribution whereas all the remaining months showed a positively skewed distribution.

The kurtosis of all data series varies between -0.66 to 24.09. The months of January, February, March and December showed a kurtosis value greater than 3 which indicated as a peak distributed curve and the remaining months and seasons showed a flat distributed curve because the kurtosis values are less than 3.

The normal, surplus and deficit years during the period 1983-2017 are shown in Fig.4.1.

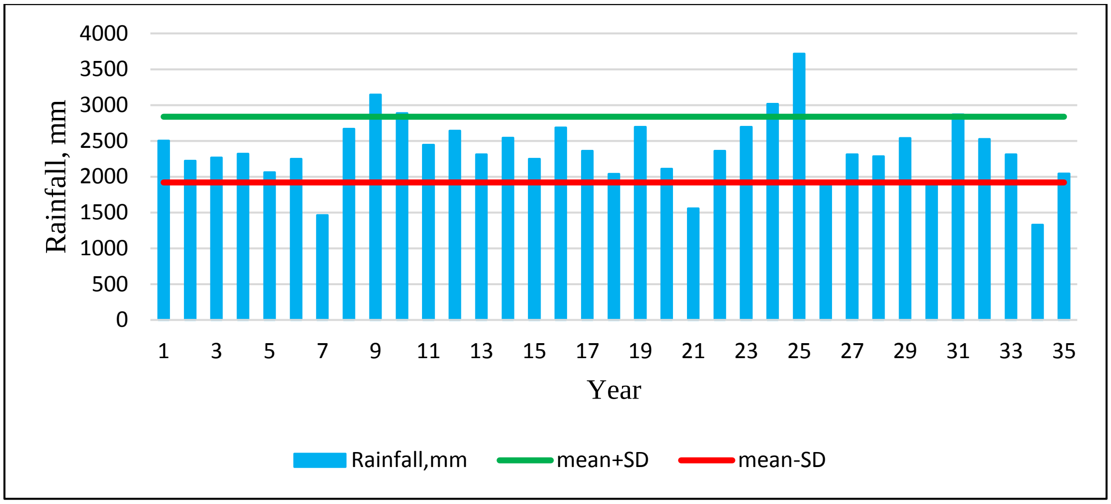

Fig. 4.1 Annual rainfall showing normal, deficit and surplus years in Pattambi (1983-2017).

From Fig. 4.1, it was observed that the rainfall in individual years which was getting more than the summation of mean and SD noted as surplus rainfall years. The years 9th, 10th, 24th, 25th and 31st were observed as the surplus years. The rainfall in individual year which was getting less than the difference between mean and SD noted as deficit years. Accordingly 7th, 21st, 26th and 34th years were showed as deficit years. The rest of the years were indicated as normal years.

The mean annual, seasonal, monthly and weekly variation of rainfall in Pattambi region during the period of 1983-2017 is shown in the Fig. 4.2, 4.3, 4.4 and 4.5 respectively. It was observed that the highest CV indicated high variability of rainfall and the lowest CV indicated the less variability of rainfall. Accordingly the year 1997 showed less variability of rainfall due to its lowest CV (0.38%) and the year 2002 showed high variability of rainfall (Fig. 4.2). Similarly the rainfall was less variable in South-West monsoon season (25.42%) and summer season (26.5%) because of its lowest CV (Fig. 4.3). In the case of monthly rainfall the months of June (33.27%) and August (34.09%) were less variable (Fig. 4.4). Weekly rainfall analysis showed that rainfall from 22nd SMW to 45th SMW (ranges from 90% to 110%) was less variable as compared to the other weeks due to the lower CV values (Fig. 4.5).

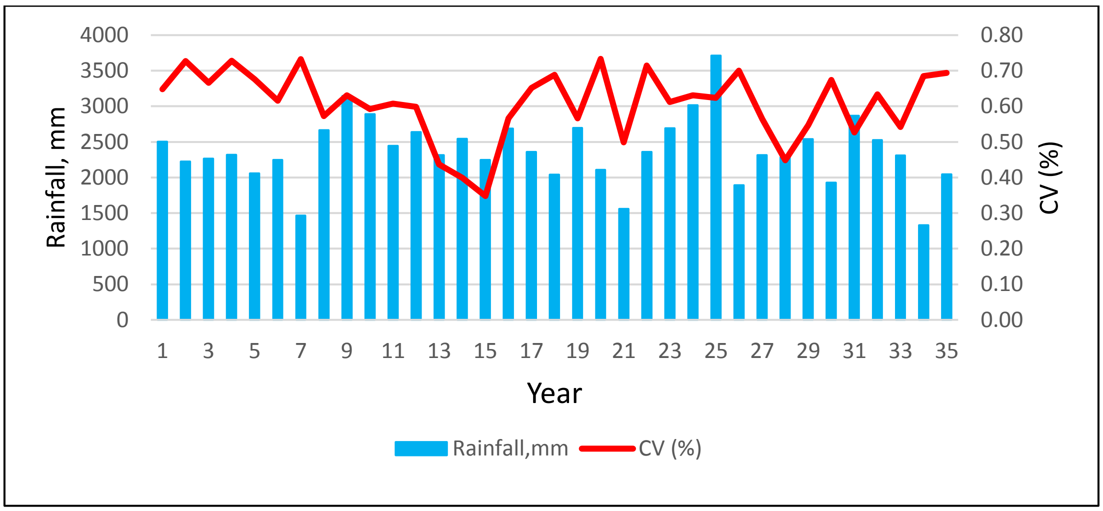

Fig. 4.2 Variation of annual rainfall of Pattambi (1983-2017)

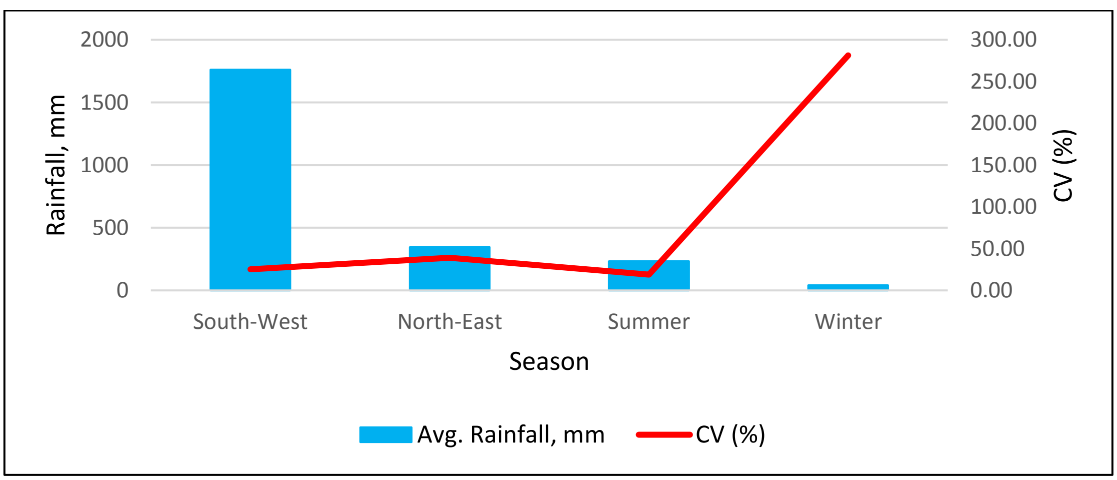

Fig. 4.3 Variation of Seasonal rainfall of Pattambi (1983-2017)

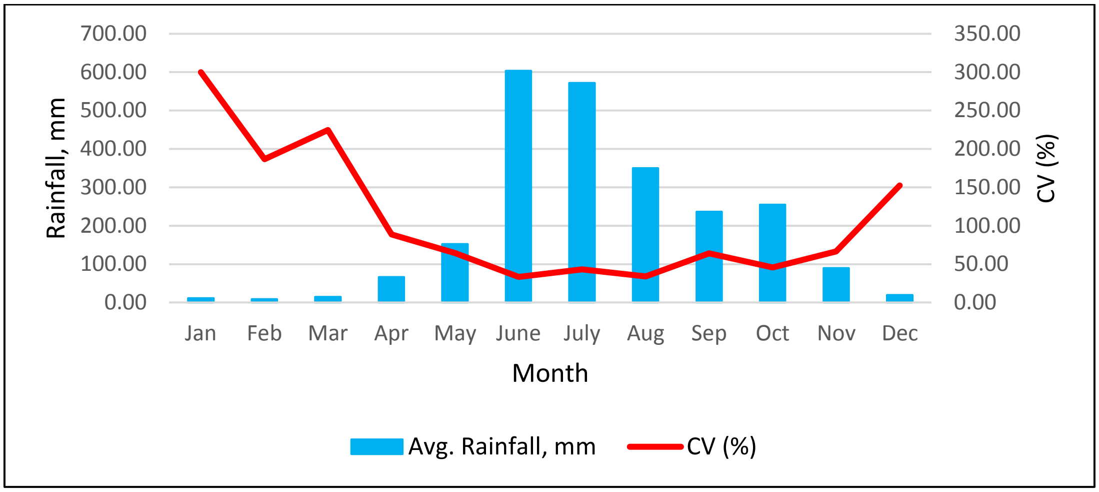

Fig. 4.4 Variation of mean monthly rainfall of Pattambi (1983-2017)

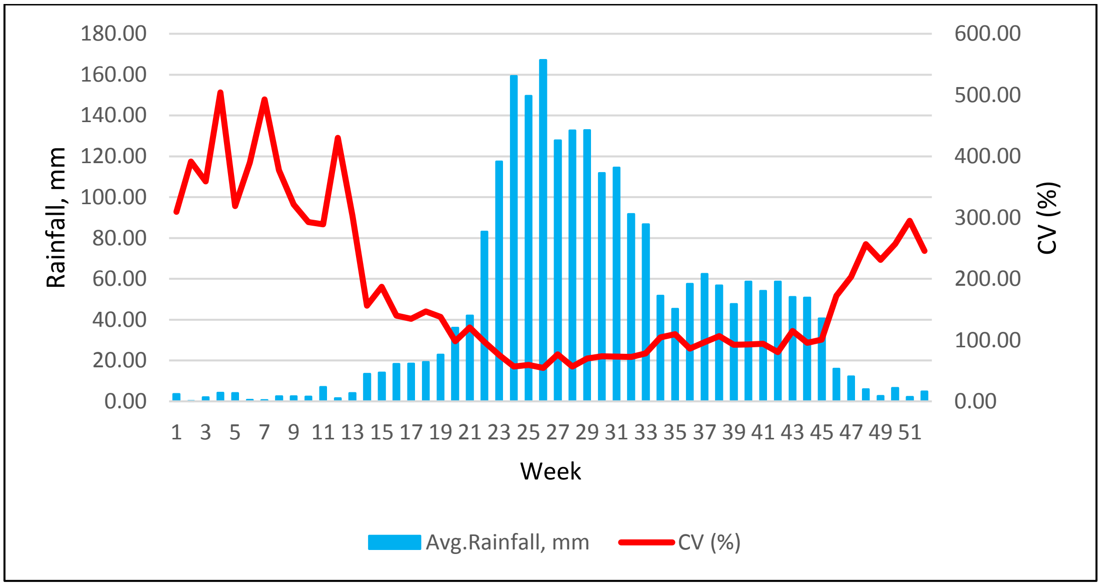

Fig. 4.5 Variation of mean weekly rainfall of Pattambi (1983-2017)

4.2 TREND ANALYSIS OF RAINFALL

The trend anlaysis of rainfall of Pattambi region during the period 1983-2017 was done monthly, seasonal and annually using the Mann-Kendall test and Sen's slope estimator.

4.2.1 Trend Analysis Using Mann-Kendall Test

The results of the Mann-Kendall test of monthly rainfall recorded at RARS, Pattambi during the period 1983-2017 was given in the Table 4.2.

Table 4.2 Mann-Kendall trend analysis of monthly rainfall of Pattambi (1983-2017)

S. No	Month	Z-statistics (Computed)	Z-value (10% level of significance)	Z-value (5% level of significance)	Trend	Trend at 5% level of significance
1.	January	-1.43	1.645	1.96	Falling	No
2.	February	1.07	1.645	1.96	Rising	No
3.	March	0.97	1.645	1.96	Rising	No
4.	April	1.94^{+}	1.645	1.96	Rising	No
5.	May	1.19	1.645	1.96	Rising	No
6.	June	-0.88	1.645	1.96	Falling	No
7.	July	-1.02	1.645	1.96	Falling	No
8.	August	-0.10	1.645	1.96	Falling	No
9.	September	1.63	1.645	1.96	Rising	No
10.	October	0.70	1.645	1.96	Rising	No
11.	November	-0.51	1.645	1.96	Falling	No
12.	December	0.40	1.645	1.96	Rising	No

('+' indicates significant trend at 10% level of significance)

From Table 4.2, it was observed that the monthly rainfall in some months showed a rising trend whereas a falling trend in some other months. The rising trend was observed in the months of February, March, April, May, September, October and December whereas the falling trend was seen in January, June, July, August and November. The significant trend was observed when the computed Z-statistics value is greater than the Z-value corresponding to the 5% level of significance (1.96) and if the computed Z-statistics value is less than Z-value corresponding to the 5% level of significance (1.96), then there was no significant trend. Accordingly there was no significant trend observed in any of the months at 5% level of significance, but a significant trend was observed in the month of April at 10% level of significance.

Table 4.3 Mann-Kendall trend analysis of annual and seasonal rainfall of Pattambi (1983-2017)

S. No	Rainfall Series	Z-statistics (Computed)	Z-value (1% level of significance)	Z-value (5% level of significance)	Trend	Trend at 5% level of significance
1.	Annual	-0.70	2.33	1.96	Falling	No
2.	South-West	-0.37	2.33	1.96	Falling	No
3.	North-East	-0.58	2.33	1.96	Falling	No
4.	Summer	2.58**	2.33	1.96	Rising	Yes
5.	Winter	0.05	2.33	1.96	No trend	No

(‘**’ indicates significant trend at 1% level of significance)

A rising trend was observed in summer season whereas a falling trend was observed in the South-West and North-East monsoon seasons. There was no trend observed in winter season as the Z-statistics value is almost zero. There was a significant trend in the summer season as the computed Z-statistics value is more than the Z-value corresponding to the 5% level of significance (1.96) and no significant trend was seen in the remaining seasons. There was a significant trend during summer season at 1% level of significance. Though the annual rainfall showed a falling trend there was no significant trend at 5% level of significance. The trends of annual and seasonal (South-West, North-East, summer and winter) rainfall were shown in Fig. 4.6, 4.7, 4.8, 4.9 and 4.10 respectively.

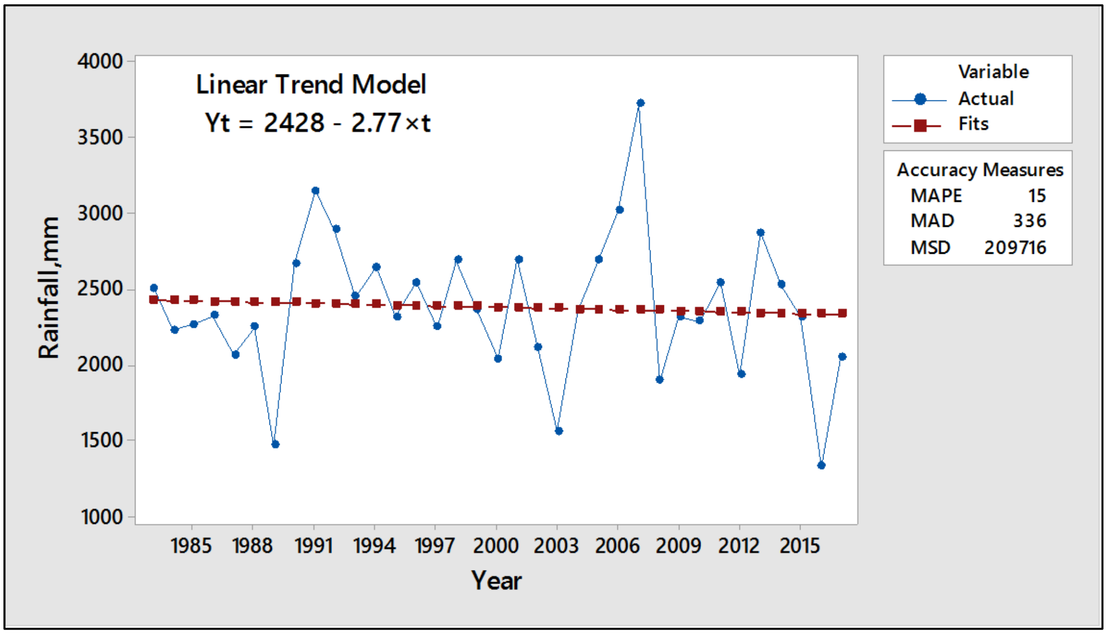

Fig. 4.6 Annual rainfall trends of Pattambi (1983-2017)

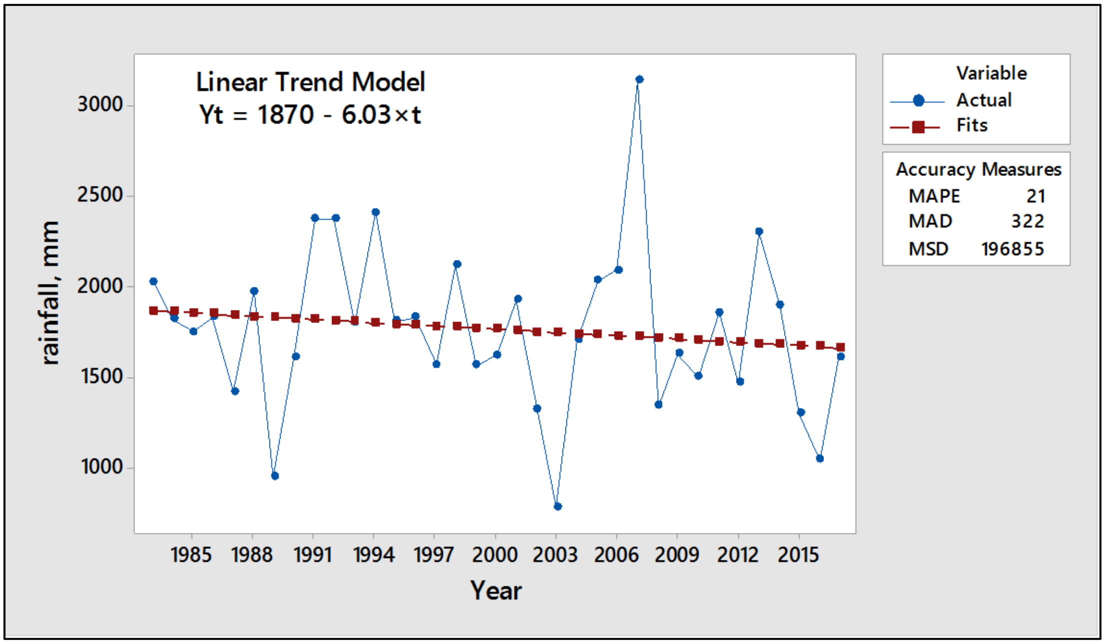

Fig. 4.7 South-West monsoon rainfall trends of Pattambi (1983-2017)

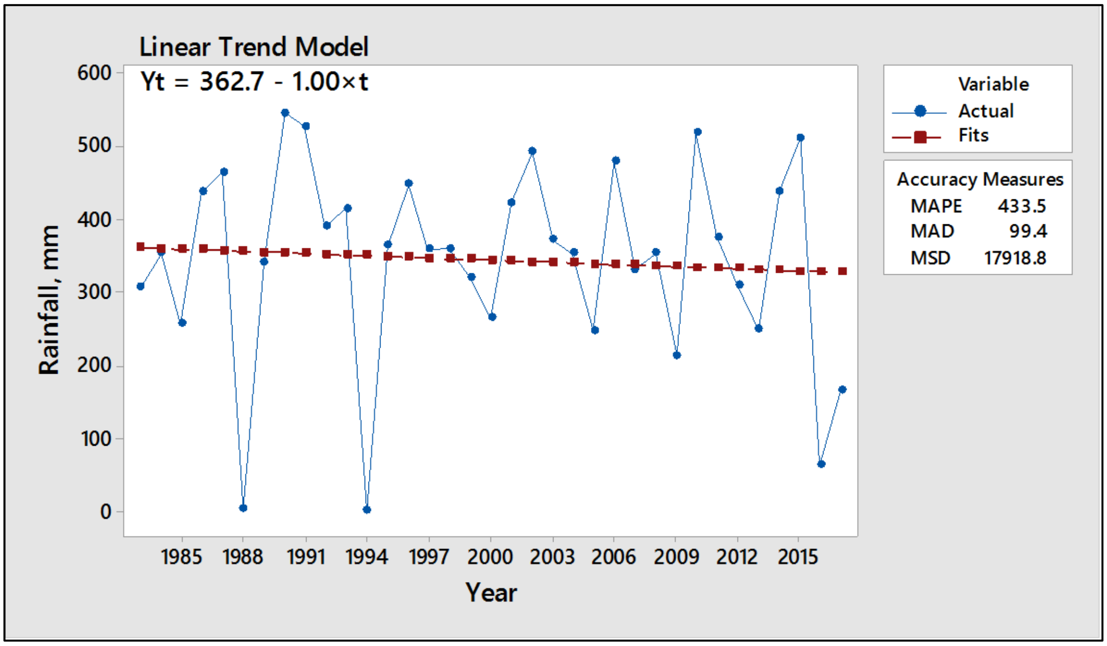

Fig. 4.8 North-East monsoon rainfall trends of Pattambi (1983-2017)

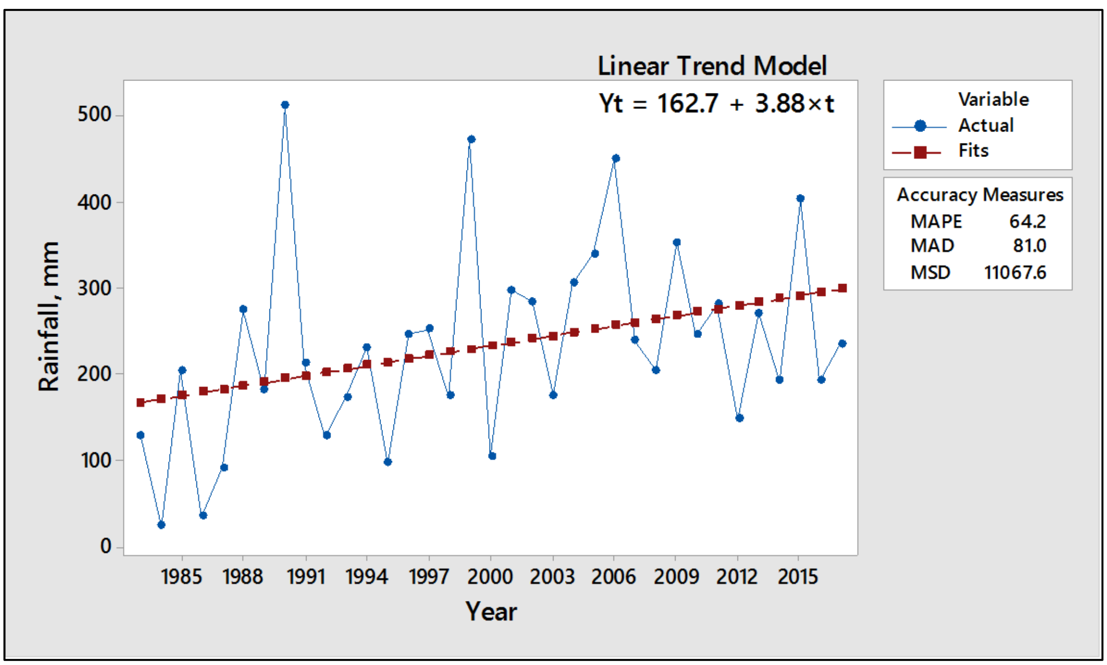

Fig. 4.9 Summer season rainfall trends of Pattambi (1983-2017)

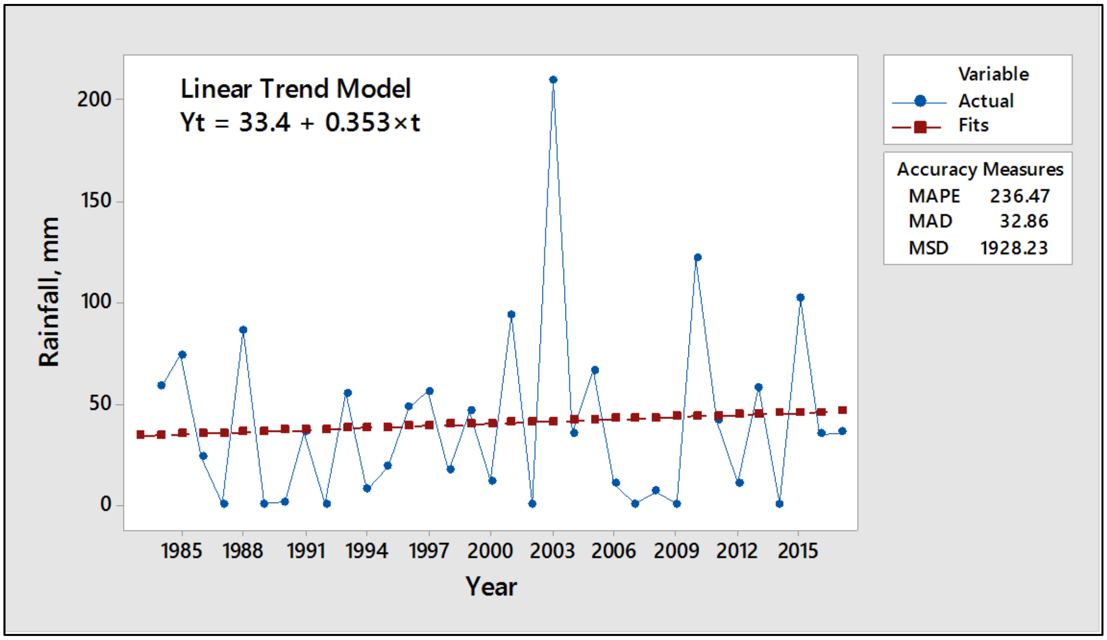

Fig. 4.10 Winter season rainfall trends of Pattambi from (1983-2017)

4.2.2 Trend Analysis Using Sen's Slope Estimator

The results of the Sen's slope estimator trend analaysis of annual and seasonal rainfall of Pattambi during the period 1983-2017 is given in Table 4.4.

The two important parameters in this test, confidence limits and the Sen's slope are shown in the Table 4.4. The confidence limits of the Sen's slope indicates that if the Sen's slope estimator had fallen in the region of the confidence limits, the Sen's slope values are correct. The positive slope indicated the rising trend whereas the negative slope indicated the falling trend. In this study the summer season rainfall showed a rising trend whereas the annual rainfall, South-West monsoon and North-East monsoon showed a falling trend. The winter season did not show any trend as the estimated Sen's slope was zero.

Table 4.4 Sen's slope estimator of annual and seasonal rainfall of Pattambi (1983-2017)

S.No	Rainfall Series	Sen's slope	Trend	Confidence limits for slope at 5% level of significance
1.	Annual	-0.462	Falling	LL = -1.191; UL = 1.819
2.	South-West	-1.111	Falling	LL = -4.802; UL = 3.862
3.	North-East	-0.623	Falling	LL = -2.811; UL = 1.664
4.	Summer	2.078	Rising	LL = 0.550; UL = 3.108
5.	Winter	0.000	No Trend	LL = -0.425; UL = 0.381

(LL= Lower Limit; UL= Upper Limit)

The results of the Sen's slope estimator of monthly rainfall are given in the Table 4.5. The monthly rainfall showed both falling and rising trends. The rising trend was observed in April, May, September and October whereas the falling trend was observed in June, July, August and November. January, February, March and December did not show any trend as the Sen's slope estimated was zero. The confidence limits for slope at 5% level of significance was also shown in the table which indicated that the Sen's slope estimator had fallen in the region of the confidence limits. So the Sen's slope values are correct.

Table 4.5 Sen's slope estimator of monthly rainfall of Pattambi (1983-2017)

S. No	Month	Sen's slope	Trend	Confidence limits for slope at 5% level of significance
1.	January	0.000	No Trend	LL = 0.000; UL = 0.000
2.	February	0.000	No Trend	LL = 0.000; UL = 0.000
3.	March	0.000	No Trend	LL = 0.000; UL = 0.036
4.	April	1.914	Rising	LL = 0.000; UL = 4.143
5.	May	1.795	Rising	LL = -1.246; UL = 4.826
6.	June	-3.783	Falling	LL = -11.119; UL = 6.133

7.	July	-4.696	Falling	LL = -15.081; UL = 5.339
8.	August	-0.285	Falling	LL = -5.680; UL = 6.038
9.	September	4.645	Rising	LL = -0.789; UL = 11.604
10.	October	1.464	Rising	LL = -3.134; UL = 6.481
11.	November	-0.603	Falling	LL = -3.583; UL = 1.814
12.	December	0.000	No Trend	LL = -0.140; UL = 0.342

(LL= Lower Limit; UL= Upper Limit)

4.3 RAINFALL PROBABILITY AT DIIFERENT LEVELS OF EXCEEDANCE

Rainfall analysis was done using daily rainfall data of Pattambi region for the period 1983-2017. The rainfall probability analysis at different levels of exceedance was calculated separately for weekly, monthly, seasonally and annually using incomplete gamma distribution.

4.3.1 Weekly Rainfall Probability at Different Levels of Exceedance

Weekly rainfall data was used to calculate probability at different levels of exceedance and the results are shown in Table 4.6.

Table 4.6 Weekly rainfall probability of Pattambi at different levels of exceedance (mm)

Weeks	Probability levels				
	90%	75%	50%	25%	10%
1	0.1	0.7	2.4	6.2	11.9
2	0.0	0.0	0.0	0.0	0.0
3	0.2	0.6	1.8	4.2	7.5
4	0.1	0.5	2.2	6.8	14.1
5	0.1	0.6	2.4	6.7	13.4
6	0.0	0.0	0.8	4.1	6.2
7	0.0	0.0	0.5	3.4	5.0

8	0.0	0.0	2.4	6.7	13.4
9	0.2	0.7	2.1	4.9	8.8
10	0.2	0.7	2.0	4.6	8.2
11	0.1	0.8	3.6	10.5	21.5
12	0.2	0.6	1.6	3.5	6.0
13	0.1	0.6	2.5	6.7	13.2
14	0.5	2.3	7.9	19.6	36.8
15	0.4	2.0	7.7	20.4	39.6
16	0.5	2.5	9.7	26.0	51.0
17	0.7	3.1	10.6	26.6	50.3
18	0.4	2.2	8.7	24.0	47.7
19	1.6	5.5	15.9	35.6	63.0
20	2.5	8.5	23.8	52.2	91.6
21	1.4	6.4	22.2	55.7	105.3
22	9.8	25.5	59.3	115.9	189.9
23	23.6	48.4	93.5	161.3	244.3
24	37.6	71.5	130.2	215.4	317.6
25	35.3	67.4	122.9	203.6	300.3
26	35.5	70.3	132.1	223.5	334.4
27	24.2	50.7	99.6	174.0	265.6
28	42.4	72.6	121.2	188.0	265.5
29	30.2	58.4	107.8	180.0	267.0
30	21.7	45.8	90.5	158.5	242.4
31	29.9	54.5	95.9	154.8	224.4
32	29.5	50.0	82.7	127.5	179.2
33	13.9	31.8	66.8	121.9	191.5
34	3.9	12.4	33.4	71.8	124.3

35	3.0	10.3	29.3	64.8	114.3
36	8.3	19.9	43.5	81.5	130.2
37	4.0	13.7	39.0	86.4	152.5
38	2.0	9.1	31.7	79.7	150.8
39	3.6	11.6	31.4	67.7	117.5
40	3.7	12.8	36.7	81.9	145.2
41	4.1	13.1	35.1	75.3	130.3
42	6.9	18.2	42.8	84.2	138.5
43	3.0	10.7	31.5	71.3	127.4
44	3.9	12.4	33.5	71.9	124.5
45	1.8	7.2	23.5	56.6	104.5
46	0.4	2.1	8.6	23.4	46.2
47	0.3	1.6	6.5	17.6	34.9
48	0.2	0.9	3.5	9.1	17.7
49	0.3	0.9	2.1	4.3	7.2
50	0.2	1.0	4.1	11.1	21.8
51	0.2	0.8	2.0	4.3	7.5
52	0.2	0.8	3.0	7.8	15.0

The Pattambi region was expected to receive a very less amount of rainfall (less than 3 mm) from 1st to 19th and 46th to 52nd SMWs at 75% probability. All the SMWs from 24th to 32nd might receive an amount of rainfall more than 50 mm except in 30th SMW at 75% probability. On the other hand 2nd, 6th, 7th and 8th SMWs might not receive any amount of rainfall at this level. The 28th SMW was expected to receive the highest amount of rainfall (72.6 mm) at 75% probability level. The 28th SMW was expected to receive the highest amount of rainfall (42.4 mm) at 90% probability. The SMW 26th was expected to receive the highest amount of rainfall of 132.1 mm, 223.5 mm and 334.4 mm at 50%, 25% and 10% probability levels respectively.

The weekly rainfall of Pattambi at different probability levels and its variation are depicted in Fig. 4.11.

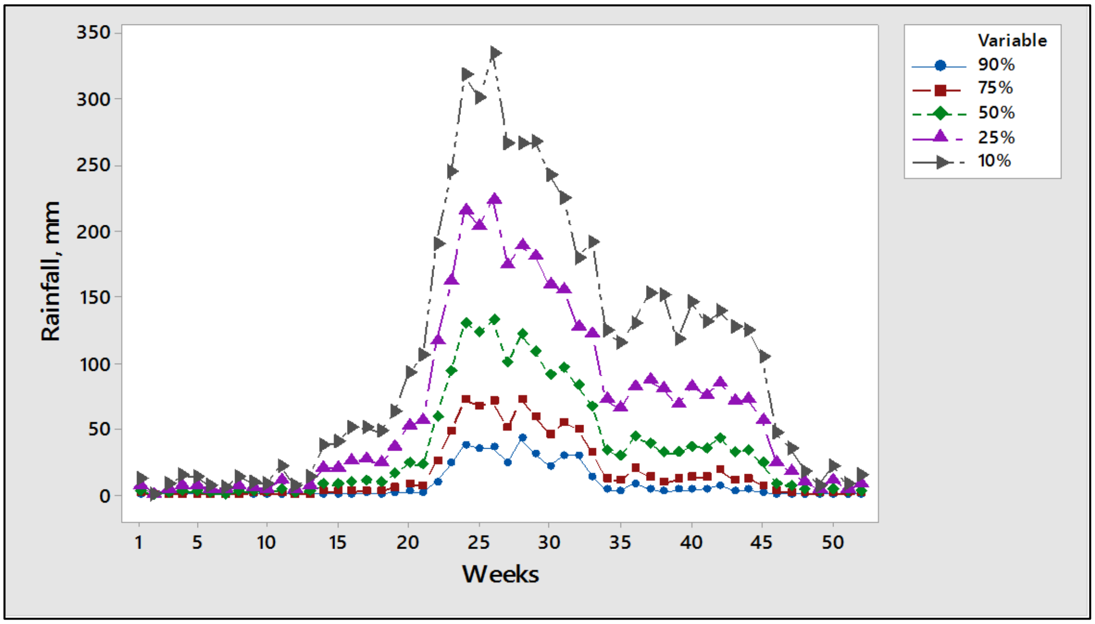

Fig.4.11 Weekly rainfall of Pattambi at different probability levels

It was clear that the rainfall at all probability levels was high during 24^{th} SMW to 35^{th} SMW whereas a low amount of rainfall during 1^{st} SMW to 13^{th} SMW and 46^{th} SMW to 52^{nd} SMW. The remaining weeks are expected to receive normal rainfall.

4.3.2 Monthly Rainfall Probability at Different Levels of Exceedance

Monthly rainfall data was used to calculate the monthly rainfall probability at different levels of exceedance and the results are shown in Table 4.7.

Table 4.7 Monthly rainfall probability of Pattambi at different levels of exceedance (mm)

S. No	Month	Probability levels				
		90%	75%	50%	25%	10%
1.	January	0.9	3.1	6.7	32.1	52.1
2.	February	0.9	3.2	6.7	19.4	29.4
3.	March	1.4	4.8	10.2	35.2	54.9
4.	April	8.3	27.5	58.9	105.1	141.5
5.	May	26.4	87.3	139.9	217.0	277.9
6.	June	346.6	471.1	578.6	736.3	860.9
7.	July	256.8	409.5	541.3	734.7	887.4
8.	August	197.2	271.1	334.9	428.6	502.5
9.	September	42.2	136.2	217.3	336.3	430.3
10.	October	105.3	177.9	240.4	332.3	404.8
11.	November	13.3	50.2	82.1	128.9	165.8
12.	December	2.5	9.5	15.6	38.8	57.1

The region was expected to receive less rainfall (less than 10 mm) in the months of January, February, March and December at 75% probability of rainfall. The remaining all months was expected to receive more than 50 mm except in the month of April. The month of June was expected to receive the highest amount of rainfall (471.1 mm) and lowest during January (3.1 mm) at 75% probability level. The same month was expected to receive a highest amount of rainfall of 346.6 mm, 578.6 mm and 736.3 mm at 90%, 50% and 25% probability level and lowest during February with 0.9 mm, 6.7 mm and 19.4 mm respectively. The highest amount of rainfall at 10%

probability level was expected in the month of July (887.4 mm). The monthly rainfall probability of Pattambi at different levels of exceedance and its variation is shown in Fig. 4.12.

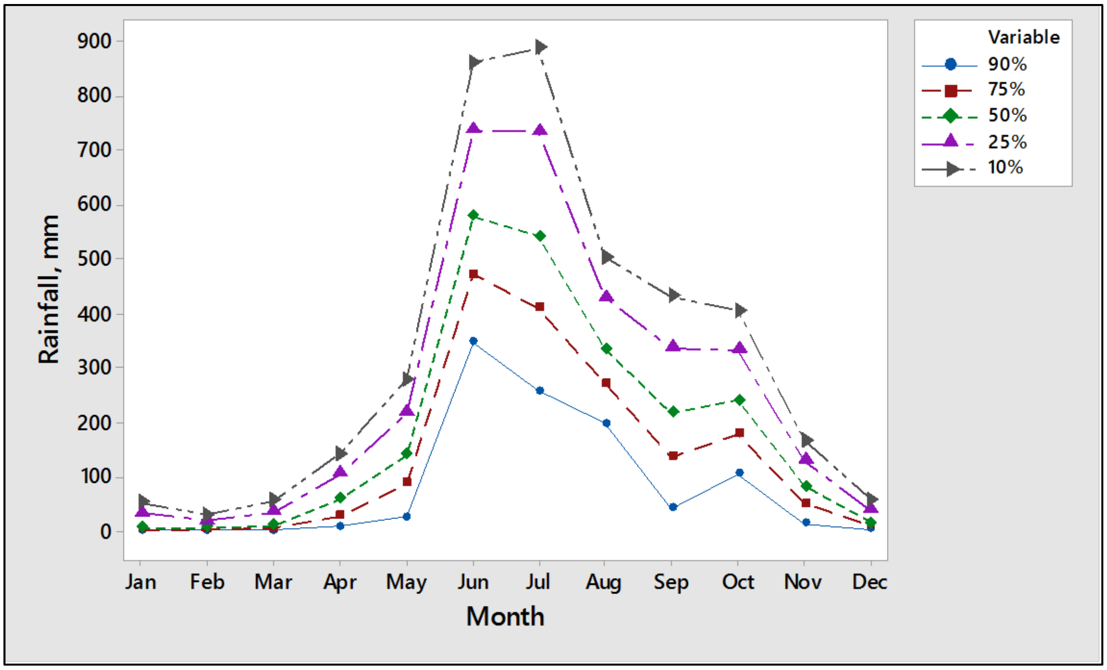

Fig.4.12 Monthly rainfall of Pattambi at different probability levels

It was clear that the months of June and July was expected to receive the high amount of rainfall at all probability levels as compared to other months whereas the January, February, Mar, April, November and December months was expected to receive the low amount of rainfall at all probability levels of exceedance.

4.3.3 Seasonal and Annual Rainfall Probability at Different Levels of Exceedance

Seasonal and annual rainfall data was used to calculate the rainfall probability at different levels of exceedance and the results are shown in Table 4.8.

Table 4.8 Seasonal and annual rainfall probability of Pattambi at different levels of exceedance (mm)

S. No	Rainfall Series	Probability levels				
		90%	75%	50%	25%	10%
1.	South-West	1188.7	1466.4	1706.0	2057.5	2335.2
2.	North-East	172.8	256.0	327.8	433.2	516.4
3.	Summer	88.9	158.5	218.6	306.7	376.3
4.	Winter	6.1	10.8	34.4	69.0	96.3
5.	Annual	1805.2	2051.6	2350.9	2678.0	2996.9

The winter season was expected to receive less amount of rainfall of 10.8 mm only at 75% probability level. The highest amount of rainfall was received during South-West monsoon (1466.4 mm) followed by North-East monsoon (256 mm), summer (158.5) and winter (10.8 mm) respectively. Similarly at 90%, 50%, 25% and 10% the highest amount of rainfall was expected during South-West monsoon (1188.7 mm, 1706 mm, 2057.5 mm and 2335.2 mm) and the lowest amount of rainfall was expected during winter season (6.1 mm, 34.4 mm, 69 mm and 96.3 mm).

The annual rainfall at 90%, 75%, 50%, 25% and 10% probability levels of exceedance was found to be 1805.2, 2051.6, 2350.9, 2678 and 2996.9 mm respectively. The variation of seasonal and annual rainfall probability of Pattambi at different levels of exceedance are shown in Fig. 4.13 and 4.14 respectively.

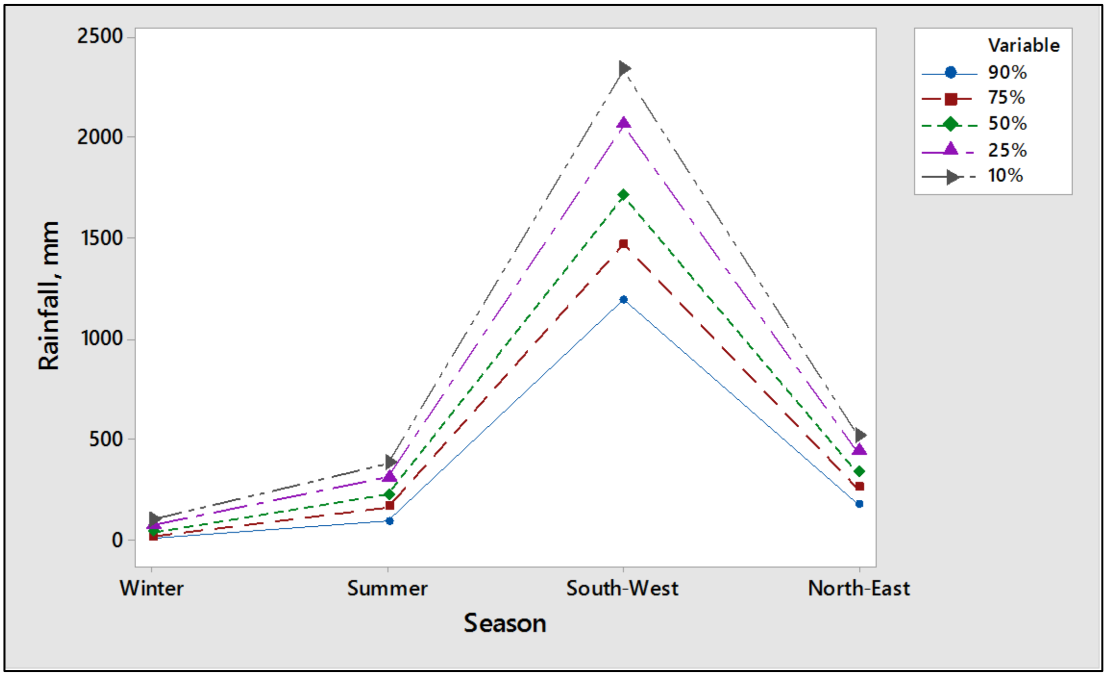

Fig.4.13 Seasonal rainfall of Pattambi at different probability levels

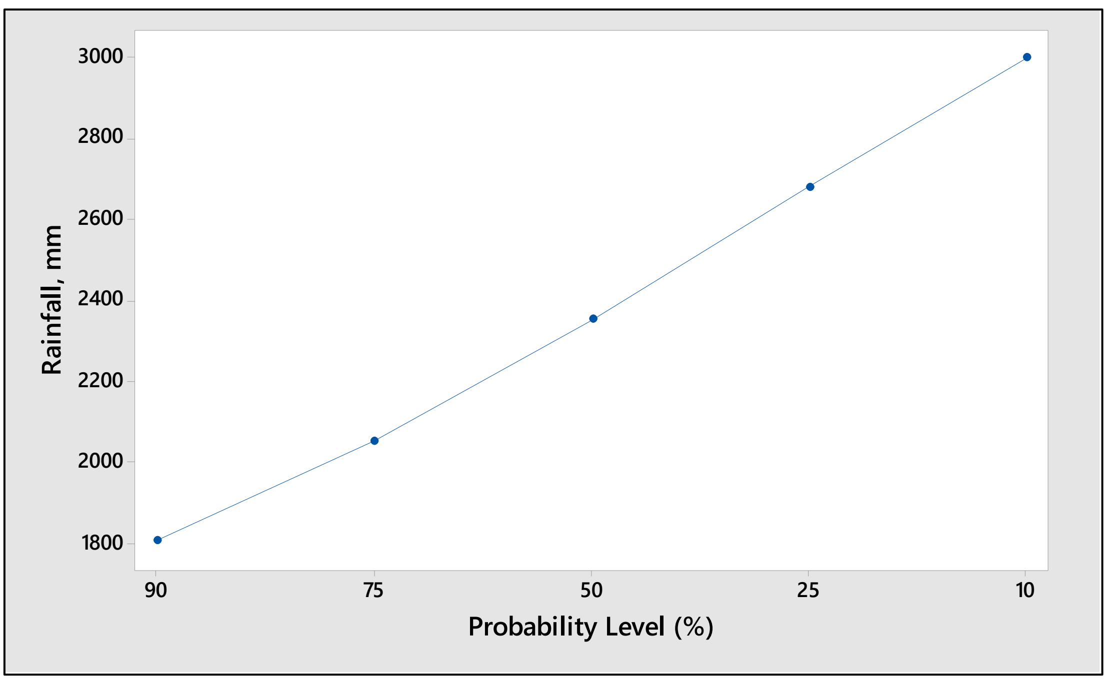

Fig.4.14 Annual rainfall of Pattambi at different probability levels

It was clear that the South-West monsoon season was expected to receive high amount of rainfall at all probability levels whereas the winter season was expected to receive less amount of rainfall. A moderate rainfall was expected to receive in other seasons (Fig. 4.14). The probability analysis of annual rainfall showed that a rainfall of 2051.6 mm was expected to occur at 75% probability. But at 90% probability, there was only less amount of rainfall whereas at 10% there was a chance of getting high rainfall.

4.4 EVALUATION OF PROBABILITY DISTRIBUTION FUNCTIONS

The probability distributions viz. Normal, Log normal, Log-Pearson III, Weibull and Gumbel max distributions were evaluated to identify the most appropriate probability distribution function in annual, monthly and weekly rainfall. The PDFs and CDFs of annual, monthly and weekly rainfall were fitted using easyfit software to get the parameters of the distributions and the results are shown in Fig. 4.15, 4.16, 4.17, 4.18, 4.19 and 4.20 respectively.

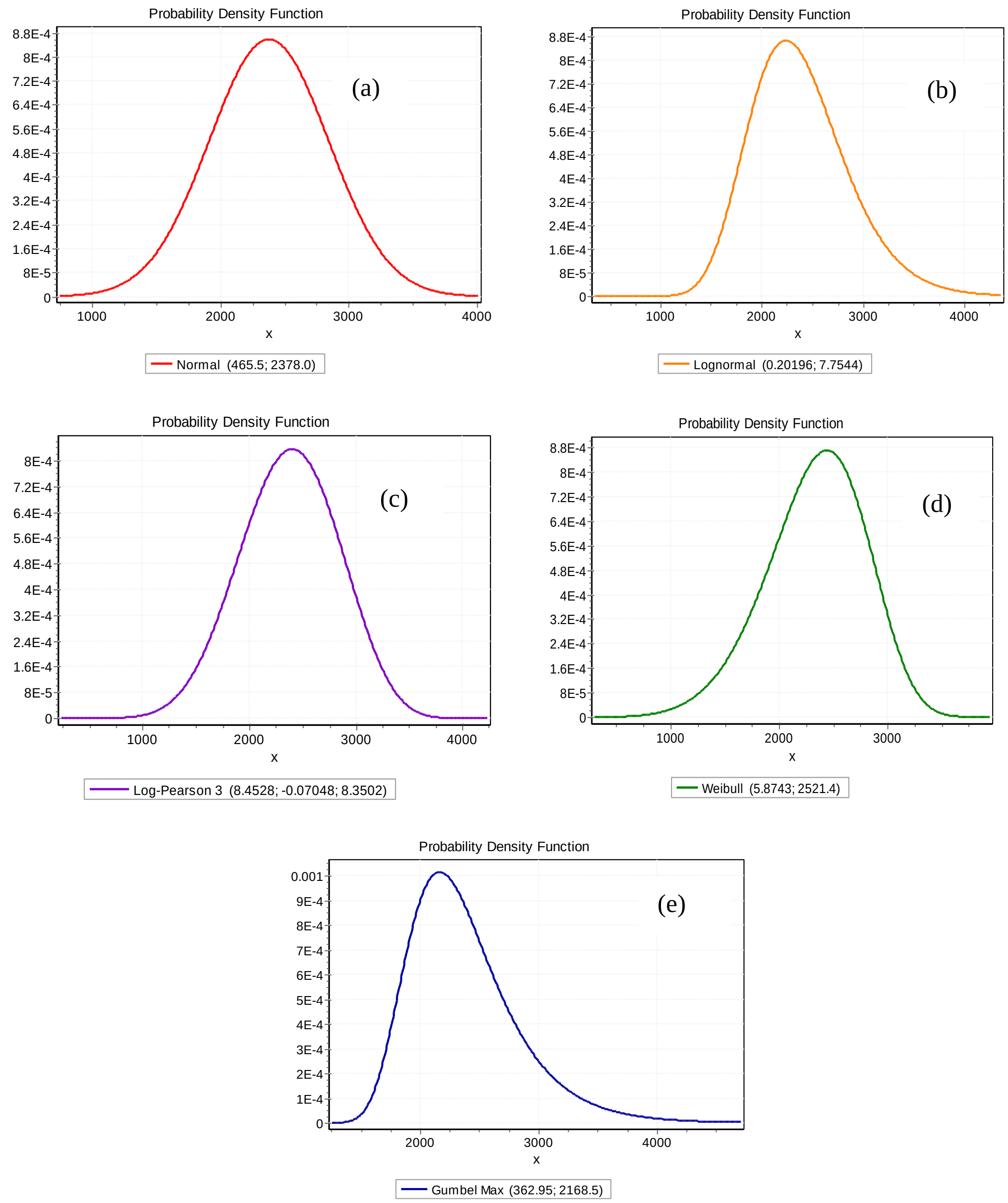

Fig. 4.15 PDFs of different probability distributions of annual rainfall (a) Normal; (b) Lognormal; (c) Log-Pearson III; (d) Weibull; (e) Gumbel max

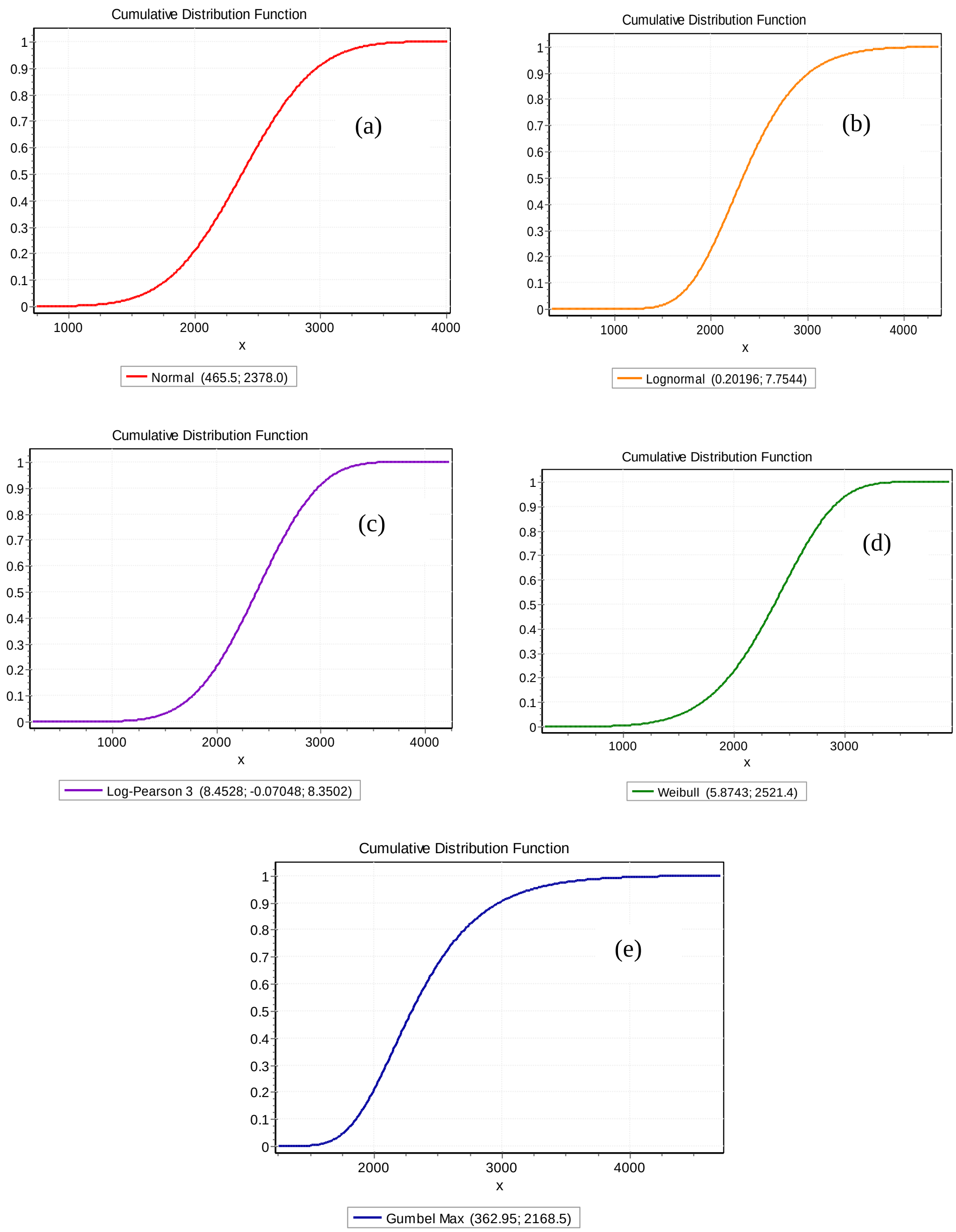

Fig. 4.16 CDFs of different probability distributions of annual rainfall (a) Normal; (b) Lognormal; (c) Log-Pearson III; (d) Weibull; (e) Gumbel max

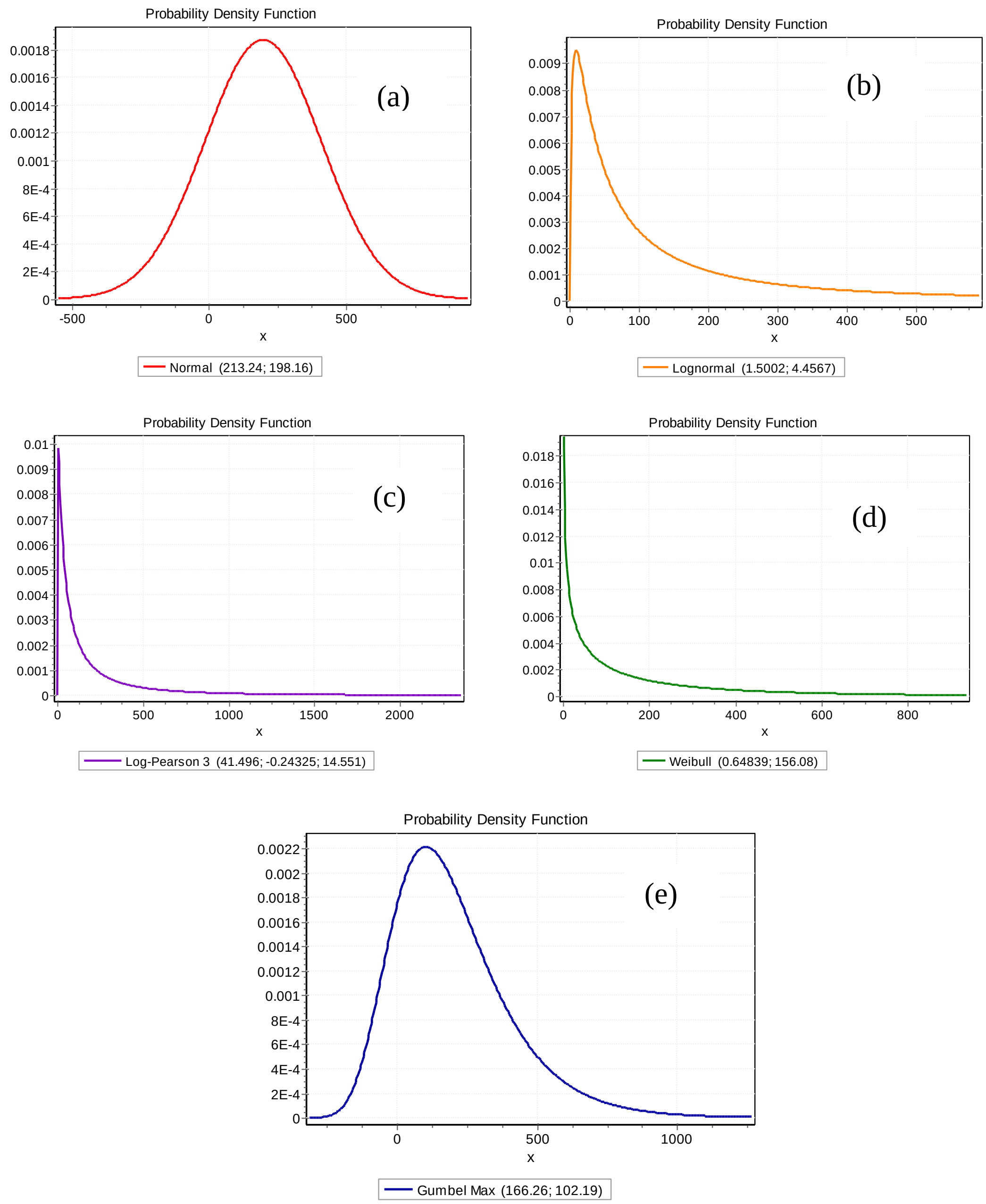

Fig. 4.17 PDFs of different probability distributions of monthly rainfall (a) Normal; (b) Lognormal; (c) Log-Pearson III; (d) Weibull; (e) Gumbel max

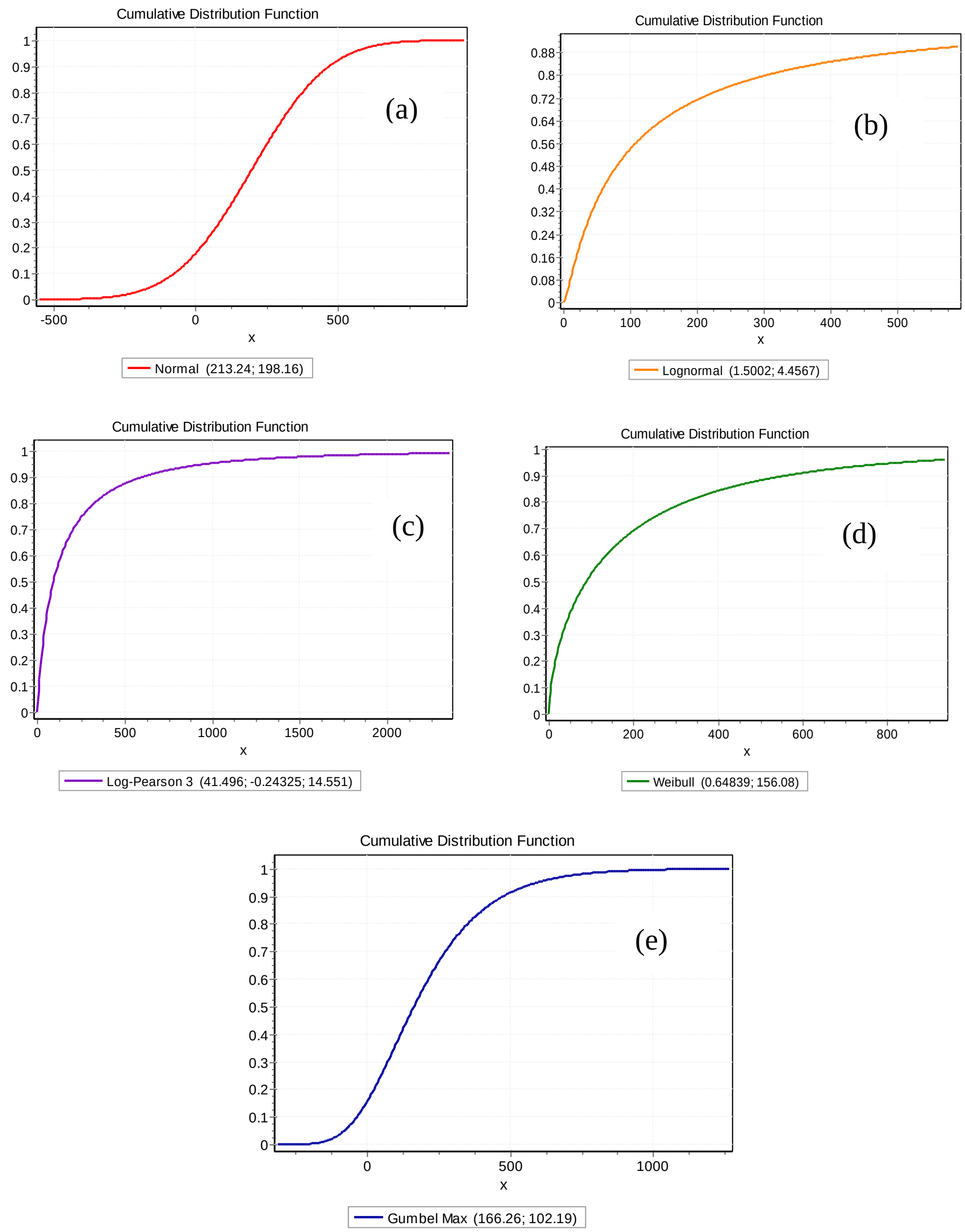

Fig. 4.18 CDFs of different probability distributions of monthly rainfall (a) Normal; (b) Lognormal; (c) Log-Pearson III; (d) Weibull; (e) Gumbel max

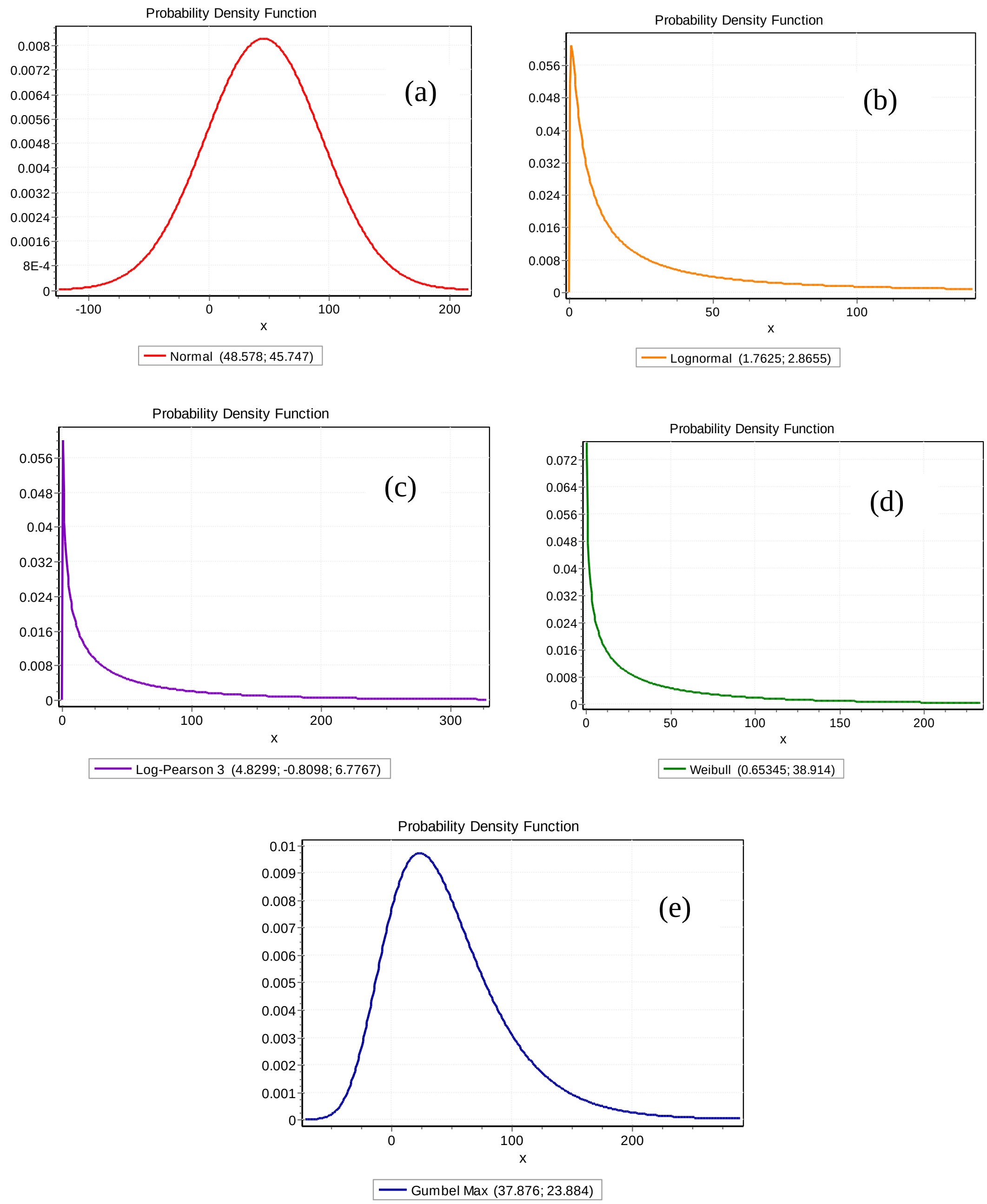

Fig. 4.19 PDFs of different probability distributions of weekly rainfall (a) Normal; (b) Lognormal; (c) Log-Pearson III; (d) Weibull; (e) Gumbel max

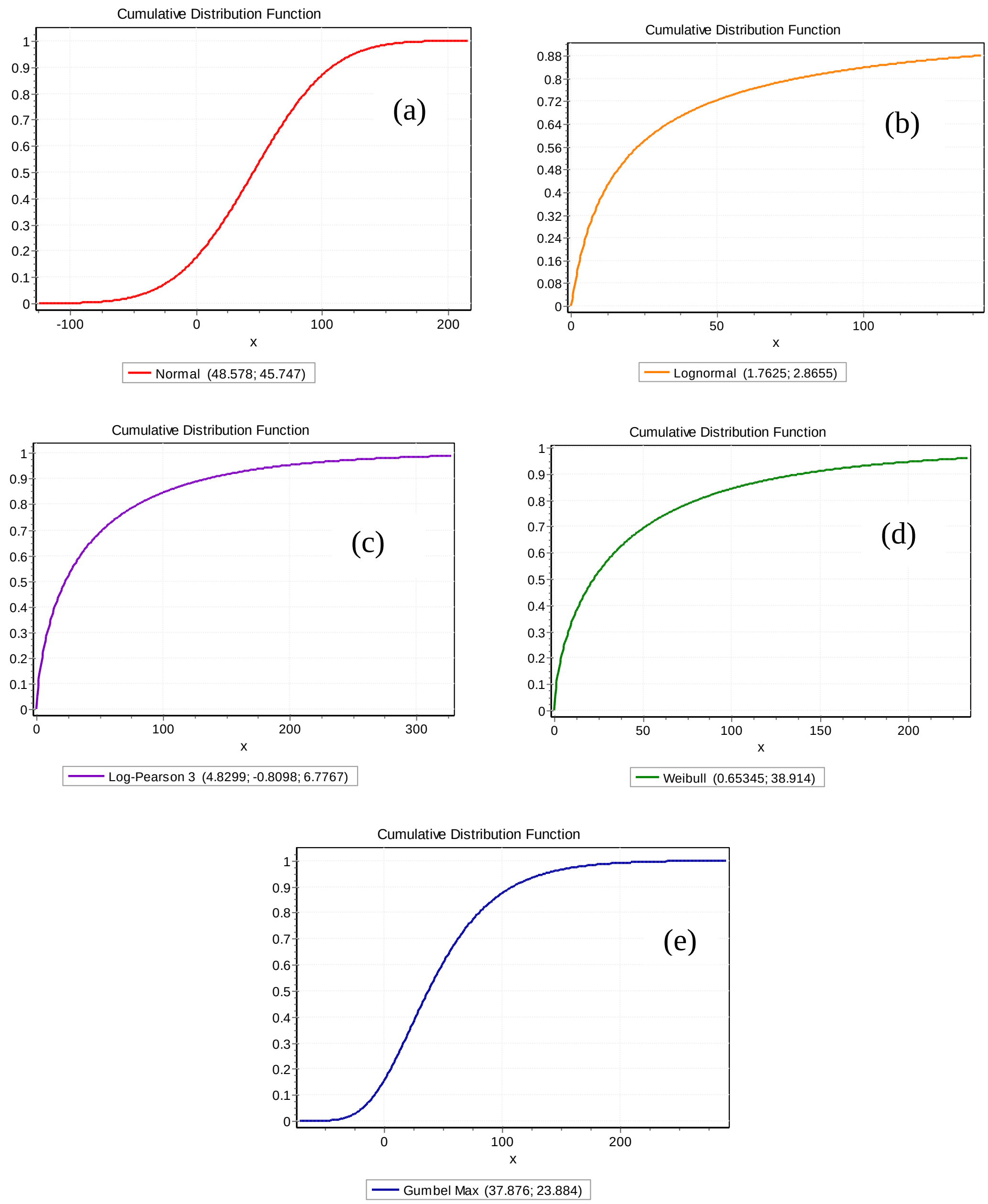

Fig. 4.20 CDFs of different probability distributions of weekly rainfall (a) Normal; (b) Lognormal; (c) Log-Pearson III; (d) Weibull; (e) Gumbel max

The parameters of the different fitted probability distributions of annual rainfall, monthly rainfall and the weekly rainfall is given below in the Table 4.9, 4.10 and 4.11 respectively.

Table 4.9 Parameters of the fitted probability distribution of annual rainfall

S. No	Distribution	Parameters
1.	Normal	σ=465.5; μ=2378.0
2.	Lognormal	σ=0.20196; μ=7.7544
3.	Log-Pearson III	α=8.4528; β= -0.07048; γ=8.3502
4.	Weibull	α=5.8743; β=2521.4
5.	Gumbel max	σ=362.95; μ=2168.5

Table 4.10 Parameters of the fitted probability distribution of monthly rainfall

S. No	Distribution	Parameters
1.	Normal	σ=213.24; μ=198.16
2.	Lognormal	σ=1.5002; μ=4.4567
3.	Log-Pearson III	α=41.496; β=-0.24325; γ=14.551
4.	Weibull	α=0.64839; β=156.08
5.	Gumbel max	σ=166.26; μ=102.19

Table 4.11 Parameters of the fitted probability distribution of weekly rainfall

S. No	Distribution	Parameters
1.	Normal	σ=48.578; μ=45.747
2.	Lognormal	σ=1.7625; μ=2.8655
3.	Log-Pearson III	α=4.8299; β=-0.8098; γ=6.7767
4.	Weibull	α=0.65345; β=38.914
5.	Gumbel max	σ=37.876; μ=23.884

4.4.1 Identification of Best Fit Probability Distribution Using Goodness of Fit

The selection of best fit probability distribution function was identified using three different goodness of fit tests viz. Kolmogorov-Smirnov test, Anderson-Darling test and Chi-Square test for annual, monthly and weekly rainfall. The results are presented in Table 4.12, 4.13 and 4.14 respectively.

Table 4.12 Test values of various probability distribution functions for annual rainfall

S.No	Distribution	Kolmogorov Smirnov (KS)		Anderson Darling (AD)		Chi-Square (χ^2)	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Normal	0.11263	1	0.47618	1	1.5991	2
2	Lognormal	0.14946	4	0.72339	4	2.9883	3
3	Log-Pearson III	0.11356	2	0.56672	2	1.5694	1
4	Weibull	0.12244	3	0.57959	3	6.0269	5
5	Gumbel max	0.16602	5	1.2571	5	2.9965	4

From the Table 4.12 it was clearly inferred that the statistic value (0.11263 for KS test and 0.47618 for AD test) of the normal distribution was the least with a rank of 1. Hence, the normal distribution was identified as the best fit for annual rainfall based on the Kolmogorov-Smirnov and Anderson Darling tests. But the Log-Pearson III distribution was found to be the best fit for annual rainfall based on the Chi-Square test as the estimated statistic value (1.5694) was less with a rank of 1. Hence, it was concluded that Log-Pearson III distribution was identified as the best fit for annual rainfall of the region as the Chi-Square test is more reasonable.

Table 4.13 Test values of various probability distribution functions for monthly rainfall

S.No	Distribution	Kolmogorov Smirnov (KS)		Anderson Darling (AD)		Chi-Square (χ^2)	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Normal	0.19476	5	0.75011	5	0.69269	4
2	Lognormal	0.17393	4	0.49662	4	0.21089	2
3	Log-Pearson III	0.16536	2	0.3946	2	0.25099	3
4	Weibull	0.14641	1	0.37113	1	0.03269	1
5	Gumbel max	0.17293	3	0.49394	3	0.90268	5

From the Table 4.13 it was clearly found that the Weibull distribution was the best fit for the monthly rainfall of Pattambi as the statistic values were found least for Weibull distribution (0.14641, 0.37113 and 0.03269 for KS, AD and χ^2 tests respectively) with a rank of 1.

Table 4.14 Test values of various probability distribution functions for weekly rainfall

S.No	Distribution	Kolmogorov Smirnov (KS)		Anderson Darling (AD)		Chi-Square (χ^2)	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Normal	0.18819	5	2.9266	5	7.2028	5
2	Lognormal	0.1634	4	1.2973	3	5.6164	4
3	Log-Pearson III	0.11903	1	0.70637	1	0.54773	2
4	Weibull	0.12285	2	0.73955	2	0.38776	1
5	Gumbel max	0.15798	3	1.8953	4	3.7196	3

From the Table 4.14 it was found that the statistic values of KS and AD test was the least for Log-Pearson III distribution (0.11903 and 0.70637) with a rank of 1. Hence, Log-Pearson III distribution was found best fit for weekly rainfall. But accordingly to Chi-Square test the least statistic value (0.38776) was obtained for Weibull distribution with a rank of 1. Since the Chi-Square is more reasonable, Weibull distribution was taken as the best fit distribution for weekly rainfall in this study.

A description of statistical parameters of probability distribution functions evaluated in this study is appended in Table 4.15.

Table 4.15 Parameters of best fit probability distribution of annual, monthly and weekly rainfall.

S.No	Rainfall period	Goodness of fit	Distribution	Parameters
1.	Annual	Kolmogorov-Smirnov	Normal	σ=465.5; μ=2378.0
		Anderson-Darling	Normal	σ=465.5; μ=2378.0
		Chi-Square	Log-Pearson III	α=8.4528; β= -0.07048; γ=8.3502
2.	Monthly	Kolmogorov-Smirnov	Weibull	α=0.64839; β=156.08
		Anderson-Darling	Weibull	α=0.64839; β=156.08
		Chi-Square	Weibull	α=0.64839; β=156.08
3.	Weekly	Kolmogorov-Smirnov	Log-Pearson III	α=4.8299; β= -0.8098; γ=6.7767
		Anderson-Darling	Log-Pearson III	α=4.8299; β= -0.8098; γ=6.7767
		Chi-Square	Weibull	α=0.65345; β=38.914

From the Table 4.15, the statistical parameters for Log-Pearson III distribution of annual rainfall was found to be α=8.4528, β=-0.07048 and γ=8.3502 whereas the same for Weibull distribution of monthly rainfall was α=0.64839 and β=156.08. The Weibull distribution of weekly rainfall was identified with statistical parameters of α=0.65345 and β=38.914.

4.4.2 Comparison of Weekly Rainfall at 75% Probability Level of Exceedance of Incomplete Gamma Distribution with Weibull Distribution

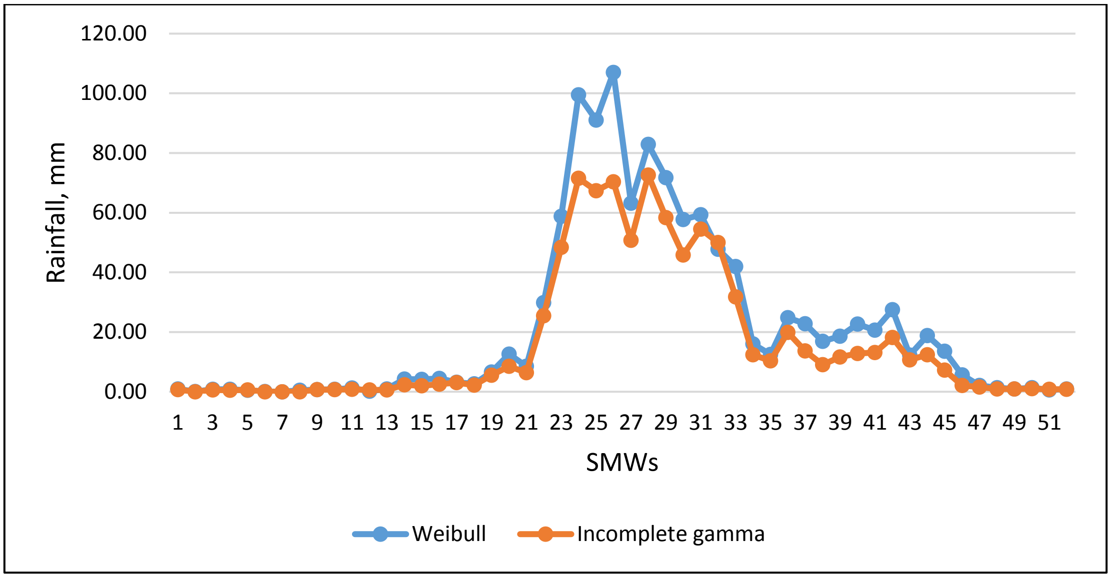

Fig.4.21 Comparison of weekly rainfall at 75% probability between incomplete gamma and Weibull distribution

From Fig. 4.21, it was clearly observed that the rainfall probabilities with Weibull and incomplete gamma distributions at 75% level of exceedance was getting almost similar values in all weeks except in the weeks from 24th SMW to 30th SMW. The probability level at 75% was taken for comparison because at 75% probability level there was more chance of occurrence of the event. The 26th SMW received the highest amount of rainfall of 107 mm and 71 mm according to Weibull distribution and incomplete gamma distribution respectively.

4.5 COMPARISON OF PROBABLE EVAPOTRANSPIRATION DEMAND OF THE CROPS WITH PROBABLE RAINWATER AVAILABILITY

The evapotranspiration demands of the major crops in the region (rice, banana and vegetables) were compared with probable rainfall availability and surplus and deficit were worked out.

4.5.1 Probable Rainwater Availability

The expected weekly rainfall amounts at 75% probability level of exceedance determined using Weibull distribution was taken as probable rainfall. Then the probable rainfall was compared with the probable evapotranspiration demands of different crops (Rice, Banana and Vegetables-Tomato) in the region. The rainfall probability at 75% level of exceedance by Weibull distribution is given in Table 4.16.

Table 4.16 Probable weekly rainwater availability of Pattambi at 75% level by Weibull distribution

SMW	Rainfall, mm	SMW	Rainfall, mm	SMW	Rainfall, mm
1	0.90	19	6.60	36	24.80
2	0.10	20	12.65	37	22.73
3	0.80	21	8.56	38	16.85
4	0.80	22	29.88	39	18.61
5	0.50	23	58.75	40	22.72
6	0.10	24	99.49	41	20.59
7	0.00	25	91.02	42	27.46
8	0.50	26	107.00	43	12.33
9	0.70	27	63.22	44	18.77
10	0.80	28	82.86	45	13.58
11	1.20	29	71.73	46	5.60
12	0.20	30	57.67	47	2.10

13	0.90	31	59.30	48	1.30
14	4.20	32	47.73	49	0.90
15	4.10	33	41.96	50	1.30
16	4.51	34	16.02	51	0.60
17	3.20	35	12.45	52	0.90
18	2.60				

4.5.2 Probable evapotranspiration demands

The weekly ET_o values estimated by FAO-56 Penmann-monteith are given in Appendix III. The expected weekly ET_o values at 50% probability level was estimated by fitting normal distribution and the values are given in Appendix IV

4.5.3 Comparison of ET Demand, Rainwater Availability and Rain Surplus/Deficit at Pattambi for Rice Crop

The values of ET_c for rice computed based on daily ET_o at 50% probability levels of potential evapotranspiration (ET_o) and expected amount of rainfall at 75% probability level in Pattambi region are given in Table 4.17.

Table 4.17 ET_{rice} demand at different growth stages in Pattambi region

S. No	Growth Stages (1)	Daily ET_o at 50% Probability (mm) (2)	K_c (3)	Daily ET_{rice} (mm) (4)	Total ET_{rice} demand (mm) (5) = (4) X n days	75% probable rainwater availability (mm) (6)
1.	Nursery (18th and 19th SMW), 14 days	3.67	0.85	3.119	43.673	9.20

2.	Seeding (20, 21, 22 and 23rd SMW), 28 days	3.29	0.9	2.961	82.908	109.84
3.	Vegetative (24, 25, 26, 27, 28 and 29th SMW), 42 days	3.12	1.01	3.151	132.351	515.32
4.	Reproductive (30, 31, 32, 33, 34 and 35th SMW), 42 days	3.11	1.05	3.266	137.151	235.13
5.	Maturity (36, 37 and 38th SMW), 21 days	3.48	1	3.480	73.08	64.37
6.	Total				469.162	933.85

The total ET_c demand of rice at 50% probability level was estimated as 469.162 mm whereas the total rainwater availability at 75% probability during the period was estimated as 933.85 mm. This indicated that the rainwater availability was sufficient to meet the ET demands of the crop. Though the total expected availability of rainwater in the region is sufficient for crop growth, the growth stage wise distribution of rainwater was not sufficient to meet the ET demands. The comparison of the rainwater availability with the ET demands, surplus and deficit is depicted in Fig. 4.22.

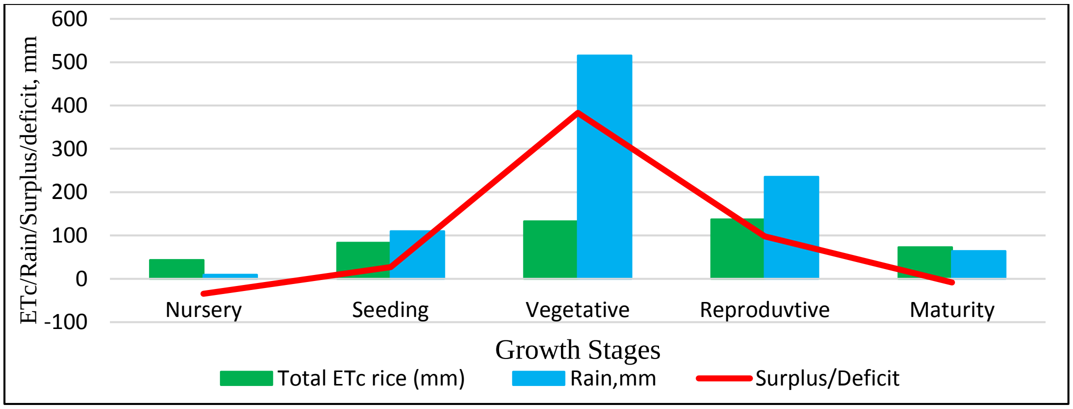

Fig. 4.22 Comparison of ET demand, rainwater availability and rain surplus/deficit at Pattambi for rice crop

From Fig. 4.22, it was found that the ET demand of the rice crop during the nursery stage was about 43.673 mm whereas the available rainwater was only 9.2 mm. Similarly during seeding stage the ET demand of the crop was about 82.908 mm and the available rainwater was about 109.84 mm. During the vegetative stage of the crop the ET demand of the crop was 132.351 mm whereas the rainwater availability was 515.32 mm. In the reproductive stage the ET demand of the crop was about 137.151 mm whereas the available rainwater was 235.13 mm. During the maturity stage of the crop the ET demand was about 73.08 mm whereas the available rainwater was about 64.37 mm respectively. This clearly indicated that there was deficit of rainwater availability during nursery, and maturity stages whereas surplus in seeding, vegetative and reproductive stages. So, there is a need of supplemental irrigation during deficit stages. But, the rainwater was surplus during the seeding, vegetative and reproductive stages. During these stages the surplus rainwater can be stored and can be utilized for raising some less water requiring crops.

4.5.4 Comparison of ET Demand, Rainwater Availability and Rain Surplus/Deficit at Pattambi for Banana

The values of ET_c for banana was computed based on daily ET_o at 50% probability levels of potential evapotranspiration (ET_o) and expected amount of rainfall at 75% probability level in Pattambi region are given in Table 4.18.

Table 4.18 ET_{banana} demand at different growth stages in Pattambi region

S. No	Growth Stages (1)	Daily ET_o at 50% Probability (mm) (2)	K_c (3)	Daily ET_{banana} (mm) (4)	Total ET_{banana} demand (mm) (5) = (4) X n days	75% probable rainwater availability (mm) (6)
1.	Initial stage (8 to 24th SMW), 120 days	3.63	0.45	1.63	196.02	238.83
2.	Development (25 to 37th SMW), 90 days	3.29	0.78	2.57	230.96	698.48
3.	Mid stage (38 to 52nd, 1st and 2nd SMW), 120 days	3.42	1.05	3.59	430.92	164.62
4.	Late stage (3 to 10th SMW), 60 days	4.11	0.95	3.90	234.27	4.20
5.	Harvest (11 and 12th SMW), 14 days	4.08	0.8	3.26	32.64	1.40
6.	Total				1124.81	1107.53

The total ET_c demand of banana was estimated as 1124.81 mm whereas the rainwater availability was 1107.53 mm. This indicated that available rainwater was not sufficient for growing banana in Pattambi region. Though the expected availability of rainwater in the region was not sufficient for entire crop growth the growth stage wise distribution of rainwater was found adequate to meet the ET demands in initial and development stages. The comparison of the rainwater availability with the ET demands, surplus and deficit is depicted in Fig. 4.23.

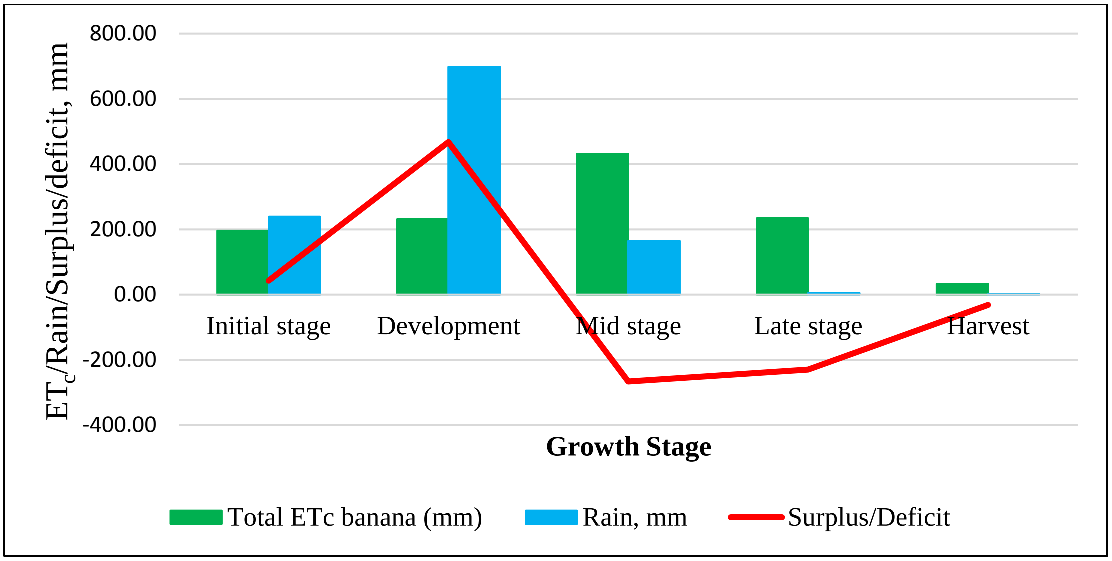

Fig. 4.23 Comparison of ET demand, rainwater availability and rain surplus/deficit at Pattambi for banana

It was found that during the initial stage the ET demand of banana was about 196.02 mm and the available rainwater was 238.83 mm. Similarly during development stage the ET demand of the crop was about 230.96 mm and the available rainwater was 698.48 mm. During the mid-stage of the crop the ET demand of the crop was 430.92 mm and the rainwater availability was 164.62 mm. In the late stage the ET demand of the crop was about 234.27 mm and the available rainwater was 4.2 mm. During the harvest stage of the crop the ET demand was about 32.64 mm and the available rainwater was 1.4 mm respectively. This clearly indicated that there was deficit of rainwater availability during all stages except initial and development stages. During initial and development stages of the crop there was a surplus rainwater of about 510.33 mm as this rainwater could be utilized for the further stages by saving the rainwater in water harvesting structures nearby farm. There is a need of supplemental irrigation during the mid-stage, late stage and harvesting stage as the rainwater availability was very less during these stages.

4.5.6 Comparison of ET Demand, Rainwater Availability and Rain Surplus/Deficit at Pattambi for vegetable crop

The values of ET_c for vegetable (Tomato) crop was computed based on daily ET_o at 50% probability levels of potential evapotranspiration (ET_o) and expected amount of rainfall at 75% probability level in Pattambi region are given in Table 4.19.

Table 4.19 ET_{tomato} demand at different growth stages in Pattambi region

S. No	Growth Stages (1)	Daily ET_o at 50% Probability (mm) (2)	K_c (3)	Daily ET_{tomato} (mm) (4)	Total ET_{tomato} demand (mm) (5) = (4) X n days	75% probable rainwater availability (mm) (6)
1.	Initial stage (43 and 44th SMW), 14 days	3.25	0.45	1.46	20.48	31.10
2.	Development (45, 46 and 47th SMW), 21 days	3.39	0.75	2.54	53.39	21.28
3.	Mid stage (48, 49 and 50th SMW), 21 days	3.28	1.15	3.77	79.21	3.50
4.	Late stage (51, 52 and 1st SMW), 21 days	4.15	0.875	3.63	76.26	2.40

5.	Harvest (2 and 3rd SMW), 14 days	4.41	0.625	2.76	38.59	0.9
6.	Total				267.92	59.18

The total ET_c demand of tomato was estimated as 267.92 mm whereas the rainwater availability was only 59.18 mm. This indicated that available rainwater was not sufficient for growing tomato in Pattambi region. The expected availability of rainwater in the region was not sufficient to meet the ET demands of tomato. The comparison of the rainwater availability with the ET demands, surplus and deficit is depicted in Fig. 4.24.

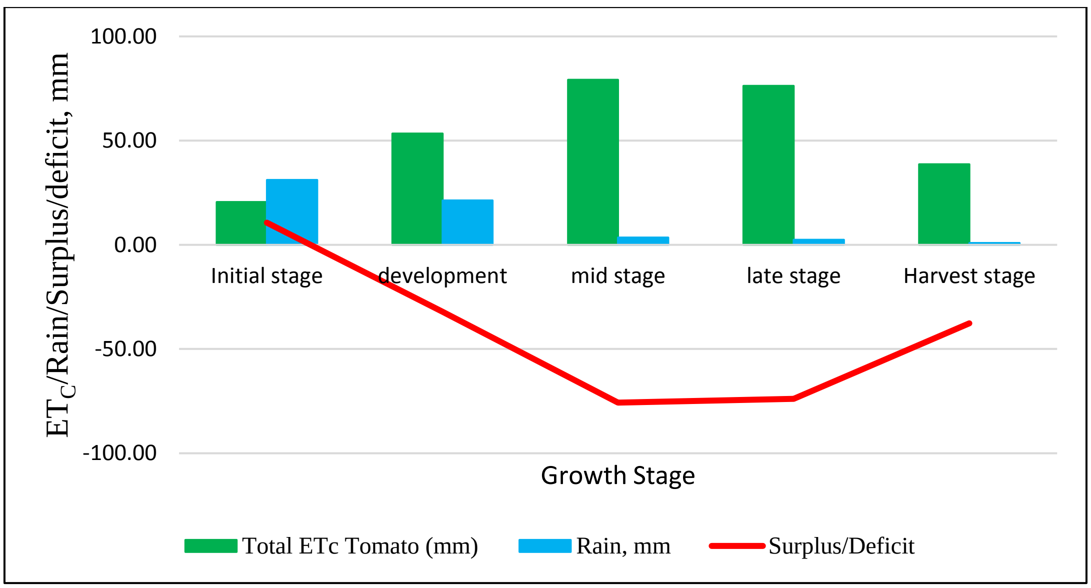

Fig. 4.24 Comparison of ET demand, rainwater availability and rain surplus/deficit at Pattambi for tomato

It was found that during the initial stage the ET demand of tomato was about 20.48 mm whereas the available rainwater was 31.1 mm. During development stage the ET demand of the crop was about 53.39 mm whereas the available rainwater was

21.28 mm. During the mid-stage of the crop, the ET demand was 79.21 mm and the rainwater availability was only 3.5 mm. In the late stage of the crop the ET demand was about 76.26 mm and the available rainwater was only 2.4 mm. During the harvest stage of the crop the ET demand was about 38.59 mm whereas the available rainwater was only 0.9 mm. This clearly indicated that there was a deficit of rainwater availability during all stages except initial stage. So, there is need of supplemental irrigation during each stage. The excess rainwater that could be stored in the water harvesting structures during the initial stage or earlier when there was a surplus rainwater could be used in deficit period. Hence it was concluded that instead of growing tomato, some short duration vegetable crops with low ET demand like amaranthus, okra, chillies etc. can be raised during the period.

4.6 CLIMATIC WATER BALANCE

For assessing the climatic water balance, the various water balance components like actual evapotranspiration (AET), water surplus (SUR) and water deficit (DEF) were estimated. Water surplus (SUR) and water deficit (DEF) components are significant in water balance studies. The information about, when the period of water surplus and deficit occur in a season or year is helpful to find ideal period for starting of crop season and stages. It also helps in flood and drought analysis.

4.6.1 Computation of Weekly Climatic Water Balance by Thronthwaite and Mather Method (1955)

The results of the computed climatic water balance components are presented below in Table 4.20.

Table 4.20 Climatic Water Balance components at Pattambi region (1983-2017).

SMW	P (mm)	ET_o (mm)	AET (mm)	DEF (mm)	SUR (mm)	Im	MAI
1	3.59	27.96	4.58	23.38	0.99	-80.07	0.16
2	0.05	29.82	29.82	0.00	29.77	99.82	1.00

3	2.02	31.42	31.42	0.00	29.39	93.56	1.00
4	4.15	25.28	9.99	15.29	5.84	-37.36	0.40
5	4.04	30.37	6.19	24.18	2.16	-72.51	0.20
6	0.82	30.53	30.53	0.00	29.71	97.33	1.00
7	0.51	29.06	29.06	0.00	28.55	98.25	1.00
8	2.44	25.10	7.20	17.90	4.76	-52.34	0.29
9	2.53	25.22	6.69	18.53	4.16	-56.98	0.27
10	2.33	28.31	28.31	0.00	25.98	91.76	1.00
11	6.94	28.15	7.98	20.17	1.04	-67.94	0.28
12	1.52	28.12	28.12	0.00	26.60	94.60	1.00
13	4.00	28.62	28.62	0.00	24.62	86.02	1.00
14	13.37	27.30	22.56	4.73	9.20	16.36	0.83
15	14.09	23.30	26.45	3.15	12.36	39.55	1.14
16	18.26	20.79	28.32	7.53	10.06	12.18	1.36
17	18.52	28.26	28.26	0.00	9.74	34.47	1.00
18	19.23	27.32	27.32	0.00	8.09	29.60	1.00
19	22.81	23.66	30.89	7.23	8.08	3.59	1.31
20	35.99	25.38	25.38	0.00	10.61	41.82	1.00
21	42.03	17.92	17.92	0.00	24.11	134.57	1.00
22	83.03	24.80	24.80	0.00	58.23	234.74	1.00
23	117.40	22.36	22.36	0.00	95.04	425.01	1.00
24	159.36	22.51	22.51	0.00	136.85	607.85	1.00
25	149.63	24.48	24.48	0.00	125.15	511.28	1.00
26	167.22	22.06	22.06	0.00	145.16	658.07	1.00
27	127.74	21.69	21.69	0.00	106.05	488.91	1.00
28	132.58	23.80	23.80	0.00	108.78	457.04	1.00
29	132.76	21.54	21.54	0.00	111.22	516.30	1.00

30	111.79	22.16	22.16	0.00	89.63	404.51	1.00
31	114.46	21.22	21.22	0.00	93.24	439.31	1.00
32	91.65	21.06	21.06	0.00	70.59	335.10	1.00
33	86.74	24.14	24.14	0.00	62.59	259.26	1.00
34	51.79	22.15	22.15	0.00	29.64	133.79	1.00
35	45.30	22.67	22.67	0.00	22.63	99.83	1.00
36	57.58	24.00	24.00	0.00	33.58	139.90	1.00
37	62.44	24.02	24.02	0.00	38.42	159.95	1.00
38	56.73	23.34	23.34	0.00	33.38	143.02	1.00
39	47.63	20.15	20.15	0.00	27.49	136.46	1.00
40	58.64	19.71	19.71	0.00	38.93	197.51	1.00
41	54.10	21.63	21.63	0.00	32.47	150.14	1.00
42	58.57	21.08	21.08	0.00	37.49	177.89	1.00
43	51.04	21.92	21.92	0.00	29.11	132.79	1.00
44	50.70	23.89	23.89	0.00	26.81	112.20	1.00
45	40.56	23.41	23.41	0.00	17.15	73.25	1.00
46	16.02	22.18	22.18	0.00	6.17	27.81	1.00
47	12.15	25.40	25.40	0.00	13.25	52.16	1.00
48	5.95	22.52	22.52	0.00	16.57	73.58	1.00
49	2.60	24.33	24.33	0.00	21.73	89.32	1.00
50	6.56	21.11	8.11	13.00	1.55	-54.21	0.38
51	2.13	27.91	27.91	0.00	25.78	92.36	1.00
52	4.75	29.75	29.75	0.00	25.00	84.04	1.00
Annual	2378.85	1274.90	1155.65	155.08	1985.54		

From the Table 4.20 and Fig. 4.25, it was observed that the total rainfall of 52 SMWs was computed as 2378.85 mm. The average rainfall was more than 20 mm during 19th SMW to 45th SMW, more than 30 mm rainfall per week during 20th SMW to 45^{th} SMW and more than 50 mm rainfall per week during 22^{nd} SMW to 44^{th} SMW except 39 SMW. The period during 22^{nd} SMW to 38^{th} SMW and 40^{th} SMW to 44^{th} SMW, the weekly rainfall was greater than 50 mm per week for consecutive period, which could be identified as the period for growing low land rice crop of 120 days duration. The highest weekly rainfall (167.22 mm) was found to occur in 26^{th} SMW, whereas the lowest rainfall (0.05 mm) was found to occur in 2^{nd}SMW.

Weekly total ET_o was greater than 20 mm during the period from 1^{st} to 52^{nd} SMW except 21^{st} and 40^{th} SMW, whereas it was greater than 30 mm per week during 5^{th} and 6^{th} SMWs. The total water surplus and deficit was estimated as the 1985.54 mm and 155.08 mm respectively. The weekly water surplus values varied from 0.99 mm to 145.16 mm whereas the weekly water deficit values varied from 0.00 mm to 24.18 mm. The computed weekly climatic water balance components are depicted in Fig. 4.25.

The Moisture Adequacy Index (MAI) was found to be more than 0.75 in almost every week except in few weeks (1, 4, 5, 8, 9, 11 and 50^{th} SMWs) which indicated that there was a good potential for growing crops during the period. The Moisture Index (I_m) was found to be more than 100 during 21-44 weeks which indicated that the type of climate during that period is per humid and the remaining weeks falls under humid climate except in 1, 4, 5, 8, 9, 11 and 50^{th} weeks which falls under dry sub humid climate (Table 4.20).

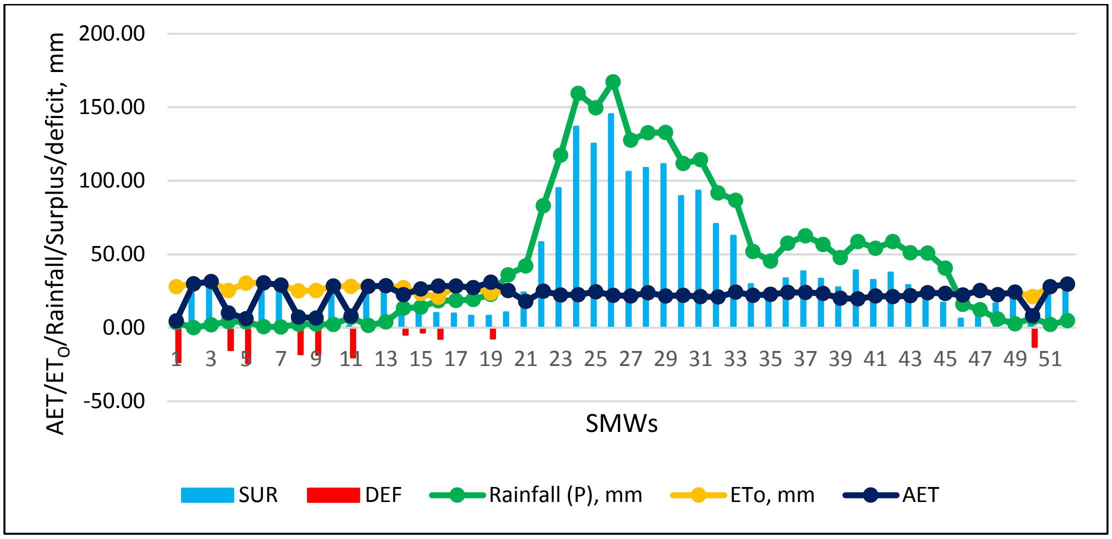

Fig. 4.25 Weekly climatic water balance components of Pattambi region (1983-2017)

4.6.2 Water Availability Period

a) Based on MAI

Since the region falls under humid tropical condition, the onset of growing season considered at a week when MAI was greater than or equal to 0.75, which was considered as a minimum moisture level for starting the sowing of crops (Guptha *et al.*, 2010). The results showed that almost every week except 1, 4, 5, 8, 9, 11 and 50th SMWs had MAI more than 0.75 which indicated that these weeks have minimum moisture level for starting the sowing of crops like rice. The weeks 1st and 5th have less than 0.25 MAI indicated the termination of growing period. Hence water availability/length of growing period would be as high as 259 days extending from 12th to 49th SMW (Fig. 4.26).

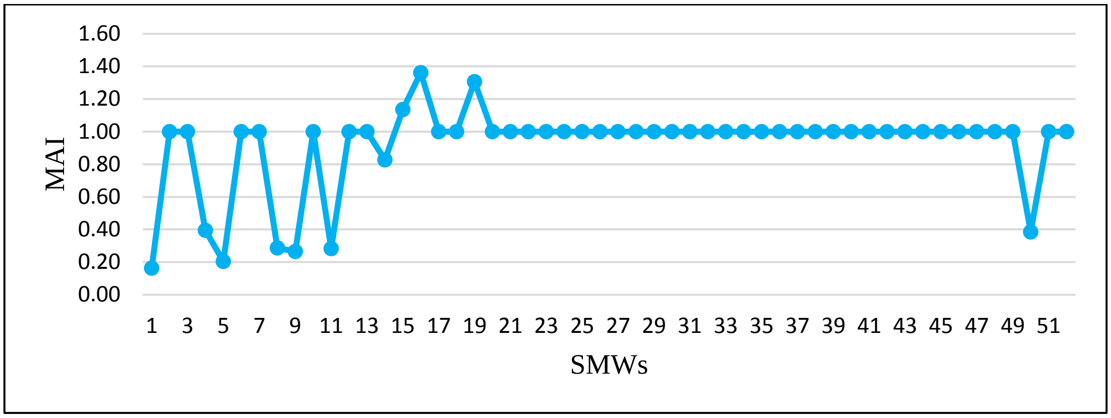

Fig. 4.26 Moisture Adequacy Index of Pattambi region (1983-2017)

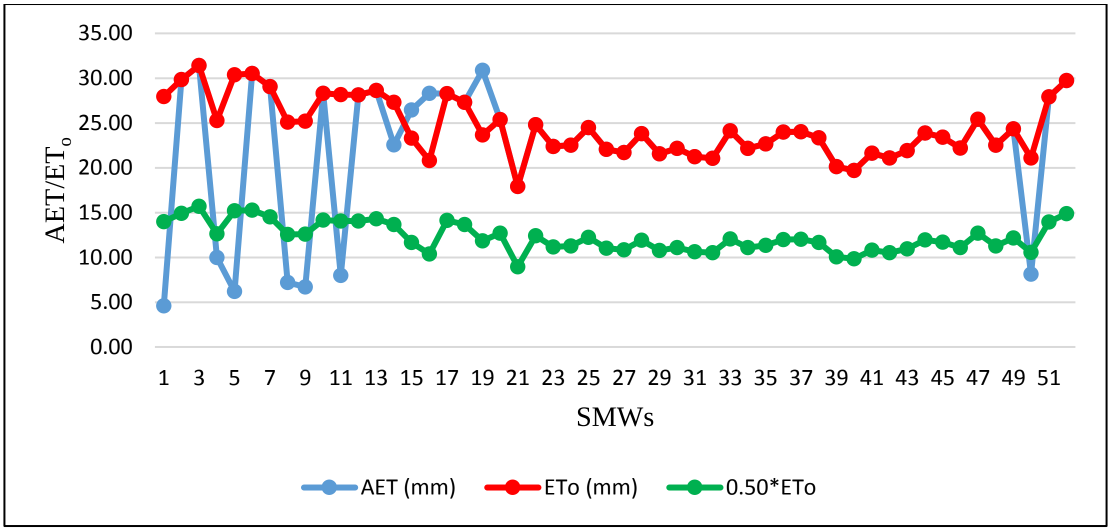

Fig. 4.27 Water availability period at Pattambi (1983-2017)

b) Based on Surplus/Deficit

Water Surplus

Under the average rainfall condition the water availability period would be high in Pattambi region, if AET greater than the 50% of ET_o. Accordingly it was observed that the surplus water was observed in almost every weeks except 1, 4, 5, 8, 9, 11 and 50th SMWs. Hence it is concluded that the water availability period would be as high as 259 days extending from 12th to 49th SMW (Fig. 4.27).

Water Deficit

Under the average rainfall condition the water availability period would be less if AET less than the 50% of ET_o. From the Fig.4.27 it was observed that the water deficit was observed in 1, 4, 5, 8, 9, 11 and 50th SMWs. Hence it is inferred that the water deficit period would be as less as 49 days.

SUMMARY AND CONCLUSION

CHAPTER V

SUMMARY AND CONCLUSION

Water is the most important and limiting natural resource in the world. The economic development of any country depends on many factors in which water is one of the most important factors. Rainfall is the main source available for water. The knowledge of the rainfall analysis is crucial for crop planning in a region, designing of water conservation structures and full use of rainfall. The changes in rainfall and its distribution, probability and trends would influence the spatial and temporal distribution of runoff, soil moisture and groundwater reserves which in turn affect the agricultural productivity. Crop production in an area has a direct relation with the amount and distribution of rainfall. So correct evaluation of water availability period is an important pre-requisite for crop planning. Climatic water balance is widely used for determining water availability period. In the present research work, the rainfall data of Pattambi was analysed to study the variability, trends and probability of rainfall. A weekly climatic water balance was also assessed to determine the surplus/deficit of rainwater.

The results pertaining to the variability of rainfall revealed that the annual rainfall over the Pattambi region was about 2377.96 mm with a standard deviation of 458.8 mm and a coefficient of variation was about 19.29% which indicated that the rainfall is highly stable. The seasonal rainfall of the Pattambi region was observed as 1761.93 mm for South-West monsoon, 344.62 mm for North-East monsoon, 232.63 mm for summer season and 39.91 mm for winter season with standard deviations of 447.84 mm, 134.24 mm, 112.27 mm and 44.05 mm respectively. The coefficient of variation of the seasonal rainfall indicated that the rainfall is less variable in South-West monsoon season with CV 25.42% followed by North-East, summer and winter seasons with CV of 38.95%, 48.26% and 110.37% respectively. The rainfall in the winter season was undependable because of its high coefficient of variation. The

South-West monsoon season (74.09%) contributed the highest amount of rainfall to the total followed by North-East monsoon (14.49%), summer (9.78%) and winter (1.68%) seasons. June and July were the months recorded the highest percentage of rainfall of 25.39% and 24.06% respectively. Weekly rainfall variability showed that rainfall was stable during 21st to 45th SMWs as the CV ranged from 90 % to 110 %.

The skewness of all the data series was found between -0.97 to 4.66. The North-East monsoon season showed a negatively skewed distribution whereas South-West monsoon, summer and winter seasons showed a positively skewed distribution. The months of June and October showed a negatively skewed distribution whereas all the remaining months showed a positively skewed distribution. The kurtosis of all data series varies between -0.66 to 24.09. The months of January, February, March and December showed a kurtosis value greater than 3 which indicated as a peak distributed curve and the remaining months and seasons showed a flat distributed curve because the kurtosis values are less than 3.

The trend analysis of rainfall of Pattambi region was done using the Mann-Kendall test and Sen's slope estimator. The results revealed that a rising trend was observed in the months of February, March, April, May, September, October and December whereas a falling trend was seen in January, June, July, August and November respectively. There was no significant trend observed in any of the months at 5% level of significance, but a significant trend was observed in the month of April at 10% level of significance. There was no trend observed in winter season as the Z-statistics value is almost zero. There was a significant trend observed in the summer season as the computed Z-statistics value (2.58) is more than the Z-value corresponding to the 5% level of significance (1.96) and no significant trend was seen in the remaining seasons. But there was a significant trend observed in summer season at 1% level of significance. The annual rainfall showed a falling trend and no significant trend was observed at 5% level of significance.

The trend analysis using Sen's slope estimator revealed that there was a falling trend observed in annual rainfall. A falling trend was observed in South-West monsoon and North-East monsoon seasons whereas rising trend in summer. The winter season does not showed any trend as the estimated Sen's slope was zero. The rising trend was observed in April, May, September and October whereas falling trend was observed in June, July, August and November respectively. January, February, March and December were the months that does not show any trend.

The weekly rainfall probability at different levels of exceedance revealed that the rainfall varied from 10.3 to 72.6 mm during 21st to 46th SMWs and the rest of the weeks varied from 0 to 9.1 mm at 75% probability. The weekly rainfall at 90%, 50%, 25% and 10% probability levels varied from 0 to 334.4 mm.

The monthly rainfall probability at different levels of exceedance revealed that the highest monthly rainfall at 75% exceedance was expected to occur during June (471.1 mm) and lowest during January (3.1 mm). The highest monthly rainfall at 90% exceedance was expected to occur during June (346.6 mm) and lowest during January and February (0.9 mm). The highest monthly rainfall at 50% exceedance was expected to occur during June (578.6 mm) and lowest during January and February (6.7 mm). The highest monthly rainfall at 25% exceedance was expected to occur during June (736.6 mm) and lowest during February (19.4 mm). The highest monthly rainfall at 10% exceedance was expected to occur during July (887.4 mm) and lowest during February (29.4 mm).

The seasonal and annual rainfall probability at different levels of exceedance revealed that the highest seasonal rainfall at 75% exceedance was expected to occur during South-West monsoon (1466.4 mm) and lowest during winter season (3.1 mm). The highest seasonal rainfall at 90% exceedance was expected to occur during South-West monsoon (1188.7 mm) and lowest during winter season (6.1 mm). The highest seasonal rainfall at 50% exceedance was expected to occur during South-West monsoon (1706 mm) and lowest during winter season (34.4 mm). The highest seasonal rainfall at 25% exceedance was expected to occur during South-West monsoon (2057.5 mm) and lowest during winter season (69 mm). The highest seasonal rainfall at 10% exceedance was expected to occur during South-West monsoon (2335.2 mm) and lowest during winter season (96.3 mm). The annual rainfall at 90%, 75%, 50%, 25% and 10% probability levels of exceedance was found to be 1805.2, 2051.6, 2350.9, 2678 and 2996.9 mm respectively.

The fitting of probability distribution functions for Pattambi region revealed that according to Kolmogorov-Smirnov goodness of fit test the annual rainfall followed the Normal distribution with a statistic value of 0.11263 and parameter values as α=465.5; μ=2378.0. The monthly rainfall followed Weibull distribution with a statistic value of 0.14641 and parameter values as α=0.64839; β=156.08. The weekly rainfall followed Log-Pearson III distribution with a statistic value of 0.11903 and α=4.8299; β= -0.8098; γ=6.7767 as parameter values.

According to Anderson-Darling goodness of fit test the annual rainfall followed the Normal distribution with a statistic value of 0.47618 and α=465.5; μ=2378.0 as parameter values. The monthly rainfall followed the Weibull distribution with a statistic value of 0.37113 and α=0.64839; β=156.08 as parameter values. The weekly rainfall followed Log-Pearson III distribution with a statistic value of 0.70637 and α=4.8299; β= -0.8098; γ=6.7767 as parameter values.

According to Chi-Square goodness of fit test the annual rainfall followed Log-Pearson III distribution with a statistic value of 1.5694 and α=8.4528; β= -0.07048; γ=8.3502 as parameter values. The monthly rainfall followed Weibull distribution with a statistic value of 0.03269 and α=0.64839; β=156.08 as parameter values. The weekly rainfall followed Weibull distribution with a statistic value of 0.38776 and α=0.65345; β= 38.914 as parameter values. However Weibull distribution was identified as the best fit weekly rainfall distribution for the region as Chi-Square test is more reliable.

The total ET_c demand of rice at 50% probability level was estimated as 469.162 mm whereas the total rainwater availability at 75% probability during the period was estimated as 933.85 mm. This indicated that the rainwater availability was sufficient to meet the ET demands of the crop. But there was deficit of rainwater availability during nursery and maturity stages whereas surplus in seeding, vegetative and reproductive stages. This indicated that the raising of the healthy crop might not be possible during nursery stage. So, there was a need of supplemental irrigation during this stage.

The total ET_c demand of banana was estimated as 1124.81 mm whereas the rainwater availability was 1107.53 mm. This indicated that available rainwater was not sufficient for growing banana in Pattambi region. But there was deficit of rainwater availability during all stages except initial and development stages. During initial and development stages of the crop there was surplus rainwater of about 510.33 mm. This rainwater could be harvested for use in deficit period.

The total ET_c demand of tomato was estimated as 267.92 mm whereas the rainwater availability was only 59.18 mm. This indicated that available rainwater was not sufficient for growing tomato in Pattambi region. There was a deficit of rainwater availability observed during all stages except initial stage. So, there was need of supplemental irrigation in all the stages except initial stage. Hence it is recommended to grow some short duration vegetable crops with low ET demand like amaranthus, okra, chillies etc. instead of tomato.

Water surplus (SUR) and water deficit (DEF) components are significant in climatic water balance studies. The information about, when the period of water surplus and deficit occur in a season or year is helpful to find ideal period for starting of crop season and stages. The total water surplus and deficit was estimated as the 1985.54 mm and 155.08 mm respectively. The weekly water surplus values varied from 0.99 mm to 145.16 mm whereas the weekly water deficit values varied from 0.00

mm to 24.18 mm. The Moisture Adequacy Index (MAI) was found to be more than 0.75 in almost every week except in few weeks (1, 4, 5, 8, 9, 11 and 50th SMWs) which indicated that there was a good potential for growing crops. The Moisture Index (I_m) was found to be more than 100 during 21-44 weeks which indicated that the type of climate during that period is per humid and the remaining weeks falls under humid climate except in 1, 4, 5, 8, 9, 11 and 50th weeks which falls under dry sub humid climate.

Water availability period based on MAI indicated that almost every week except 1, 4, 5, 8, 9, 11 and 50th SMWs had MAI values more than 0.75 which indicated that these weeks have minimum moisture level for starting the sowing of crops like rice. The weeks 1st and 5th have less than 0.25 MAI indicated the termination of growing period. Water availability period based on surplus/deficit indicated that the surplus water was observed in almost every weeks except 1, 4, 5, 8, 9, 11 and 50th SMWs whereas the water deficit was observed in 1, 4, 5, 8, 9, 11 and 50th SMWs.

Further scope of research

- Climatic water balance can also be studied on monthly, seasonal and annual basis.
- Drought evaluation can also be studied.
- Probability analysis can be studied for various water balance components.
- Joint probability distribution of rainfall and reference crop evapotranspiration can be studied.

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APPENDICES

APPENDIX-I (a)

Average weekly rainfall data of Pattambi region (1983-2017)

SMW	Rainfall, mm	SMW	Rainfall, mm	SMW	Rainfall, mm
1	3.59	19	22.81	36	57.58
2	0.05	20	35.99	37	62.44
3	2.02	21	42.03	38	56.73
4	4.15	22	83.03	39	47.63
5	4.04	23	117.40	40	58.64
6	0.82	24	159.36	41	54.10
7	0.51	25	149.63	42	58.57
8	2.44	26	167.22	43	51.04
9	2.53	27	127.74	44	50.70
10	2.33	28	132.58	45	40.56
11	6.94	29	132.76	46	16.02
12	1.52	30	111.79	47	12.15
13	4.00	31	114.46	48	5.95
14	13.37	32	91.65	49	2.60
15	14.09	33	86.74	50	6.56
16	18.26	34	51.79	51	2.13
17	18.52	35	45.30	52	4.75
18	19.23				

APPENDIX-I (b)

Monthly rainfall (mm) data of Pattambi region (1983-2017)

Year/Month	January	February	March	April	May	June	July	August	September	October	November	December
1983	0.00	0.00	0.00	0.00	128.50	282.10	712.90	556.60	470.80	198.40	108.00	43.50
1984	0.00	14.80	18.00	0.00	5.00	747.40	811.30	209.70	46.20	314.80	38.40	17.60
1985	56.20	0.00	0.00	53.00	150.40	901.50	521.80	247.44	78.20	159.80	97.60	0.90
1986	22.10	0.00	14.50	0.00	19.30	847.40	318.30	426.90	233.80	192.30	244.80	0.00
1987	0.00	0.00	0.00	7.10	84.00	577.30	363.40	310.70	166.70	236.60	228.10	86.00
1988	0.00	0.00	0.00	137.10	137.10	569.70	594.60	339.40	466.30	0.00	2.60	0.00
1989	0.00	0.00	0.00	87.80	92.60	19.50	437.60	244.60	239.80	295.30	46.80	0.00
1990	1.00	0.00	0.00	78.20	433.20	530.00	730.00	310.30	38.20	446.30	99.30	0.00
1991	35.60	0.00	0.00	136.80	75.00	878.80	995.70	497.40	0.00	494.20	33.50	0.00
1992	0.00	0.00	0.00	37.20	90.40	836.80	788.90	469.90	273.20	218.50	172.50	0.00
1993	0.00	54.70	1.00	8.70	163.60	734.80	699.40	314.10	47.00	297.20	117.50	7.20
1994	0.00	0.00	32.10	124.80	74.10	825.50	1013.60	386.40	182.40	0.00	0.00	0.00
1995	15.66	2.96	6.50	12.02	77.51	671.14	562.38	371.70	199.44	220.38	143.38	29.60
1996	7.32	10.94	0.20	69.74	176.00	602.88	732.06	373.24	119.91	350.30	97.47	1.44
1997	34.10	20.12	1.13	102.15	148.22	557.26	388.93	371.13	248.11	271.33	87.75	16.50

1998	0.00	0.00	0.00	40.20	134.20	678.70	590.70	397.30	448.30	316.80	44.10	37.30
1999	0.00	8.40	0.40	37.80	433.50	659.80	708.10	150.60	39.80	278.30	42.70	0.80
2000	0.00	10.50	0.00	56.40	47.70	592.90	327.90	518.20	179.06	194.90	70.10	42.00
2001	0.00	51.60	0.00	155.30	142.00	790.70	466.20	215.60	449.13	279.28	144.55	0.00
2002	0.00	0.00	2.70	57.90	222.90	472.00	376.40	420.90	51.10	421.30	70.80	12.00
2003	183.60	13.60	0.00	0.00	174.92	151.58	79.40	313.56	233.48	298.12	74.64	34.90
2004	0.00	0.00	4.10	105.00	195.64	743.54	347.10	486.70	122.20	313.30	40.20	0.00
2005	21.00	45.00	0.00	238.30	101.40	567.60	736.60	271.80	453.70	121.10	126.20	10.12
2006	0.00	0.00	36.10	16.70	396.60	688.40	470.40	426.70	500.60	352.90	127.10	0.00
2007	0.00	0.00	0.00	53.90	184.80	728.40	1307.50	483.00	619.00	297.40	34.40	6.00
2008	0.00	0.00	117.50	13.60	73.20	535.10	322.70	174.80	302.00	345.70	7.60	0.00
2009	0.00	0.00	141.90	52.50	158.60	358.90	693.91	296.91	275.80	160.00	53.22	121.27
2010	0.00	0.00	0.00	114.50	130.30	569.10	521.68	233.38	174.10	430.90	87.24	21.17
2011	0.00	20.00	0.00	172.20	108.40	759.00	456.90	339.76	296.02	229.70	147.00	10.46
2012	0.00	0.00	0.00	104.40	42.50	459.70	297.80	489.30	220.20	234.90	74.60	6.20
2013	0.00	51.50	18.55	81.25	171.09	903.49	896.90	253.90	242.60	155.20	93.60	0.20
2014	0.00	0.00	0.00	23.80	167.40	423.00	623.70	608.40	238.20	360.70	78.30	0.00
2015	0.00	0.00	59.20	139.40	203.90	435.50	429.60	201.40	229.40	317.80	194.20	101.50
2016	0.00	0.00	0.00	0.30	191.70	480.60	344.60	120.20	92.80	59.60	4.10	34.30
2017	0.00	0.00	42.30	1.60	190.60	550.50	354.40	412.90	291.20	64.20	101.70	35.40

APPENDIX-I (c)

Seasonal rainfall data of Pattambi region (1983-2017)

Year	South-West (mm)	North-East (mm)	Winter (mm)	Summer (mm)
1983	2022.40	306.40		128.50
1984	1814.60	353.20	58.30	23.00
1985	1748.94	257.40	73.80	203.40
1986	1826.40	437.10	23.00	33.80
1987	1418.10	464.70	0.00	91.10
1988	1970.00	2.60	86.00	274.20
1989	941.50	342.10	0.00	180.40
1990	1608.50	545.60	1.00	511.40
1991	2371.90	527.70	35.60	211.80
1992	2368.80	391.00	0.00	127.60
1993	1795.30	414.70	54.70	173.30
1994	2407.90	0.00	7.20	231.00
1995	1804.65	363.76	18.62	96.03
1996	1828.08	447.77	47.86	245.94
1997	1565.43	359.08	55.66	251.50
1998	2115.00	360.90	16.50	174.40
1999	1558.30	321.00	45.70	471.70
2000	1618.06	265.00	11.30	104.10
2001	1921.63	423.83	93.60	297.30
2002	1320.40	492.10	0.00	283.50
2003	778.02	372.75	209.20	174.92
2004	1699.54	353.50	34.90	304.74
2005	2029.70	247.30	66.00	339.70

2006	2086.10	480.00	10.12	449.40
2007	3137.90	331.80	0.00	238.70
2008	1334.60	353.30	6.00	204.30
2009	1625.52	213.22	0.00	353.00
2010	1498.26	518.14	121.27	244.80
2011	1851.68	376.70	41.17	280.60
2012	1467.00	309.50	10.46	146.90
2013	2296.89	248.80	57.70	270.88
2014	1893.30	439.00	0.00	191.20
2015	1295.90	512.00	101.50	402.50
2016	1038.20	63.70	34.30	192.00
2017	1609.00	165.90	35.40	234.50

APPENDIX-I (d)

Annual rainfall data of Pattambi region (1983-2017)

Year	Rainfall,mm	Year	Rainfall,mm
1983	2500.80	2001	2694.35
1984	2223.20	2002	2108.00
1985	2266.84	2003	1557.78
1986	2319.40	2004	2357.78
1987	2059.90	2005	2692.82
1988	2246.80	2006	3015.50
1989	1464.00	2007	3714.40
1990	2666.50	2008	1892.20
1991	3147.00	2009	2313.01
1992	2887.40	2010	2282.36
1993	2445.20	2011	2539.44
1994	2638.90	2012	1929.60
1995	2312.66	2013	2868.27
1996	2541.49	2014	2524.00
1997	2246.73	2015	2311.90
1998	2687.60	2016	1328.20
1999	2360.20	2017	2044.80
2000	2039.66		

APPENDIX-II

Probable weekly rainwater availability of Pattambi at 75% level by Weibull distribution

SMW	Rainfall, mm	SMW	Rainfall, mm	SMW	Rainfall, mm
1	0.90	19	6.60	36	24.80
2	0.10	20	12.65	37	22.73
3	0.80	21	8.56	38	16.85
4	0.80	22	29.88	39	18.61
5	0.50	23	58.75	40	22.72
6	0.10	24	99.49	41	20.59
7	0.00	25	91.02	42	27.46
8	0.50	26	107.00	43	12.33
9	0.70	27	63.22	44	18.77
10	0.80	28	82.86	45	13.58
11	1.20	29	71.73	46	5.60
12	0.20	30	57.67	47	2.10
13	0.90	31	59.30	48	1.30
14	4.20	32	47.73	49	0.90
15	4.10	33	41.96	50	1.30
16	4.51	34	16.02	51	0.60
17	3.20	35	12.45	52	0.90
18	2.60				

APPENDIX-III

Weekly reference or potential evapotranspiration values of Pattambi by FAO-56 Penman-Monteith method

Week	Penman-Monteith Model						
	T_{mean} (°C)	U2 (m/s)	Δ (K Pa/°C)	ϒ (K Pa/°C)	e_a-e_d (K Pa)	R_n-G	ET_o (mm/day)
1	26.79	1.57	0.207	0.067	1.469	9.16	3.99
2	26.74	1.70	0.207	0.067	1.561	9.45	4.26
3	26.75	1.61	0.207	0.067	1.563	10.51	4.49
4	26.96	1.46	0.209	0.067	1.600	7.58	3.61
5	27.14	1.45	0.211	0.067	1.605	10.24	4.34
6	28.63	1.48	0.227	0.067	1.858	9.49	4.36
7	27.85	1.16	0.219	0.067	1.657	10.21	4.15
8	28.31	1.17	0.224	0.067	1.650	8.23	3.59
9	28.85	1.19	0.230	0.067	1.700	8.12	3.60
10	29.18	1.18	0.234	0.067	1.685	9.72	4.04
11	29.60	1.14	0.239	0.067	1.661	9.81	4.02
12	30.52	1.17	0.250	0.067	1.530	10.04	4.02
13	30.02	1.12	0.244	0.067	1.577	10.29	4.09
14	29.86	1.03	0.242	0.067	1.564	9.87	3.90
15	29.71	1.03	0.240	0.067	1.503	8.09	3.33
16	29.87	1.06	0.242	0.067	1.530	6.74	2.97
17	29.65	1.05	0.239	0.067	1.450	10.55	4.04
18	29.62	1.13	0.239	0.067	1.433	9.98	3.90
19	29.53	1.15	0.238	0.067	1.286	8.50	3.38
20	29.23	1.09	0.234	0.067	1.292	9.43	3.63
21	29.14	1.08	0.233	0.067	1.128	6.19	2.56
22	27.77	0.99	0.218	0.067	1.042	9.93	3.54
23	26.85	0.76	0.208	0.067	0.763	9.63	3.19

24	27.12	0.85	0.211	0.067	0.710	9.71	3.22
25	26.38	0.89	0.203	0.067	0.764	10.61	3.50
26	26.26	0.85	0.202	0.067	0.771	9.42	3.15
27	26.37	0.87	0.203	0.067	0.791	9.17	3.10
28	26.06	0.94	0.199	0.067	0.755	10.27	3.40
29	25.97	0.89	0.199	0.067	0.727	9.25	3.08
30	26.05	0.93	0.199	0.067	0.719	9.53	3.17
31	26.12	1.04	0.200	0.067	0.719	8.95	3.03
32	26.10	1.00	0.200	0.067	0.721	8.90	3.01
33	26.29	0.96	0.202	0.067	0.756	10.40	3.45
34	26.55	1.11	0.205	0.067	0.802	9.11	3.16
35	26.65	1.02	0.206	0.067	0.815	9.43	3.24
36	26.72	0.93	0.206	0.067	0.847	10.11	3.43
37	26.71	0.95	0.206	0.067	0.837	10.12	3.43
38	26.96	0.87	0.209	0.067	0.881	9.76	3.33
39	28.22	0.72	0.223	0.067	0.790	8.44	2.88
40	27.05	0.67	0.210	0.067	0.891	8.21	2.82
41	27.19	0.63	0.211	0.067	0.890	9.19	3.09
42	27.17	0.61	0.211	0.067	0.949	8.86	3.01
43	27.45	0.65	0.214	0.067	0.985	9.14	3.13
44	27.19	0.70	0.211	0.067	0.971	10.07	3.41
45	27.70	0.71	0.217	0.067	1.177	9.45	3.34
46	27.00	0.74	0.209	0.067	1.157	8.86	3.17
47	26.97	0.88	0.209	0.067	1.194	10.12	3.63
48	26.85	1.03	0.208	0.067	1.287	8.18	3.22
49	26.91	1.43	0.208	0.067	1.399	7.87	3.48
50	26.71	1.32	0.206	0.067	1.381	6.51	3.02
51	26.69	1.64	0.206	0.067	1.417	9.16	3.99
52	26.75	1.68	0.207	0.067	1.467	9.85	4.25

APPENDIX-IV

Probable weekly reference or potential evapotranspiration of Pattambi at 50% level by fitting Normal distribution

SMW	ET_o, mm	SMW	ET_o, mm	SMW	ET_o, mm
1	3.59	19	3.04	36	3.09
2	3.83	20	3.26	37	3.09
3	4.04	21	2.30	38	3.00
4	3.25	22	3.19	39	2.59
5	3.90	23	2.88	40	2.53
6	3.92	24	2.89	41	2.78
7	3.74	25	3.15	42	2.71
8	3.23	26	2.84	43	2.82
9	3.24	27	2.79	44	3.07
10	3.64	28	3.06	45	3.01
11	3.62	29	2.77	46	2.85
12	3.61	30	2.85	47	3.27
13	3.68	31	2.73	48	2.90
14	3.51	32	2.71	49	3.13
15	3.00	33	3.10	50	2.71
16	2.67	34	2.85	51	3.59
17	3.63	35	2.91	52	3.83
18	3.51				

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By

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(2016 - 18 - 015)

ABSTRACT OF THE THESIS

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ABSTRACT

Rainfall is the main source available for water. The knowledge of the rainfall analysis is crucial for crop planning in a region and designing of water conservation structures. The changes in rainfall, its distribution, probability and trends would influence the spatial and temporal distribution of runoff, soil moisture and groundwater reserves. Crop production in an area has a direct relation with the amount and distribution of rainfall. So correct evaluation of water availability period is an important pre-requisite for crop planning. Climatic water balance is widely used for determining the water surplus, water deficit and water availability period for agricultural planning. Hence in the present research work, the rainfall data of Pattambi was analysed to study the variability, trends and probability of rainfall. A weekly climatic water balance was also assessed to determine the surplus/deficit of rainwater.

The rainfall variability analysis showed that the mean annual rainfall of Pattambi region was found 2377.96 mm with a CV of 19.29 % which indicated that the rainfall is highly stable in the region. The South-West monsoon season contributed the highest (74.09 %) amount of rainfall. June and July were the months recorded the highest percentage of rainfall of 25.39 % and 24.06 % respectively. Weekly rainfall variability showed that rainfall was stable during 21st to 45th SMWs as the CV ranges from 90 % to 110 % only. The trend analysis of annual, seasonal and monthly rainfall according to Mann-Kendall test revealed that there was a rising and falling trends. But there was no significant trend observed at 5 % level of significance except in summer season. The Sen's slope estimator revealed that a rising trend was observed in summer season whereas falling trend was observed in annual, South-West and North-East monsoon season and no trend was observed at winter season.

The rainfall probability at different levels of exceedance were found by fitting "Incomplete gamma distribution" using Weather Cock software. The weekly rainfall probability at 75 % level of exceedance varied from 10.3 to 72.6 mm during the weeks 21st to 46th. The highest monthly rainfall at 75 % exceedance occurred during June

(471.1 mm) and lowest during January (3.1 mm). The highest seasonal rainfall at 75 % exceedance occurred during South-West monsoon (1466.4 mm) and lowest during winter season (10.8 mm). The annual rainfall at 75 % level of exceedance was found to be 2051.6 mm. Weibull distribution was identified as the best fit for weekly rainfall distribution in the region.

The total ET_c demand of rice, banana and vegetable crops at 50 % probability levels of ET_o was estimated as 469.162 mm, 1124.81 mm and 267.92 mm whereas the rainwater availability at 75 % probability level was 933.85 mm, 1107.53 mm and 59.18 mm respectively. It was observed that there was a surplus of 464.688 mm for rice, deficit of 17.28 mm for banana and deficit of 208.74 mm for vegetable crop.

The climatic water balance indicated that water surplus (SUR) and water deficit (DEF) components are significant. The total climatic water surplus and deficit in the region was estimated as 1985.54 mm and 155.08 mm. The Moisture Adequacy Index (MAI) of the region indicated that the most of the weeks were of in good potential for growing crops. The determination of water availability period revealed that 1,4,5,8, 9, 11 and 50th SMWs were in water deficit whereas the remaining weeks were in water surplus.