

# **ANALYSIS OF AGROMETEOROLOGICAL DATA OF BHUBANESWAR FOR CROP PLANNING**

BY

*Manoj Kumar Dash*

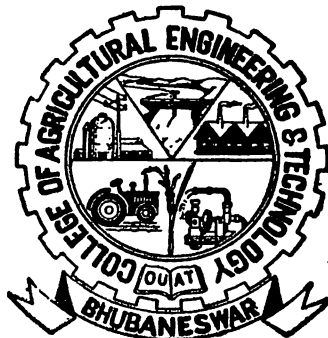
A THESIS SUBMITTED TO  
THE ORISSA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY, BHUBANESWAR  
IN PARTIAL FULFILMENT OF THE REQUIREMENTS  
FOR THE DEGREE OF

**MASTER OF TECHNOLOGY**

**AGRICULTURAL ENGINEERING**

IN

**SOIL AND WATER CONSERVATION ENGINEERING**



**DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING**  
**College of Agricultural Engineering and Technology**  
**Orissa University of Agriculture and Technology**  
**BHUBANESWAR**

**AUGUST—1992**

# ANALYSIS OF AGROMETEOROLOGICAL DATA OF BHUBANESWAR FOR CROP PLANNING

BY


*Manoj Kumar Dash*


A THESIS SUBMITTED TO  
THE ORISSA UNIVERSITY OF AGRICULTURE AND TECHNOLOGY, BHUBANESWAR  
IN PARTIAL FULFILMENT OF THE REQUIREMENTS  
FOR THE DEGREE OF


**MASTER OF TECHNOLOGY**  
**AGRICULTURAL ENGINEERING**  
**IN**  
**SOIL AND WATER CONSERVATION ENGINEERING**  
**1992**

Approved by the Advisory Committee

  
( Dr. S. D. SHARMA )  
Dean, CAET

Chairman :   
( Dr. P. C. SENAPATI )  
10.7.92

Members : 1.   
( Dr. S. D. SHARMA )

External Examiner : 

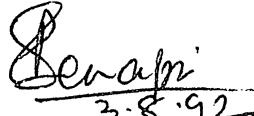
2.   
( Dr. J. C. MUDULI )  
10-7-92

Dr. P.C. Senapati  
Agricultural Engineer,  
Dryland Agriculture Research Project,  
Orissa University of Agriculture and Technology,  
Paramanandapur, Bhanuipatna - 766001  
Orissa, India.

C E R T I F I C A T E

This is to certify that the Thesis entitled " ANALYSIS OF AGROMETEOROLOGICAL DATA OF BHUBANESWAR FOR CROP PLANNING " submitted for the award of Degree of Master of Technology (Agricultural Engineering ) in the subject of Soil and Water Conservation Engineering of the Orissa University of Agriculture and Technology, Bhubaneswar is a faithful record of bonafide research work carried out by Shri Manoj Kumar Dash under my direct supervision and guidance. No part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged by him.

  
3.8.92  
( P.C. SENAPATI )

## A C K N O W L E D G E M E N T

I wish to express my deep sense of gratitude and indebtedness to my esteemed guide Dr. P.C. Senapati, Agricultural Engineer, Dry land Agriculture Research Project, O.U.A.T., Bhanuipatna for his continuous guidance, valuable advice, painstaking assistance and encouragement during the course of the study.

I am highly thankful to Dr. S.D. Sharma, Dean, College of Agricultural Engineering and Technology, Bhubaneswar for his valuable suggestions, technical guidance, timely help and constructive comments as a member of the Advisory committee of the Research work.

I am also thankful to Dr. J.C. Muduli, Reader, Department of Mathematics, College of Basic Science and Humanities, Bhubaneswar for his valuable suggestions as a member of the Advisory Committee.

Heartiest thanks are extended to the Head, Department of Agronomy, College of Agriculture, O.U.A.T., Bhubaneswar, Director, Meteorological Centre, Govt. of India, Bhubaneswar and Chief Scientist, Dryland Agriculture Research Project, O.U.A.T., Bhanuipatna for providing necessary data and information for the study.

My special thanks are to Sri Paul Panigrahi, Chief Programmer and Sri Laxman Sahoo, Asst. Programmer, Computer Centre, College of Engineering and Technology, Bhubaneswar for their timely help in developing the programmes and data analysis.

I am extremely thankful to my friends Mr. A.K. Behera, Mr. M. Senapati and Mr. B. Patra for their co-operation in conducting the study. Sincere helps from many of my other friends do not go unappreciated.

I am indebted to the Secretary, Agriculture, Government of Orissa, Director of Agriculture and Food Production, Orissa, the Director of Soil conservation, Orissa and the Additional Director of Agriculture ( Engineering ) for giving me opportunity to prosecute higher studies.

Finally, I would like to dedicate this piece of work to my beloved parents and other family members and well wishers for their cheerful encouragements, unseizing inspirations and moral support during the entire course of study.

Finally I extend my obeisance to the Almighty who is the king-pin for all happenings in this universe.

Manoj Kumar Dash.  
( MANOJ KUMAR DASH )

## TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	CERTIFICATE	i
	ACKNOWLEDGEMENT	ii
	TABLE OF CONTENTS	iv
	LIST OF TABLES	viii
	LIST OF FIGURES	x
	LIST OF ABBREVIATION	xi
1	INTRODUCTION	1
11	REVIEW OF LITERATURE	4
	2.1 Persistence Test	4
	2.2. Probability Distribution Function	8
	2.2.1. Normal distribution	9
	2.2.2. Lognormal distribution	9
	2.2.3. Gamma distribution	10
	2.2.4. Pearson distribution	10
	2.2.4.1 Type I distribution	12
	2.2.4.2 Type III distribution	13
	2.3. Rainfall Forecasting by Moving Average and Exponential Smoothing Technique	16
	2.3.1. Moving average method	17
	2.3.2. Exponential smoothing	19
	2.3.3. Estimation of Weekly rainfall by other method	22
	2.4. Forecasting of Onset of Effective Monsoon and Critical Dry Spells	24
	2.4.1. Effective monsoon	25
	2.4.2. Onset of effective monsoon	26

CHAPTER	TITLE	PAGE
	2.4.3. Critical dry spells	27
	2.4.4. Wet spells	27
2.5.	Forecasting of Dry & Wet Spells	28
2.6.	Forecasting of Commencement of Sowing Rain	31
2.7.	Water requirement of crops	34
	2.7.1 Modified Blaney-Criddle method	34
	2.7.2. Modified Radiation method	35
	2.7.3. Modified Penman method	35
	2.7.4. Pan Evaporation method	36
	2.7.5 Estimation of factor 'c'	36
	2.7.5.1 Adjustment factor for modified Blaney-Criddle method	37
	2.7.5.2 Adjustment factor for modified Radiation method	38
	2.7.5.3. Adjustment factor for modified Penman method	39
	2.7.6. Crop coefficient	40
2.7.7.	Crop-water requirement	41
2.8	Growing Degree Days	41
2.9.	Crop -Weather model	42
III	MATERIALS AND METHODS	51
3.1	Site Selection	51
3.2	Meteorological Data	51
3.3	Calculation of Persistence Test and Serials Correlation Coefficient	52
3.4	Probability Distribution Function	53
	3.4.1 Normal density function	56
	3.4.2 Log-normal density function (log-normal - 2)	56
	3.4.3 Log-normal density function (log-normal - 3)	57
3.5	Forecasting of Weekly Cumulative Rainfall by Moving Average methods	58

CHAPTER	TITLE	PAGE
3.6	Forecasting of Weekly Cumulative Rainfall by Exponential Smoothing technique	58
3.7	Forecasting of Onset of Effective Monsoon and Critical Dry Spells	61
3.7.1	Onset of effective monsoon	61
3.7.2	Dry and wet spell and critical dry spell	62
3.7.3	Mean date of onset of effective monsoon	62
3.7.4	Standard deviation (S.D) of onset of effective monsoon	63
3.7.5	Median date of onset of effective monsoon	63
3.7.6	Quartile Deviation (Q)	63
3.7.7	Earliest and latest probable date of onset of effective monsoon	64
3.8	Forecasting of Dry and Wet Spells	66
3.9	Forecasting of Commencement of Sowing Rain	68
3.10	Estimation of Reference Crop-Evapotranspiration (ET <sub>o</sub> )	69
3.10.1	Modified Blaney-Criddle method	69
3.10.2	Modified Radiation method	70
3.10.3	Modified Penman method	71
3.11	Crop Evapotranspiration	74
3.12	Forecasting of Crop Yield Based on Growing Degree Days	75
3.13	Crop-Weather Model	77
IV	RESULTS AND DISCUSSION	80
4.1	Persistence Test & Serial correlation coefficient	80
4.2.	Probability Distribution Function.	83
4.3.	Forecasting of Weekly Cumulative Rainfall by Moving Average Method	86
4.4.	Forecasting of Weekly Cumulative Rainfall by Exponential Smoothing Method	87
4.5.	Forecasting of Onset of Effective Monsoon and Critical Dry Spells	89

CHAPTER	TITLE	PAGE
4.6	Forecasting of Dry & Wet Spells .	92
4.7.	Forecasting of Commencement of Sowing Rain	93
4.8.	Estimation of Crop Evapotranspiration	96
4.9	Forecasting of Crop Yield Based on Growing Degree Days	97
4.10	Development of Crop-Weather Model	104
v	SUMMARY AND CONCLUSION	112
5.1	Summary	112
5.2	Conclusion	113
	LITERATURE CITED	117
	APENDIX - A	126
	APENDIX - B	154
	APENDIX - C	158
	APENDIX - D	162
	APENDIX - E	186

## LIST OF TABLES

TABLE NO.	TITLE	PAGE
3.1	Duration of different growth phase of crops under consideration	76
4.1	Regression models relating yield and growing degree days for arhar	102
4.2	Regression models relating yield and growing degree days for groundnut	102
4.3	Regression models relating yield and growing degree days of maize	103
4.4	Regression models relating yield and growing degree days of upland paddy	103
4.5	Coefficient of correlation between arhar yield and weather parameters	106
4.6	Coefficient of correlation between groundnut yield and weather parameters	106
4.7	Coefficient of correlation between maize yield and weather parameters	106

4.8	Coefficient of correlation between upland paddy yield and weather parameters	107
4.9	Different weather elements during sensitive periods of arhar along with yield data from 1976 -1991	109
4.10	Different weather elements during sensitive periods of groundnut along with yield data from 1976 -1991	109
4.11	Different weather elements during sensitive periods of maize along with yield data from 1976 - 1991	110
4.12	Different weather elements during sensitive periods of upland paddy along with yield data from 1976 - 1991	110

## L I S T O F F I G U R E S

FIGURE NO.	T I T L E	PAGE
4.1	Cummulative probability of having 75 mm, 100 mm, 200 mm, 300 mm & 500 mm rainfall and probability of having 2 consecutive dry weeks	95
4.2	Crop coefficient curve for arhar	98
4.3	Crop coefficient curve for groundnut	99
4.4	Crop coefficient curve for maize	100

## LIST OF ABBREVIATIONS

ASCE	American Society of Civil Engineers
o	
C	Degree Celsius
CAET	College of Agricultural Engineering & Technology
cd	cube root data
CDS	Critical Dry Spells
ck	coefficient of kurtosis
cs	coefficient of skewness
cv	coefficient of variance
E	East
Eqn.	Equation
et al.	and other fellows
etc.	Et.cetera
FAD	Food and Agriculture Organization
Fig.	Figure
Hec.	Hectare
IARI	Indian Agricultural Research Institute
ICAR	Indian Council of Agricultural Research
i.e.	that is
IMD	Indian Meteorological Department
IIT	Indian Institute of Technology
o	
K	Degree Kelvin
Km.	Kilometre
md	modular data
m	meter
min.	minute
mm.	millimetre
N	North
No.	Number
od	original data
OEM	Onset of Effective Monsoon
OUAT	Orissa University of Agriculture & Technology
sd	square root data
sec.	second
WMO	World Meteorological Organiza- tion

## CHAPTER I

### INTRODUCTION

Crop growth and the sequences of crops grown during a year are determined by the interactions of climate, soil, land and management parameters. Crops are grown throughout the year depending upon their nature. The crop's nature is controlled by certain agroclimatic factors, such as rainfall, temperature, solar radiation and evapotranspiration etc.

Seasonal water availability controls the crops to be grown, which is determined by the agroclimatic conditions. The atmospheric parameters determine the amounts of water added to the system by precipitation and the amounts of the water leaves the system by evaporation from the soil surface and transpiration from the crops. The soil and the physiographic characteristics only change from place to place, but the agroclimatic variable not only changes with location but also with time.

Orissa predominantly being an agricultural state depends on rainfall for its agricultural production. The average annual rainfall ranges from 1100 mm. to 1500 mm. and its distribution is very much erratic and uneven. Thus the agricultural production is highly unstable. Even during monsoon season the state suffers from simul-

taneous problems of disposal of surplus water caused by heavy storms in some parts and water deficit due to lack of adequate rainfall in other parts. The production potentiality of the state can be greatly enhanced or maintained at a steady pace by implementing better water management systems. Development of water management system requires knowledge of variability of meteorological events with time.

Thus owing to peculiar distribution of the natural resources of soil and climate, the state of Orissa call for some specificity with regard to appropriate cropping systems and related farming systems technology.

For this reason it is imperative to study the historical weather records to evaluate the feasibility of crop intensification. Reliable crop weather technology models are needed for yield prediction and for the determination of climatic risks in crop production.

Methods for agrometeorological forecasts are mainly based on crop-weather relationship statistical models. Models developed from historic data make it possible to obtain the expected values fairly in advance so that appropriate action may be taken to avail of beneficial aspect of weather and minimise or avoid the detrimental effect. ✓ Thus this study for the region of Bhubaneswar is proposed to be undertaken with the following objectives.

1. Development of forecasting models on the basis of weekly data and studying their efficacy.
2. Forecasting of onset of effective monsoon and critical dry spells.
3. Estimation of water requirement of different crops based on agro-meteorological observations.
4. Development of climate-crop production models. )

## CHAPTER II

### REVIEW OF LITERATURE

This chapter deals with review of some of the works done in the past by the researchers on time series analysis, frequency analysis of hydrological events, forecasting models of hydrological events and crop-weather models etc.

A time series is a sequence of values arrayed in order of their occurrence which can be characterised by statistical properties. The sequence of values is represented by

$x(t_1), x(t_2), x(t_3), \dots$

Where  $t_1 < t_2 < t_3 \dots$  A time series may be

a function of any single variable which takes the place of time. A non-random time series has an oscillatory component. The observed values in a purely random time series fluctuate erratically about some mean value. The fact that a time series exhibits more or less erratic fluctuations suggests that the number of times that the values are above or below a given value is indicative of the randomness or non-randomness of the time series (Chow, 1964).

#### Persistence Test

Persistence test is also known as non parametric test. Persistence is a test that does not depend on the

particular form of the basic frequency function from which the samples are drawn. In other words persistence test or non-parametric test does not make any assumption regarding the form of the population (Gupta et al., 1983);

Chow (1964) and Clarke (1973) studied the methods for the measurement of a time series. The non-parametric methods of determining, if a time series is random are

- i) median cross test
- ii) the turning point test

Lavert as referred by Yevjevich (1963), listed that there are nine different statistical parameters to measure the persistence of a time series. Those are

- (1) Covariance of higher order in relation to mean value
- (2) Benson's persistence coefficient
- (3) Persistence ratio
- (4) Von Baur's divergence coefficient
- (5) Surplus number in statistical model
- (6) Persistence factor
- (7) Serial correlation coefficients and correlogram
- (8) Von Barlet's equivalent repeating number
- (9) Kendel's measure of persistence

Apart from this there are certain other methods for measuring the non-randomness of the time series (Gupta, et el. 1983).

(1) Basic distribution test

(2) Wald-wolfonitz run test

Yevjevich (1963) suggested the use of variance spectrum analysis for measuring the non randomness of the time series.

The most common technique of determining the degree of persistence in a time series, which has been followed here is by serial correlation coefficient.

A widely used measure of association between two variables  $x_t$  and  $y_t$  is the product moment of correlation coefficient, which may be defined as

$$p = \frac{\text{Cov}(x_t, y_t)}{(\text{SD } x_t)(\text{SD } y_t)} \quad \dots(2.1)$$

Where the numerator in Eqn. (2.1) is the covariance of  $x_t$  and  $y_t$  and the denominator is the square root of the product variance of  $x_t$  and  $y_t$ .

If interest is centred on the association between successive term in the same series  $x_t$  rather than on that between concurrent terms in the two different series,  $x_t$  and  $y_t$ , a measure similar to equation (2.1) may be employed. Referred to as the auto correlation function

$$p_k = \frac{\text{Cov}(x_t, x_{t+k})}{(\text{SD } x_t)(\text{SD } x_{t+k})} \quad \dots(2.2)$$

express the correlation which exists between all pairs of observations  $x_t$  and  $x_{t+k}$ . The distance  $k$  is known as the lag between  $x_t$  and  $x_{t+k}$ . The numerator of equation (2.2) is known as the auto covariance at lag  $k$ .

The serial correlation or auto-correlation is thus used to account for the effect of serial dependence of series. If the value of the time series  $x$ , say  $x_{t+k}$  at time unit  $t+k$  is dependent on the value of  $x_t$ , then the correlation between the values of  $x_t$  and  $x_{t+k}$  may be taken as a measure of dependence.

The serial correlation coefficients are therefore defined as correlation coefficients (linear association) between the members of the series that are  $k$  units apart (Mutreja, 1986).

The degree of persistence is inversely proportional to the length of time interval between observations of a discrete time series. Yearly studies conducted by Yule (1945) cited by Kotz (1959), confirmed that serial correlation coefficient of annual rainfall in Great Britain were insignificant. Brittan (1961) and Hershfield (1962) concluded that annual rainfalls are random or independent. Namias (1952), Pattison (1965) and Yevjevich et al. (1973) reported that in most cases the monthly rainfall amount were found to be independent. Chow (1964) and Pattison (1965) also indicated that when the time interval between observations of a time series is short, the carry over effect, or the persistence becomes more pronounced. Feyerhern et al. (1965)

express the correlation which exists between all pairs of observations  $x_t$  and  $x_{t+k}$ . The distance  $k$  is known as the lag between  $x_t$  and  $x_{t+k}$ . The numerator of equation (2.2) is known as the auto covariance at lag  $k$ .

The serial correlation or auto-correlation is thus used to account for the effect of serial dependence of series. If the value of the time series  $x$ , say  $x_{t+k}$  at time unit  $t+k$  is dependent on the value of  $x_t$ , then the correlation between the values of  $x_t$  and  $x_{t+k}$  may be taken as a measure of dependence.

The serial correlation coefficients are therefore defined as correlation coefficients (linear association) between the members of the series that are  $k$  units apart (Mutreja, 1986).

The degree of persistence is inversely proportional to the length of time interval between observations of a discrete time series. Yearly studies conducted by Yule (1945) cited by Kotz (1959), confirmed that serial correlation coefficient of annual rainfall in Great Britain were insignificant. Brittan (1961) and Hershfield (1962) concluded that annual rainfalls are random or independent. Namias (1952), Pattison (1965) and Yevjevich et al. (1973) reported that in most cases the monthly rainfall amount were found to be independent. Chow (1964) and Pattison (1965) also indicated that when the time interval between observations of a time series is short, the carry over effect, or the persistence becomes more pronounced. Feyerhern et al. (1965)

found daily precipitation amounts to be dependent in time. Pattison (1965) and Franz (1970) found persistence in hourly precipitation amounts.

Various significance tests of serial correlation coefficients are reported in literature for circular and open discrete series by Anderson (1942), Bartlett (1935,1946) and Blackman and Tukey (1959). An approximate test of significance suggested by Clarke (1973) for a sample of large number of observations  $N$ , may be obtained by comparing serial correlation coefficient with range  $\pm 2/\sqrt{N}$ , which is double of a large sample standard error i.e  $\pm 1/\sqrt{N}$ . The values lying outside this range indicate the presence of persistence in the data sequence. Further Clarke (1973) pointed out that lag one serial correlation coefficient,  $p$ , only can serve as a sufficient measure of describing the strength of the relation between a value in the sequence and that preceding it one time interval. If the value of  $p$  lies within the two limits of  $\pm 2/\sqrt{N}$ , then it is treated to be insignificantly different from zero and series is said to be a random series.

## 2 Probability Distribution Function

A lot of researches have been done to fit a distribution to precipitation data or have transformed the data to obtain a fit by a particular distribution close to normality.

### 2.2.1 Normal Distribution

This is symmetrical, continuous distribution, theoretically representing the distribution of accidental errors about their mean, or the so called Gaussian law of errors. The probability density is

$$p(x) = \frac{1}{(SD) \sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2(SD)^2}} \dots (2.3)$$

Where  $x$  is the variate,  $\mu$  is the mean value of variate and  $SD$  is the standard deviation. In this distribution, the mean, mode and median are the same. The cumulative probability of a value being equal to or less than  $x$  is

$$p(x \leq) = \frac{1}{(SD) \sqrt{2\pi}} \int_{-\infty}^x e^{-\frac{(x-\mu)^2}{2(SD)^2}} dx \dots (2.4)$$

This represents the area under the curve between the variates of  $-\infty$  and  $x$ .

### 2.2.2 Lognormal Distribution

This is transformed normal distribution in which the variate is replaced by its logarithmic value. This distribution represents the so called law of Galton as it was first studied by Galton in 1875.

The probability density is

$$p(x) = \frac{1}{(SD_y) e^y \sqrt{2\pi}} e^{-\frac{(\ln y - \mu)^2}{2(SD_y)^2}} \dots (2.5)$$

Where  $y = \ln x$  where,  $x$  is the variate,  $\mu_y$  is the mean of  $y$  and  $SD_y$  is the standard deviation of  $y$ .

2.2.3 **Gamma Distribution**

The probability density function of this distribution is

$$P(x) = \frac{x^{a-1} e^{-x/b}}{b^a \Gamma(a)} \quad \dots (2.6)$$

with  $b > 0$ ,  $a > -1$  for  $x > 0$   
and  $P(x) = 0$  for  $x \leq 0$

Where  $a$  and  $b$  are constants and  $\Gamma(a+1) = a!$  is a gamma function. The cumulative probability being equal to or less than  $x (< \infty)$  is known as incomplete gamma function.

The statistical parameters are

Mean =  $b(a+1)$

and variance =  $b^2(a+1)$

2.2.4 **Pearson Distribution**

Karl Pearson has derived a series of probability function to fit virtually any distribution. The general and basic equation to define the probability density of a pearson distribution is

$$P(x) = e^{-\int_{-\infty}^x (a+x)/(b_0 + b_1 x + b_2 x^2) dx} \dots(2.7)$$

Where  $a$ ,  $b_0$ ,  $b_1$ , and  $b_2$  are constants.

The criteria for determining types of distribution are

$\beta_1$ ,  $\beta_2$  and  $K$  where

$$\beta_1 = \frac{\mu_3^2}{\mu_2^3}$$

$$\beta_2 = \frac{\mu_4}{\mu_2^2}$$

$$K = \frac{\beta_1 (\beta_2 + 3)^2}{4(4\beta_2 - 3\beta_1)(2\beta_2 - 3\beta_1 - 6)}$$

Where  $\mu_2$ ,  $\mu_3$  and  $\mu_4$  are second, third and fourth moments about the mean.

When  $\beta_1 = 0$ ,  $\beta_2 = 3$  and  $K = 0$ , the Pearson distribution is identical to the normal distribution.

Chow (1964) suggested that Type I and III distributions are often used in hydrologic frequency analysis.

2.2.4.1 Type I distribution : For type I,  $K < 0$ .

Its probability density is

$$p(x) = p_0 \left( 1 + \frac{x}{a_1} \right)^{\frac{m_1}{1}} \left( 1 - \frac{x}{a_2} \right)^{\frac{m_2}{2}} \dots (2.8)$$

Where  $\frac{m_1}{a_1} = \frac{m_2}{a_2}$  and the origin is at the mode.

The values of  $m_1$  and  $m_2$  are given by

$$m_1 \text{ or } m_2 = \frac{1}{2} \left[ r - 2 \pm r(r+2) \frac{\sqrt{\mu_2 \beta_1}}{2(a_1 + a_2)} \right]$$

When  $\mu_2$  is positive,  $m_2$  is the positive root and  $m_1$  is

the negative root and

$$r = \frac{6(\beta_2 - \beta_1 - 1)}{6 + 3\beta_1 - 2\beta_2}$$

$$a_1 + a_2 = \frac{1}{2} \sqrt{\mu_2} \left[ \beta_1 (r+2)^2 + 16(r+1) \right]$$

$$\text{and } p_0 = \frac{N}{a_1 + a_2} \frac{\binom{m_1}{1} \binom{m_2}{2} \Gamma(m_1 + m_2 + 2)}{\binom{m_1 + m_2}{1} \binom{m_1 + m_2}{2} \Gamma(m_1 + 1) \Gamma(m_2 + 1)}$$

Where N is the total frequency.

2.2.4.2 Type III distribution

For type III distribution

$$K = \infty \quad \text{or} \quad 2\beta_2 = 3\beta_1 + 6$$

The probability density with the origin at mode is

$$p(x) = p_0 (1 + x/a)^{c - cx/a} e^{-cx/a} \quad \dots(2.9)$$

where  $c = \frac{4}{\beta_1} - 1$

$$a = \frac{c}{2} \frac{\mu_3}{\mu_2}$$

$$\text{and } p_0 = \frac{N}{a_1 + a_2} \frac{\binom{m_1}{1} \binom{m_2}{2} \Gamma(m_1 + m_2 + 2)}{\binom{m_1 + m_2}{1} \binom{m_1 + m_2}{2} \Gamma(m_1 + 1) \Gamma(m_2 + 1)}$$

Where N is the total frequency.

2.2.4.2 Type III distribution

For type III distribution

$$K = \infty \quad \text{or} \quad 2\beta_2 = 3\beta_1 + 6$$

The probability density with the origin at mode is

$$p(x) = p_0 (1 + x/a)^{c - cx/a} e^{-cx/a} \quad \dots(2.9)$$

$$\text{where } c = \frac{4}{\beta_1} - 1$$

$$a = \frac{c}{2} \frac{\mu_3}{\mu_2}$$

$$p_0 = \frac{N}{a} \frac{c^{c+1}}{e^{-c} \Gamma(c+1)}$$

Slade (1936) is the first to fit a continuous probability distribution to the annual precipitation data. He found that the logarithmic transformed data has fitted to the normal distribution satisfactorily. Thom (1940) and Beer et al. (1946) fitted smooth distribution curves to the annual and monthly precipitation data respectively, rather than using a specific distribution function. Whitecomb (1940) fitted a Pearson type III distribution curve to monthly precipitation data. Thom (1957) used a gamma distribution to fit a storm amounts and then transferred the gamma distribution a normal distribution.

Chow (1954) suggested the use of the log-probability law which is similar to the lognormal distribution with two parameters except for the additional parameters, that is the coefficient of variation. All the cases reported above are for the time series which do not contain zero values. It is possible that the above conclusion may not hold good if the series includes zero values.

Apart from the logarithmic transformation

several other transformations like square root, cube root, one fourth power and modular coefficient of actual data that would make the hydrological data normally distributed have also been reported by Stidd (1953). Franz (1970) and Markovic (1965) illustrated by fitting the normal, two and three parameters lognormal and gamma distribution function to the modular coefficients transformed data (i.e. actual data / average of the series) of the observed annual precipitation and annual runoff for the data collected from several measurement stations. This transformation does not show even the slightest advantage over the actual data as far as the goodness of fit for different distributions are concerned.

Gumbel (1941), Brooks and Corruthers (1953), Gumbel (1954), Hershfield and Kohlar (1960), Hershfield (1962), Benson (1962), Hall and David (1963), Shane and Lynn (1964), Chow (1964), Markovic (1965), Yejevich (1972), Sales and Benyeden (1978) have applied gamma distribution with two and three parameter, Pearson Type III, extreme value, binomial and poisson distribution to hydrological data.

A method that does not involve complicated statistics is the ranking order method, described by Doorenbos and Pruitt (1977). The assumption in this

method is that monthly rainfall is more or less normally distributed (W.M.O., 1982).

2 3

### **Rainfall Forecasting by Moving Average and Exponential Smoothing Technique**

Time series analysis is the process of determination of the structure and the future estimate for a given activity. Forecasting and prediction are used in this text as synonymous terms. A time series analysis of good quality is characterised by a minimal deviation from the actual activity level in the planned period. Undoubtedly experience counts in time series analysis for forecasts. Predictions arrived at, through the development and proper application of mathematical techniques certainly provide more reliable estimates than intuitive forecasts.

Ramlingam (1976) suggested least square regression, simple moving average, exponential smooting and seasonal variations with trend effect techniques for time series analysis. Gilchrist (1976) while discussing the criteria and the process of forecasting, suggested stocastic growth curves, probabilistic and multivariate models. Clarke (1973), under the patronage of FAO of the United States reviewed the existing literature and mathematical models in hydrology and presented the concept in a concise manner useful for practical engineers in the field. For time series

analysis approach to forecasting, he illustrated the application of fourier series and the Box and Jenkins multiplicative models. However the necessary computations are tedious and time consuming and their applicability to weekly rainfall data needs thorough investigation. In general, the shorter the time interval between successive values in a synthetic sequence, the more difficult it is to find a model that adequately describes the characteristics of the hydrological variable. The method of transition matrix or the Grace and Eagleson's Urn model, as described by Clarke (1973) may give solutions to the complex problem to a certain extent. However, the computation time required increases in cost in proportion to the accuracy.

### 2.3.1 Moving Average Method .

The global constant mean model which is expressed as

$$a_{i,k-1} = \mu + E_{i,k} \quad \dots (2.10)$$

Where  $\mu$  is the constant mean and  $E_{i,k}$  is one of the sequence of independent random variable with zero mean and constant variance,  $E_{i,k}$  refers to the

(k) the time series  $a_{i,k}$ . It is believed that, though this model is a good one for short period of time, it is unlikely that the value of  $\mu$  for any one locality in time is exactly the same as that for another. Thus the demand values that have occurred in the more recent

periods are considered for estimating the simple moving average.

Mathematically, the 's' period moving average for the forecast of  $\hat{a}_{i,k-1}$  may be expressed as given by Ramlingam (1976).

$$\hat{a}_{i,k-1} = \frac{a_{i-1,k-1} + a_{i-2,k-1} + \dots + a_{i-s,k-1}}{s} \quad \dots(2.11)$$

Where

$\hat{a}_{i,k-1}$  = forecast for the period i, and

$a_{i-1,k-1}$  = actual values in periods  
i-1, i-2, i-3, ....i-s.

As quoted by Gilchrist (1976), Davis pointed out that when the interest is in forecasting, it would be more reasonable to use a moving average which gives higher weightage to recent data than the past data.

Brooks and Carruthers (1950) quoted that for the "Reductions of Greenwich meteorological observations" the 50 years daily averages were smoothed by taking means of 5 years and again taking overlapping means of 5 of the values so obtained.

Though this overlapped moving average estimates ' $\mu$ ' locally in the sense that it assigns maximum

weightage to current information, it suffers from two disadvantages.

- (i) It only uses the recent observations and ignores the rest.
- (ii) It does not possess a simple recurrence form.

Ramlingam (1976) further concluded that when a forecast is established by using the moving average technique, the forecast tends to be too low if the time series has an upward trend. On the other hand, the forecast is too high if the time series has a downward trend.

In practice various S-values whose forecasts respond to bonafide movements in trend is selected to determine the later forecasts.

### .3.2. Exponential Smoothing

Ramlingam (1976) stated that exponential smoothing technique is an efficient forecasting method. The calculation of a single exponential smoothing forecast is simply the latest plus a fraction. This fraction is known as smoothing constant. This is nothing but the difference between the actual

value in the current period and the latest forecast.

The equation for the exponential smoothed forecast,

considering annual time series  $a^{(k)}$  can be given as

$$\hat{a}_{i,k-1} = a_{i-1,k-1} + \alpha (a_{i,k-1} - \hat{a}_{i-1,k-1}) \dots (2.12)$$

Where  $\hat{a}_{i,k-1}$  = exponentially smoothed forecast for the next period. This estimate is used to forecast for the next period,

$a_{i-1,k-1}$  = exponentially smoothed forecast established in the last period,

This is the latest forecast.

$\alpha$  = smoothing constant ( $0 \leq \alpha \leq 1$ )

and  $a_{i,k-1}$  = actual value of the current period.

Equation (2.12) can be arranged as

$$\hat{a}_{i,k-1} = \alpha a_{i,k-1} + (1-\alpha) \hat{a}_{i-1,k-1} \dots (2.13)$$

Where  $\hat{a}_{i-1,k-1}$  may be expressed as

$$\hat{a}_{i-1,k-1} = \alpha \hat{a}_{i-1,k-1} + (1-\alpha)\hat{a}_{i-2,k-1} \dots (2.14)$$

In this manner by continuing successively the process of substituting for

$$\hat{a}_{i-2,k-1}, \hat{a}_{i-3,k-1}, \hat{a}_{i-4,k-1}$$

and so on, the following equation would result.

$$\hat{a}_{i,k-1} = \alpha \hat{a}_{i,k-1} + \alpha(1-\alpha) \hat{a}_{i-1,k-1} + \alpha(1-\alpha)^2 \hat{a}_{i-2,k-1} + \alpha(1-\alpha)^3 \hat{a}_{i-3,k-1} + \dots (2.15)$$

According to Ramlingam (1976) the "apparent trend",

$g_{i,k-1}$  in period  $i$ , for the  $(k-1)$ th polynomial

coefficient, annual time series  $(a^{(k)}, k=1,2,\dots,n+1)$

can be calculated by the following formula

$$g_{i,k-1} = \hat{a}_{i,k-1} - \hat{a}_{i-1,k-1} \dots (2.16)$$

Now, if  $G_{i,k-1}$  represents the exponentially smoothed

trend in period  $i$ , then

$$G_{i,k-1} = G_{i-1,k-1} + \alpha (g_{i,k-1} - G_{i-1,k-1}) \dots (2.17)$$

Subsequently, the expected value of coefficient for the current period 'i' is computed by

$$Ea_{i,k-1} = a_{i,k} + (1-\alpha/\alpha) G_{i,k-1} \dots (2.18)$$

Therefore, the forecast for the (i+1) the period is calculated using  $Ea_{i,k-1}$  by extrapolation as follows

$$a_{i+1,k-1} = Ea_{i,k-1} + G_{i,k-1} \dots (2.19)$$

The best value of the smoothing constant can be established by using the fundamental principles of forecasting i.e. it is the value which gives the minimum absolute sum of deviation between the actual and the expected.

### 2.3.3 Estimation of weekly rainfall by other method

For the analysis of hydrological data Todorovic and Yevejevich in (1969) and Clarke (1973) have used a particular period data of all years for the purpose of forecast.

In absence of reliable working models, field engineers use probabilistic approaches to compute rainfall. The Weibull formula, generally applied for Orissa condition [Pandit (1990), Beura (1991), Mohapatra (1991)] to obtain rainfall at different probability levels.

Basu and Khamuri (1989) used the statistical theory of association in forecasting the rainfall amount by utilising the prevailing synoptic meteorological condition, during the period 1982 to 1987. The meteorological condition responsible for different rainfall ranges has been classified and the measures of association of such rainfall ranges on the particular synoptic weather situations are calculated by Yule-coefficient of association and Tschuprow's <sup>coefficient</sup> through contingency table method.

Upadhaya et al. (1986) used the dynamical approach for quantitative precipitation forecast. The quantitative precipitation forecast refers to the quantity of rainfall expected at a point or in a catchment during the specified duration, say 12 hr. or 24 hr.

Gowarikar et al. (1991) used a power regression model for long range forecast of south west monsoon rainfall over India.

#### 2.4 Forecasting Of Onset of Effective Monsoon and Critical Dry Spells

The important characteristic of rainfall influencing production of crops is the date of onset of a spell of rain which will enable in building up a minimum moisture content in the soil. The duration of this spell, the date of occurrence and duration of intervening dry spells, distribution of weekly minimum, maximum and normal rainfall, seasonal rainfall and number of rainy days are also of prime importance. An advance knowledge of the monsoon would enable a farmer to plan his cropping strategy. Reliable forecasting of the rainfall will enable the farmer to choose his implements, taking advantage of available soil moisture conditions (Ashok Raj, 1979).

Forecasting of rainfall can be done by different methods. Singh (1979) has used different techniques for forecasting of weekly rainfall.

Gowariker et al. (1991) used power regression model for long range forecasting of south west monsoon rainfall over India. This is a complicated procedure. This utilizes 16 parameters which is a cumbersome procedure. Based on this model the Indian Meteorological Department has been issuing the operational long range forecast of monsoon rainfall over India since 1988 and these forecasts have proved to be correct.

Basu et al. (1989) has used statistical synoptic model for forecasting of daily rainfall over Mayurakshi basin area. This is a quantitative rainfall forecasting method used for flood forecasting. This needs Yule's coefficient of association and Tschuprow's coefficient through contingency table method of forecasting.

Ashok Raj (1979) has developed a forecasting model using simple statistical calculation for the prediction of onset of effective monsoon, average number of critical dry spells and their duration, the end of effective monsoon etc.

Raman (1974) analysed the daily rainfall data in order to forecast the commencement of sowing rain for black cotton soil area of Maharashtra. He defined the commencement of sowing rain as a 7 day spell with a total rainfall of 25 mm out of which 5 days must have 1 mm or more rain each day, which would be sufficient to provide moisture reserve for commencement of sowing. But one millimeter is too small to call a day as rainy day. The Indian Meteorological Department defines a rainy day as a day with atleast 2.5 mm rainfall.

#### 2.4.1

#### **Effective Monsoon.**

Ashok Raj (1979) defined effective monsoon from the agricultural point of view that any rainfall should be high enough so as to have the soil profile charged with enough moisture after meeting the evaporation

losses to take up agricultural operations. He suggested that, the knowledge about the texture and moisture retaining capacity of the soil along with the crops to be grown should be gathered to calculate the amount of rains required for taking up agricultural operation in order to define the effective monsoon in a more precise term. For large areas the daily rainfall data will be available but the soil texture differs. Hence the above definition of effective monsoon holds good as a general one.

#### 2.4.2 Onset of Effective Monsoon

Ashok Raj (1979) has defined a 7 days spell must satisfy the following conditions to be defined as the date of onset of effective monsoon.

- (i) The first day's rain in the 7 day spell is not less than the average daily evaporation in millimeter.
- (ii) If 'e' is the average daily evaporation then the total rain during the 7 day spell is not less than  $(5e+100)$  mm.
- (iii) At least 4 out of these 7 days are rainy days as defined by Indian Meteorological Department.

The significance of the first condition is that if the average daily evaporation of a place is 'e' mm and after a prolonged dry spell, if the rain on the first day of a 7 day- spell is less than 'e' mm then it

is clear that no water will be available for the soil on that day. The second condition signifies that (5e+10) mm of rainfall in a 7 day-spell will allow 10 mm of water left on the soil for agricultural operations. The third condition signifies that enough moisture reserve is built up in the soil and enables the identification of seven day spell as the onset of effective monsoon otherwise such 7 day spells are known as pre-monsoon showers.

#### 2.4.3 Critical Dry Spells (CDS)

The interval between the end of the 7-day spell, beginning with the onset of effective monsoon and another rainy day with 5 e mm rain or the commencement of another 7 day rainy spell with a total of 5e mm minimum rainfall then this spell can be defined as the first dry spell. If the duration of this dry spell exceeds a certain value depending on the crop-soil complex of the place under consideration, then this dry spell is called the first critical dry spell. On the other hand such spells are included in first wet spell.

#### 4.4 Wet Spell

The interval between the onset of effective monsoon and the commencement of the first critical dry spell is called the first wet spell. The subsequent wet spells are defined as the interval between the critical dry spells. Thus the wet spells are spells of prolonged

rain with possible intervening dry spell of duration less than the value which makes the dry spell critical.

## 2.5

**Forecasting of Dry and Wet Spells**

The success or failure of crops particularly under rainfed condition, is closely linked with the rainfall pattern. Particularly in regions where rainfall is erratic or where short dry periods can be expected within the wet season, it is important to know the probability of having consecutive dry periods of 2 or 3 weeks during the growing season of a crop. Hence for the purpose of crop planning and to carry out the agricultural practices it is important to know the sequence of dry and wet periods (Pandarinath, 1991).

Victor and Sastry (1979) used the Markov chain probability model to find the long term frequency behavior of wet or dry weather spells.

Markov chain model has also been used for computation of probability of occurrence of daily precipitation by Stern (1991).

Pandarinath (1991) used the Markov chain model to study the probability of dry and wet spells in terms of the shortest period like week. When applied to the periods like week, this model enables the determination of probability of occurrence of dry or wet weather during the preceding week.

Robertson (W.M.O., 1982) has also applied the Markov chain model with daily rainfall data to establish drought frequencies. He suggested that if such a period coincides with a sensitive phenological stage this could damage the crop development. On the otherhand, dry periods at the ripening stage of the crop are some times beneficial. Robertson has considered 10 day periods for the drought frequency calculation.

Robertson (W.M.O., 1982), defined a dry decade if the decade rainfall i.e. 10 day rainfall in total is less than 30 mm and the wet decade if the decade rainfall is 30 mm or more. He used the following method for calculation of the probabilities of the decade.

$$(i) \quad P(D) = F(D)/n \quad \dots \quad (2.20)$$

$$(ii) \quad P(DD) = F(DD)/F(D) \quad \dots \quad (2.21)$$

$$(iii) \quad P(W) = F(W)/n \quad \dots \quad (2.22)$$

$$(i.v) \quad P(WW) = F(WW)/F(W) \quad \dots \quad (2.23)$$

Where,  $F(D)$ -actual number of dry decades

$F(W)$  = actual number of wet decades

$F(DD)$  = the number of dry decades that are preceded by dry decades

$n$  = the total number of decades taken for analysis

It is now possible to calculate the probability of a certain number of consecutive wet or dry decades starting at any one decade during a certain year. The probability of <sup>two</sup> consecutive wet decades or dry decades is calculated by the following formula given by Robertson (W.M.O, 1982).

$$P(W_2) = P(W) \times P(WW)^{2-1} \quad \dots \quad (2.24)$$

$$P(D_2) = P(D) \times P(DD)^{2-1} \quad \dots \quad (2.25)$$

Similarly Pandrinath (1991) has calculated the probability of dry and wet weeks during monsoon period over Andhra Pradesh. He has taken the duration as 7 days only of the monsoon period. The monsoons weeks are counted from 1st June to 30th September. With a view to cover the entire monsoon season the 17th week is taken as 10 days. He considered a threshold of 20 mm per week to demarcate dry weeks i.e in a given week when the rainfall is less than 20 mm that week has been classified dry week and a week with 20 mm or more rainfall as a wet week.

The various formulae used in calculation by Pandarinath (1991) is as follows.

(i)  $P(d) = F(d)/n$  where  $P(d)$  = probability of the week being dry,  $n$  = no. of years data used,  $F(d)$  = frequency of dry weeks

(ii)  $P(dd)/F(d)$ , where  $P(dd)$ =probability of the dry weeks preceded by another dry week (Conditional),  $F(dd)$ =frequency of dry week preceded by another dry week

(iii)  $2D=P(dw1) \times P(ddw2)$ , where  $2D$ = probability of 2 consecutive dry weeks,  $P(dw1)$  probability of the week being dry (1st week),  $P(ddw2)$ =probability of 2nd consecutive dry week, given the preceding week being dry

(iv)  $3D=P(dw1) \times P(ddw2) \times P(ddw3)$ , where  $3D$ =probability of 3 consecutive dry week,  $P(ddw3)$ =probability of 3rd week being dry, given the preceding week dry

(v)  $P(w)=F(w)/n$ , where  $P(w)$ =probability of the week being wet

$F(w)$ =frequency of the wet week

$P(ww)$ ,  $2W$ , and  $3W$  are calculated in the same way as the  $P(dd)$ ,  $2D$ ,  $3D$  and the notations used are having the same meaning except the weeks being wet.

### Forecasting of Commencement of Sowing Rain

An important aspect of crop planning is backward and forward accumulation of rainfall to determine the onset and termination of wet season based on precipitation data. Farmers's cropping strategies are greatly

influenced by the variability of the onset and end of rainy season. Generally farmers's opt for planting or broadcast their seeds when a certain amount of rainfall has sufficiently moistened the top soil. If for a longer period i.e. at least 25 years, the daily or weekly or decade rainfall is summed forward or backward from the peak of the dry season, until certain amount of rainfall is accumulated then the probability of having received given amount of rain can be obtained for each time interval chosen (W.M.O., 1982).

Moris and Zandstra (W.M.O., (1982) have choosen the rainfall amounts for forward and backward accumulation of rainfall depending on experience. They have advocated that 75 mm accumulation of rainfall has been considered as the onset time for the growing season for dry seeded crops and 200 mm accumulated rainfall for initiation of puddling i.e.wet land preparation of rice fields.Similarly the end of the wet season was determined by backward summing of rainfall data. It is considered that 500 mm and 300 mm accumulated values represent that the period after which sufficient rain would be expected to sustain a second rice crop or other short duration field crops, assuming a fully charged soil profile at planting.

The method adopted by W.M.O (1982) for the study of the forward and backward accumulation of rainfall

influenced by the variability of the onset and end of rainy season. Generally farmers's opt for planting or broadcast their seeds when a certain amount of rainfall has sufficiently moistened the top soil. If for a longer period i.e. at least 25 years, the daily or weekly or decade rainfall is summed forward or backward from the peak of the dry season, until certain amount of rainfall is accumulated then the probability of having received given amount of rain can be obtained for each time interval chosen (W.M.O., 1982).

Moris and Zandstra (W.M.O., (1982) have choosen the rainfall amounts for forward and backward accumulation of rainfall depending on experience. They have advocated that 75 mm accumulation of rainfall has been considered as the onset time for the growing season for dry seeded crops and 200 mm accumulated rainfall for initiation of puddling i.e. wet land preparation of rice fields. Similarly the end of the wet season was determined by backward summing of rainfall data. It is considered that 500 mm and 300 mm accumulated values represent that the period after which sufficient rain would be expected to sustain a second rice crop or other short duration field crops, assuming a fully charged soil profile at planting.

The method adopted by W.M.O (1982) for the study of the forward and backward accumulation of rainfall

influenced by the variability of the onset and end of rainy season. Generally farmers's opt for planting or broadcast their seeds when a certain amount of rainfall has sufficiently moistened the top soil. If for a longer period i.e. at least 25 years, the daily or weekly or decade rainfall is summed forward or backward from the peak of the dry season, until certain amount of rainfall is accumulated then the probability of having received given amount of rain can be obtained for each time interval chosen (W.M.O., 1982).

Moris and Zandstra (W.M.O., (1982) have choosen the rainfall amounts for forward and backward accumulation of rainfall depending on experience. They have advocated that 75 mm accumulation of rainfall has been considered as the onset time for the growing season for dry seeded crops and 200 mm accumulated rainfall for initiation of puddling i.e. wet land preparation of rice fields. Similarly the end of the wet season was determined by backward summing of rainfall data. It is considered that 500 mm and 300 mm accumulated values represent that the period after which sufficient rain would be expected to sustain a second rice crop or other short duration field crops, assuming a fully charged soil profile at planting.

The method adopted by W.M.O (1982) for the study of the forward and backward accumulation of rainfall

over Thailand is as follows. For the forward accumulation the decade rainfall for each year is added from 1st decade to find the decade number in which 75 mm and 200 mm rainfall has reached. Similarly for backward accumulation the cumulative rainfall is calculated from the last decade of the year to the 1st decade to find the decade in which 100 mm, 300 mm and 500 mm rainfall are accumulated. The years are allotted with rank number according to their serial. For each rank number the probability is calculated by the simple statistical formula given below.

$$P = (1/m + 1) \times 100 \quad \dots \quad (2.26)$$

Where 'm' is the rank number. The rank number and their probability level are arranged in ascending order along with their corresponding decade for forward accumulation of rain water. Similarly the rank number and their probability level are arranged in descending order for backward accumulation. The probability levels and the decades for 75 mm, 200 mm, 500mm, 300mm and 100mm rainfall are plotted on a graph to calculate the corresponding decade in which the desired volume of rainfall can be expected at a desired level of probability.

## 2.7 Water Requirement of Crops

Water requirement of crops is defined as the depth of water needed to meet the water loss through evapotranspiration of a disease free crop, growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment. (Doorenbos and Pruitt, 1977).

Doorenbos and Pruitt (1977) suggested the following methods for the calculation of reference crop evapotranspiration [ET<sub>o</sub>].

### 2.7.1 Modified Blaney - Criddle Method

The recommended relationship is

$$ET_o = C [ P(0.46T + 8) ] \quad \dots (2.27)$$

Where ET<sub>o</sub> = Reference crop evapotranspiration in mm / day for the month considered

T = Mean daily temperature in °C over the month considered

P = Mean daily percentage of total annual day time hours

C = Adjustment factor which depends on minimum relative humidity, sunshine hours and day time wind estimates

### 2.7.2 Modified Radiation Method

The relationship recommended is expressed as

$$E_{T_o} = C \left[ \frac{W.R}{s} \right] \dots (2.28)$$

Where  $R =$  Solar radiation in equivalent evaporation in mm / day  
 $s =$

$W =$  Weighting factor which depends on temperature and altitude

and  $C =$  Adjustment factor which depends on mean humidity and day time wind conditions

### 2.7.3 Modified Penman Method

The form of the equation in this method is

$$E_{T_o} = C \left[ W.R_n + (1-W).f(u). \left( \frac{e_a - e_d}{s} \right) \right] \dots (2.29)$$

Where

$W =$  Temperature related weighting factor

$R_n =$  Net radiation in equivalent evaporation in mm / day

$f(u) =$  Wind related function

$(e_a - e_d) =$  Difference between the saturation vapour pressure of the air temperature and the mean actual vapour pressure of the air both in mbar *and*

$C =$  Adjustment factor to compensate for the effect of day & night weather conditions.

#### 2.7.4 Pan Evaporation Method

Reference crop evapotranspiration (ET<sub>o</sub>) can be obtained from

$$ET_o = K_p \cdot E_{pan} \quad \dots \quad (2.30)$$

Where  $E_{pan}$  = Pan evaporation in mm / day and represents the mean daily value of the period considered *and*

$K_p$  = Pan coefficient, which depends on the type of pan, humidity, wind condition and pan environment.

#### 2.7.5 Estimation of Factor "c"

The adjustment factor "c" of the Blaney - Criddle method, modified Radiation method and modified Penman method is difficult to calculate. In the previous two methods the factor "c" is calculated from graphs as given by Doorenbos & Pruitt (1977). The factor "c" for Penman method is also difficult to calculate from the table given by Doorenbos & Pruitt (1977) as this depends on both day & night condition.

Allen & Pruitt (1991) have suggested easier solution for the calculation of the adjustment factor. They have replaced the graph by regression equations which is easier to calculate. The regression equations of the factor "c" for all the three methods are as follows :

2.7.5.1 The adjustment factor "c" for modified Blaney - Criddle Method

The adjustment factor 'c' in Blaney - Criddle method was best estimated using a seven parameter model of the form

$$\begin{aligned}
 C = & 0.908 - 0.00483 \text{ RH min} + 0.7949 \frac{n}{N} + \\
 & 0.0768 \left[ \ln(Ud + 1) \right]^2 - 0.0038 \text{ RH min} - \\
 & 0.000433 \text{ RH min} Ud + 0.281 \ln(Ud + 1) \cdot \ln\left(\frac{n}{N} + 1\right) \\
 & - 0.00975 \ln(Ud + 1) \cdot \left[ \ln(\text{RH min} + 1) \right]^2 \cdot \ln\left(\frac{n}{N} + 1\right)
 \end{aligned}
 \tag{2.31}$$

Where

RH min - minimum daily relative humidity in per cent

$\frac{n}{N}$  - mean ratio of actual to possible sunshine hour

$Ud$  - day time wind velocity in m / sec.

The limits on parameters as suggested by Allen & Pruitt for equation (2.31) are

$$0 \leq \text{RH min} \leq 100 \%$$

$$0 \leq \frac{n}{N} \leq 1.0$$

$$0 \leq Ud \leq 10 \text{ m sec}^{-1}$$

The '+1' values are necessary to allow use of the equation for parameter values equal to 0.

## 2.7.5.2 Adjustment factor for modified Radiation Method

Allen and Pruitt (1991) has suggested that the regression model presented by Frevert et al. (1983) to calculate the 'c' factor for radiation method provides good estimates. The Frevert et al. (1983) model for the radiation equation, adjustment factor 'c' with coefficient rounded to significant digit is

$$c = 1.066 - 0.00128 \text{ RH mean} + 0.045 U_d - 0.0002 \text{ RH mean}$$

$$U_d - 0.0000315 (\text{RH mean})^2 - 0.001103 (U_d)^2 \dots (2.32)$$

Where

$\text{RH}_{\text{mean}}$  - mean daily relative humidity in per cent

$U_d$  - daytime wind speed m / sec.

Limits on parameters as suggested by Frevert et al. (1983) for the equation (2.32) are

$$0 \leq \text{RH}_{\text{mean}} \leq 100\%$$

$$0 \leq U_d \leq 10 \text{ m sec}^{-1}$$

## 2.7.5.3 Adjustment factor for modified Penman Method

The adjustment factor 'c' for Penman method can be best estimated using a nine-parameter model comprised of combination of variables. The resulting equation is of the form

$$\begin{aligned}
 c = & 0.892 - 0.0781 U_d + 0.00219 U_d \cdot R_s + 0.000402 RH_{max} \cdot R_s \\
 & + 0.000196 \frac{U_d}{U_n} \cdot U_d \cdot RH_{max} + 0.0000198 \frac{U_d}{U_n} \cdot U_d \cdot RH_{max} \cdot R_s \\
 & + 0.00000236 (U_d)^2 \cdot RH_{max} \cdot R_s \\
 & - 0.0000086 \left( \frac{U_d}{U_n} \right)^2 \cdot U_d \cdot RH_{max} - 0.000000292 \frac{U_d}{U_n} \\
 & (U_d)^2 \cdot (RH_{max})^2 \cdot R_s - 0.0000161 \cdot RH_{max} \cdot (R_s)^2 \dots (2.33)
 \end{aligned}$$

Where

$U_d$  - day time wind speed in m / sec

$U_d / U_n$  - the ratio of day time to night time wind speeds

$RH_{max}$  - maximum daily relative humidity in per cent

$R_s$  - daily global solar radiation, mm / day

Doorenbos and Pruitt (1977) recommended setting  $U_d / U_n$  to 2.0 when unknown.

Limits on parameters for modified Penman 'c' factor in equation (2.33) are

$$3 \leq R_s \leq 12 \text{ mm d}^{-1}$$

$$30 \leq RH_{\max} \leq 90 \%$$

$$0 \leq U_d \leq 9 \text{ m s}^{-1}$$

$$1 \leq U_d / U_n \leq 4$$

However, Allen & Pruitt (1991) suggested that parameters outside these ranges should be set equal to the appropriate limit before use of the equation.

#### 2.7.6 Crop Coefficient

The four methods described previously predict the effect of climate on reference crop evapotranspiration (ETo). To account for the effect of the crop characteristics or crop water requirements, crop coefficient (Kc) need to be estimated.

Appropriate selection of Kc values are estimated taking crop characteristics, time of planting or sowing and stages of crop development and general climate condition.

Doorenbos and Pruitt (1977) recommended setting  $U_d / U_n$  to 2.0 when unknown.

Limits on parameters for modified Penman 'c' factor in equation (2.33) are

$$3 \leq R_s \leq 12 \text{ mm d}^{-1}$$

$$30 \leq RH_{\text{max}} \leq 90 \%$$

$$0 \leq U_d \leq 9 \text{ m s}^{-1}$$

$$1 \leq U_d / U_n \leq 4$$

However, Allen & Pruitt (1991) suggested that parameters outside these ranges should be set equal to the appropriate limit before use of the equation.

#### 2.7.6 Crop Coefficient

The four methods described previously predict the effect of climate on reference crop evapotranspiration (ETo). To account for the effect of the crop characteristics or crop water requirements, crop coefficient (Kc) need to be estimated.

Appropriate selection of Kc values are estimated taking crop characteristics, time of planting or sowing and stages of crop development and general climate condition.

### 2.7.7 Crop Water Requirement

The water requirement of different crops are determined by the following equation (Doorenbos and Pruitt (1977)).

$$ET_{crop} = K_c \times E_{To} \dots\dots\dots(2.34)$$

Where

$$ET_{crop} = \text{Crop evapotranspiration or water requirement in mm / day}$$

$$K_c = \text{Crop coefficient}$$

$$\text{and } E_{To} = \text{Reference crop evapotranspiration}$$

### 2.8. Growing Degree Days

Growing degree days are calculated by the following formula as suggested by Ratnam and Kavi (1990).

$$\text{Growing Degree Days (GDD)} = \sum_{i=1}^n \frac{T_{max} + T_{min}}{2} - 10 \dots(2.35)$$

Where

$$T_{max} = \text{daily maximum temperature in } ^\circ\text{C}$$

$$T_{min} = \text{daily minimum temperature in } ^\circ\text{C}$$

The temperature of ten degrees is considered as the base temperature, which is subtracted from the average temperature below which the plant will not develop.

They have studied the significance of growing degree days to crop in Karnataka.

Ganeshan et al. ( 1988) have attempted for obtaining relationship between yield of ragi with growing degree days. They have also calculated the growing degree days ~~with~~ the same formula mentioned above.

They have related the yield of ragi with growing degree days through the following models

$$(i) \quad Y = a + bx \dots\dots\dots(2.36)$$

$$(ii) \quad Y = a + b \log x \dots\dots\dots (2.37)$$

$$(iii) \quad Y = e^{\frac{a + bx}{x}} \dots\dots\dots(2.38)$$

$$(iv) \quad Y = e^{\frac{a + b \log x}{x}} \dots\dots\dots(2.39)$$

They have concluded that  $Y = e^{\frac{a + b \log x}{x}}$  model has yielded the best correlation coefficient between the yield of ragi and growing degree days.

## 2.9 Crop - Weather Model

Crop yield is affected by technological changes and weather variability. Technological changes includes the impact of increased fertilizer applications, improved management practices and pest control, high yielding seeds and other man controlled factors designed to increase yield. It can be assumed that the technological factors will increase yield smoothly through time. Weather variability both within

and between seasons is the second and only uncontrollable source of variability in yields.

The extent of weather influence on crop yield depends not only on the magnitude of weather variables but also on the distribution pattern of weather over the crop season. Hence it is necessary to divide the whole crop season into suitable intervals. This will increase the number of variables in the model which ultimately needs large number of data to be evaluated. The other approach is to decrease the number of variables in the model. The number of variables can be decreased by taking weather variables during some periods only when variables show significant correlation with yield. This approach has been adopted by Indian Meteorological Department.

As quoted by Agrawal & Jain (1990), Das (1971), Sarkar (1977) and Sarwade (1988) have adopted the aforesaid approach to develop the models for crops. They have identified significant correlations between yield and weather factor during successive overlapping periods of 7 to 60 days of the crop growing seasons. By analysing the correlation coefficients for statistical and phenological significance, the critical periods when the weather parameters have significant effect on yield are recorded. These are used through multiple regression analysis to obtain the forecast equation.

As stated by Agrawal & Jain (1990), Fisher in 1924 suggested that the effect of change in weather variable in successive weeks would not be abrupt or erratic but an orderly one that follows some mathematical law. He assumed that these effects are composed of the terms of a polynomial function of time as given below

$$A_w = a_0 [f_0(w)] + a_1 [f_1(w)] + a_2 [f_2(w)] + \dots + a_k [f_k(w)] \quad \dots(2.40a)$$

Where

$A_w$  = the effect of unit change in weather variable on yield in the  $W$  th week

$a_0, a_1, a_2, \dots, a_k$  are constants to be determined

The function  $f_i(w)$  is orthogonal polynomial of the  $i$  th

degree ( $i = 1, 2, 3, \dots, k$ )

Again

$$X_w = f_0 [f_0(w)] + f_1 [f_1(w)] + f_2 [f_2(w)] + \dots + f_k [f_k(w)] \quad \dots(2.40b)$$

Where  $X_w$  = the rainfall in  $W$ th week

and  $f_i$  = the distribution constants of  $X_w$

Substituting the expression for  $A_w$  and  $X_w$  in regression equation

$$Y = A_0 + A_1 X_1 + A_2 X_2 + \dots + A_n X_n \dots \dots (2.41)$$

Where

$Y =$  crop yield

Utilising the *properties* of orthogonal and normalised

function  $f_i(w)$ , Fisher obtained

$$Y = A_0 + a_{00} f_0 + a_{11} f_1 + \dots + a_{kk} f_k \dots \dots (2.42)$$

He suggested to use  $K = 5$  for most practical situations. Fisher has used this model for studying the influence of rainfall on yield of wheat.

Agrawal & Jain (1990) also stated that Hendricks & Scholl have modified Fisher's technique. They divided the crop season into 'n' weekly intervals and have assumed that a second degree polynomial in week number would be sufficiently flexible to express the relationship.

Mathematically, this is expressed as

$$A_w = a_0 + a_1 w + a_2 w^2 \dots \dots (2.43)$$

This is in particular

$$A_1 = a_0 + 1.a_1 + 1.a_2$$

$$A_2 = a_0 + 2.a_1 + 2.a_2$$

Substituting the expression for  $A_w$  in regression equation the model was obtained as

$$Y = A_0 + a_0 E x + a_1 E w . x + a_2 E w . x \dots (2.44)$$

In this model, number of constants to be determined reduced to 4, irrespective of  $n$ . The equation (2.44) was extended for two weather variables to study joint effect.

Stacy et al. (1957), Runge (1968) have used the model of Hendricks and Scholl to study the joint effects of temperature and rainfall on crop yields.

Agrawal et al. (1980, 1983, 1986) & Jain et al. (1980) have modified the Hendricks and Scholl model expressing effects of changes in weather variables on yield in the  $w$ th week as second degree polynomial in respective correlation coefficients between yield and weather variables. This will explain the relationship in a better way as it gives appropriate weightage to different periods. Under this assumption, the models were developed for studying the effects of weather variables on yield using complete crop season data whereas forecast model utilised partial crop season data.

With this modification, the model for studying individual effects becomes

$$Y = a + b_0 z + b_1 z + b_2 z + CT \quad \dots(2.45)$$

Where Z's are generated variables.

Y is crop yield, a, b, (j = 0, 1, 2, ) and e are constants, T is year number included to correct the long term upward or downward trend in yield.

Agrawal et al. (1983) developed models for studying joint effects of weather on yield and forecast model.

The models were further modified (Agrawal et al. 1986) by expressing the effects of changes in weather variables on yield in wth week as a linear function of respective correlation coefficients between yield and weather variables. As trend effect on yield was found to be significant, its effect was removed from yield while calculating correlation coefficients of yield with weather variables to be used on weights. Effect of second degree terms of weather variables were also studied. In total Agrawal et al. (1986) developed eight models from the earlier models.

Model I This is the earlier model

$$Y = a + b_{00} z + b_{11} z + b_{22} z + c T \dots\dots(2.46)$$

Model II In this model effects of weather on yield in different weeks were expressed as linear function of respective correlation coefficients of weather variables and yield.

The model is

$$Y = a + b_{00} z + b_{11} z + c T \dots\dots(2.47)$$

Model (II & IV

These models are same as model I & II

respectively except that  $r^w$  is obtained using adjusted yield.

Model V This is obtained by including quadratic terms of weather variables in model I.

$$Y = a + b_{00} z + b_{11} z + b_{22} z + b_{00} z + b_{11} z + b_{22} z + c T \dots\dots(2.48)$$

Model VI This is obtained by including quadratic terms of weather variables in model II.

$$Y = a + b_{00} z + b_{11} z + b_{00} z + b_{11} z + c T \dots\dots(2.49)$$

Model VII & VIII

These models are same as models V and VI respectively except that correlation coefficients are obtained using adjusted yield.

These models were extended for studying joint effects and developing forecast models.

Agrawal et al. (1990) have used the following models to study the effects of weather variables on crop yield and forecast model for wheat crop in Amritsar.

Model for studying single effect

$$Y = a + b_o z_o + b_1 z_1 + c T \dots\dots\dots(2.50)$$

Model for studying joint effects

$$Y = a (b_{ij} z_{ij} + b_{i'j} z_{i'j} + b_{ii'w} z_{ii'w}) + c T \dots\dots(2.51)$$

$r_{ii'w}$  is the correlation coefficient of yield and the product of the two weather variables, i & i' taken to study joint effect with week.

Ganesan et al. (1988) have used the following models for obtaining relation between yield of ragi & weather parameters like growing degree days, open pan evaporation and evapotranspiration.

The models were

$$Y = e^{a + b \log x} \dots\dots\dots(2.52)$$

$$Y = a + b x \dots\dots\dots(2.53)$$

$$Y = a + b \log x \dots\dots\dots(2.54)$$

$$\text{and } Y = e^{a + b x} \dots\dots\dots(2.55)$$

Where  $Y =$  Yield of ragi in  $q/ha$

$X =$  Weather parameter i.e. growing degree days or open pan evaporation or evapotranspiration.

They found  $Y = e^{a + b \log x}$  is the most suitable model.

Shankar and Gupta (1987) while studying the effect of weather variables on yield of paddy at Chinsura have adopted the model

$$Y = a + b_1 x_1 + b_2 x_2 + \dots\dots\dots + b_k x_k \dots\dots\dots(2.53)$$

where  $a, b_1, b_2, \dots\dots\dots, b_k$  are all constants .

$X_1, X_2, \dots\dots\dots, X_k$  are the weather elements during different phenological periods of crop growth and  $Y$  is the yield.

## CHAPTER III

### MATERIALS AND METHODS

The detailed description of the materials used and methods employed during the course of study is described below.

#### 3.1 Site Selection

Bhubaneswar is situated at 20 degree 15' N latitude, 85 degree 32'E longitude and at 25.9 m above the mean sea level. It is situated 64 Km away from Bay of Bengal towards West. The climate of Bhubaneswar is sub-humid. It is characterised by hot summer and general dryness except during the south west monsoon which covers the period from mid-June to mid-October, with uneven and heavy rainfall. As the present study is based on meteorological data, Bhubaneswar is the only place in Puri district of Orissa for which the data are available for a considerably longer period.

#### 2 Meteorological Data

The data are collected from meteorological observatory of Orissa University of Agriculture and Technology, Bhubaneswar for this study. Daily continuous rainfall data for 42 years from 1950 to 1991 are collected for the present study to make rainfall forecasting through different methods. Daily continuous maximum and minimum temperature relative humidity,

sunshine hour *and* wind velocity data are collected over 32 years from 1960 to 1991 for the calculation of crop-water requirement and development of crop weather models. The yield data of crops such as arhar, ground nut, maize and upland paddy, over 16 years are collected from Dryland Agriculture, Research Farm of Central Research Station, O.U.A.T., Bhubaneswar.

### 3.3 Calculation of Persistence Test and Serial Correlation Coefficient

The daily continuous rainfall data collected are fed to the computer. The daily rainfall series is divided into annual blocks each beginning on the 1st January of every year and ending on the 31st December of that year. The daily data have been converted to standard weekly data as the crop planning is made on weekly basis.

The weekly rainfall data series can be expressed in double subscripted form as

$$(r_{i,j}, i=1,2, \dots, 42; j=1,2, \dots, 52)$$

which represents rainfall in the  $j$ th week of  $i$ th year and this can be arranged in a 42X52 matrix.

The most common technique of determining the degree of persistence in a time series which has been followed in this study is by "serial correlation coeffi-

cient". The serial correlation coefficient  $p_k$  at lag  $k$  for a finite series is calculated by the formula given by Kendal and Stuart (1968), Fiering and Jackson (1971) and Yevjevich (1972) and is given below

$$p_k = \frac{1}{N-k} \frac{\sum_{i=1}^{N-k} (r_{i,j} - \bar{r})(r_{i+k,j} - \bar{r})}{\sum_{i=1}^N (r_{i,j} - \bar{r})^2} \quad \dots\dots(3.1)$$

Where  $r = 1/N \sum_{i=1}^N r_{i,j}$

$N$  = Total number of year (42 in this study)

$p_k$  = Unit of Lag ( $k=1,2,\dots, 15$  in this study)

The serial correlation coefficient is also calculated for transformed weekly rainfall series i.e.

(i) modular coefficient form ( $x_{i,j} = r_{i,j} / \bar{r}(j)$ )

(ii) Square root form ( $x_{i,j} = (r_{i,j})^{1/2}$ )

(iii) Cube root form ( $x_{i,j} = (r_{i,j})^{1/3}$ )

The same thing has been calculated for fortnightly data series, the transformed fortnightly data series, monthly data series <sup>and</sup> the monthly transformed data series.

A Fortran 77 Computer programme has been developed for UNIX system with two subroutines to calculate the serial correlation coefficient with the above formula. The programme has got the facility to calculate the fortnightly data series, monthly data series and transformed data series. Weekly rainfall data series are the input to the programme.

3.4. **Probability Distribution Function**

For the purpose of study of the probability distribution function which fits the weekly rainfall time series of Bhubaneswar, the procedure adopted is detailed in the following steps.

Let  $r_{i,j}$  denote the weekly rainfall as described in article 3.3 i.e. in the  $j$ -th week of the  $i$ -th year, where  $i=1,2,\dots, 42$  and  $j = 1,2,\dots,52$ .

The following transformation of  $r_{i,j}$  have been considered in this study.

(i) Original data =  $x_{i,j} = r_{i,j}$  ..... (3.2)

(ii) Modular coefficient transformation  
 $= x_{i,j} = r_{i,j} / \bar{r}(j)$  .....(3.3)

(iii) Square root transformation  
 $= x_{i,j} = (r_{i,j})^{1/2}$  .....(3.4)

(iv) Cube root transformation  
 $= x_{i,j} = (r_{i,j})^{1/3}$  .....(3.5)

Where  $x_{i,j}$  is the transformed data of the weekly rainfall data and  $\bar{r}(j)$  represents the mean value of the time series  $r(j)$  i.e.

$$\bar{r}(j) = 1/N \sum_{i=1}^N r_{i,j} \dots\dots\dots (3.6)$$

For estimating the parameters of probability distribution function the method of maximum likely hood has been preferred (Markovic: 1965, Yevjevich 1972).

The concept of maximum likelihood function was conceived by Fisher (1950).

Let  $(x_1, x_2, \dots, x_n)$  represent a random sample of  $N$  independent observations from a population with a probability density function,

$f(x_i / l_1, l_2, \dots)$ , where  $l_1, l_2, \dots$  are parameters.

The maximum likelihood function is defined as the product

$$L = \prod_{i=1}^N f(x_i / l_1, l_2, \dots) \dots \dots \dots (3.7)$$

Then  $\ln L = \left( \ln \prod_{i=1}^N f(x_i / l_1, l_2, \dots) \right)$

$$= \sum_{i=1}^N \ln \{ f(x_i / l_1, l_2, \dots) \} \dots \dots \dots (3.8)$$

The maximum likelihood estimates of a distribution parameters  $l_1, l_2, \dots$  are provided by the solutions of the equations

$$\frac{d(\ln L)}{da_m} = 0 \dots \dots \dots (3.9)$$

Where  $m = 1, 2, \dots$  parameter index. That is,

$$\frac{d(\ln L)}{da_1} = \frac{d}{da_1} \left( \sum_{i=1}^N \ln ( f(x_i / a_1, a_2, \dots) ) \right) = 0$$

$$\frac{d(\ln L)}{da_2} = \frac{d}{da_2} \left( \sum_{i=1}^N \ln ( f(x_i / a_1, a_2, \dots) ) \right) = 0 \dots \dots \dots (3.10)$$

Thus 'm' number of equations are obtained for 'm' parameters. The estimates  $a_1, a_2, \dots$  are obtained by solving these equations and are called the maximum likelihood estimates of parameters  $\theta_1, \theta_2, \dots$  respectively.

3.4.1. Normal Density Function

$$f(x/\mu, (SD)^2) = \frac{1}{(SD)\sqrt{2\pi}} \exp \left\{ -1/2 (x-\mu)^2 / (SD)^2 \right\}$$

$-\infty \leq x \leq \infty$  and  $(SD) > 0 \dots \dots \dots (3.11)$

Where the parameters  $\mu$  and  $(S.D.)^2$  are the expected mean and variance of the variable  $x$  respectively. The maximum likelyhood estimate of the population mean is given by

$$\hat{\mu} (j) = \frac{1}{N} \sum_{i=1}^N x_{i,j} \dots \dots \dots (3.12)$$

and the standard deviation by

$$(\hat{SD}) (j) = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_{i,j} - (\hat{\mu}) (j))^2} \dots (3.13)$$

3.4.2. Lognormal Density Function With Two Parameters (lognormal-2)

$$f ( x/(\mu_2) , (SD)_2^2 ) = \frac{1}{x (SD)_2 \sqrt{2\pi}} \exp \{ -1/2 ( \ln x - \mu_2 )^2 / (SD)^2 \}$$

$0 \leq X \leq \infty$  and  $(SD)_2 > 0 \dots \dots \dots (3.14)$

Where  $\mu_2$  and  $(SD)_2^2$  are the mean and the variance of the variable  $x$ . The maximum likelihood estimates  $\hat{\mu}_2(j)$  and  $(\hat{SD})_2(j)$  are evaluated by the formulae

$$\hat{\mu}_2(j) = \frac{1}{N} \sum_{i=1}^N \ln x_{i,j} \dots\dots\dots(3.15)$$

$$\text{and } (\hat{SD})_2(j) = \sqrt{-\frac{1}{N} E (\ln x_{i,j} - \hat{\mu}_2(j))^2} \dots\dots (3.16)$$

**3.4.3. Lognormal Density Function with Three Parameters (Log normal - 3)**

$$f(x/\mu_3, (SD)_3^2, x_0) = \frac{1}{(x-x_0)(SD)_3 \sqrt{2\pi}}$$

$$\exp \left[ -1/2 \left( \ln(x-x_0) - \mu_3 \right)^2 / (SD_3)^2 \right]$$

$$x_0 \leq x < \infty \text{ and } (SD)_3 > 0 \dots\dots\dots(3.17)$$

Where  $x_0$  = a lower boundary parameter,  $x_0 > 0$

$\mu_3$  = the population mean of  $\ln(x - x_0)$  and

$(SD)$  = the standard deviation of  $\ln(x - x_0)$

The maximum likelihood estimates of  $\hat{\mu}_3$  and  $(\hat{SD})_3$  are given by

$$\hat{\mu}_3(j) = \frac{1}{N} \sum_{i=1}^N \ln(x_{i,j} - \hat{x}_0(j)) \dots\dots(3.18)$$

$$\text{and } (\hat{SD})_3(j) = \sqrt{-\frac{1}{N} \sum_{i=1}^N [\ln(x_{i,j} - \hat{x}_0(j)) - \hat{\mu}_3(j)]^2} \dots\dots(3.19)$$

Where  $\hat{x}_0(j)$  is the maximum likelihood of estimate of the lower boundary  $x_0(j)$  and can be determined by iterative calculation procedures using the following equation

$$\begin{aligned} & \frac{N}{\sum_{i=1}^N \frac{1}{x_{i,j} - x_0(j)}} \left[ -\frac{1}{N} \sum_{i=1}^N \ln^2 (x_{i,j} - \hat{x}_0(j)) \right] \\ & - \left( \frac{1}{N} \sum_{i=1}^N \ln (x_{i,j} - \hat{x}_0(j))^2 - \frac{1}{N} \sum_{i=1}^N \ln \right. \\ & \left. (x_{i,j} - x_0(j)) \right) \left. \right] + \frac{N}{\sum_{i=1}^N} \left[ \ln (x_{i,j} - \right. \\ & \left. \hat{x}_0(j)) \right] / \left( \sum_{i=1}^N (x_{i,j} - \hat{x}_0(j)) \right) \dots\dots\dots(3.20) \end{aligned}$$

The estimates  $\hat{\mu}(j)$ ,  $(SD)(j)$ ,  $\hat{\mu}_2(j)$ ,  $(SD)_2(j)$ ,

$\hat{\mu}_3(j)$ ,  $(SD)_3(j)$  and  $\hat{x}_0(j)$  denote the parameter

estimates of the time series of the  $j$ th week, i.e.  $X \dots(j)$ .

In the present study the parameters of distribution for normal, lognormal - 2 and lognormal - 3 have been estimated by developing a Fortran 77 Computer programme with two sub-routine using the above formulae. The weekly data series are the input to the programme.

### 3.5 Forecasting of Weekly Cumulative Rainfall by Moving Average Method

For the purpose of forecasting of cumulative weekly rainfall by moving average method four periods such as 3 years, 5 years, 7 years & 9 years have been considered. Thus the following equation has been used in this study as suggested by Ramlingam (1976).

$$\hat{a}_{i,k-1} = \frac{a_{i-1,k-1} + a_{i-2,k-1} + \dots + a_{i-s,k-1}}{s} \quad (3.28)$$

Where  $\hat{a}_{i,k-1}$  = forecast for period  $i$

$a_{i,k-1}$  = actual values in periods  $i-1, i-2, \dots, i-s$

$s$  = the period considered i.e. 3, 5, 7, & 9 in this case

A Fortran - 77 Computer programme has been developed with the above formula to be used in UNIX - system.

Cumulative weekly rainfall data are the input to the programme.

### 3.6. Forecasting of Cumulative Weekly Rainfall by Exponentially Smoothing Technique

For the purpose of forecasting by exponentially smoothing method, the procedure adopted in this study is detailed below.

The equation for the exponentially smoothed forecast is written as

$$\hat{a}_{i,k-1} = \hat{a}_{i-1,k-1} + L (a_{i,k-1} - \hat{a}_{i-1,k-1}) \dots (3.29)$$

Where  $\hat{a}_{i,k-1}$  = exponentially smoothed forecast for the next period. This estimates is used to forecast the demand for the next period.

$\hat{a}_{i-1,k-1}$  = exponentially smoothed forecast established in the last period. This is the latest forecast.

$L$  = smoothing constant and  $0 \leq L \leq 1$

$a_{i,k-1}$  = actual value of the current period

The "apparent trend"  $g_{i,k-1}$  can be calculated by the following formula (Ramlingam 1976).

$$g_{i,k-1} = \hat{a}_{i,k-1} - \hat{a}_{i-1,k-1} \dots (3.30)$$

The "exponentially smoothed trend"  $G_{i,k-1}$  in period  $i$  is calculated by the formula

$$G_{i,k-1} = G_{i-1,k-1} + L (g_{i,k-1} - G_{i-1,k-1}) \dots (3.31)$$

Where  $G_{i,k-1}$  = exponentially smoothed trend in the period  $i$ .

$G_{i-1,k-1}$  = exponentially smoothed trend established in the last period.

$g_{i,k-1}$  = apparent trend in the period  $i$ .

The expected value of the current period 'i' is calculated by the formula

$$Ea_{i,k-1} = \hat{a}_{i,k-1} + \left(\frac{1-L}{L}\right) G_{i,k-1} \quad \dots \quad (3.32)$$

The forecast for (i+1) th period is calculated by the formula

$$\hat{a}_{i+1,k+1} = Ea_{i,k-1} + G_{i,k-1} \quad \dots \quad (3.33)$$

Using the above formulae for the forecast a Fortran 77 Computer programme has been developed for the UNIX-system for the present study. cumulative weekly rainfall data series are the input to the programme.

### 3.7. Forecasting of Onset of Effective Monsoon and Critical Dry Spells

In the present study the method adopted for the analysis is detailed below.

#### 3.7.1. Onset of Effective Monsoon

The following conditions of a 7 days spell must be satisfied to be defined as the date of onset of effective monsoon (AshokRaj, 1979).

(i) The first day's rain in the 7-days spell is not less than the average daily evaporation in millimeter.

$G_{i-1,k-1}$  = exponentially smoothed trend established in the last period.

$g_{i,k-1}$  = apparent trend in the period  $i$ .

The expected value of the current period 'i' is calculated by the formula

$$Ea_{i,k-1} = \hat{a}_{i,k-1} + \left(\frac{1-L}{L}\right) G_{i,k-1} \quad \dots \quad (3.32)$$

The forecast for (i+1) th period is calculated by the formula

$$\hat{a}_{i+1,k+1} = Ea_{i,k-1} + G_{i,k-1} \quad \dots \quad (3.33)$$

Using the above formulae for the forecast a Fortran 77 Computer programme has been developed for the UNIX-system for the present study. cumulative weekly rainfall data series are the input to the programme.

### 3.7. Forecasting of Onset of Effective Monsoon and Critical Dry Spells

In the present study the method adopted for the analysis is detailed below.

#### 3.7.1. Onset of Effective Monsoon

The following conditions of a 7 days spell must be satisfied to be defined as the date of onset of effective monsoon (AshokRaj, 1979).

(i) The first day's rain in the 7-days spell is not less than the average daily evaporation in millimeter.

(ii) If 'e' is the average daily evaporation then the total rain during the 7 days spell is not less than  $5e + 10$  mm.

(iii) At least 4 out of these 7 days are rainy days with minimum 2.5 mm rainfall as defined by Indian Meteorological Department.

### 3.7.2. Dry and Wet Spell and Critical Dry Spell

If the interval between the end of the 7 days spell, beginning with the onset of effective monsoon, and another rainy day with 5e mm rain or the commencement of another 7 days rainy spell with a total of 5e mm minimum rainfall then this spell can be defined as first dry spell. Depending upon the duration of this spell when the crop-soil complex relation changes it is called critical dry spell. Similarly the interval between the onset of effective monsoon and commencement of first critical dry spell is called the first wet spell. Subsequent dry and wet spells are defined accordingly.

### 3.7.3. Mean Date of Onset of Effective Monsoon

After indentifying the date of onset of effective monsoon  $X_i$  (  $i = 1, 2, 3, \dots, n$  ) in the  $i$ th year for a particular rain gauge station, the mean date  $m$  is calculated as follows.

$$m = \frac{\sum_{i=1}^n X_i}{n} \quad \dots (3.34)$$

Where 'n' is the number of years.

(ii) If 'e' is the average daily evaporation then the total rain during the 7 days spell is not less than  $5e + 10$  mm.

(iii) At least 4 out of these 7 days are rainy days with minimum 2.5 mm rainfall as defined by Indian Meteorological Department.

### 3.7.2. Dry and Wet Spell and Critical Dry Spell

If the interval between the end of the 7 days spell, beginning with the onset of effective monsoon, and another rainy day with 5e mm rain or the commencement of another 7 days rainy spell with a total of 5e mm minimum rainfall then this spell can be defined as first dry spell. Depending upon the duration of this spell when the crop-soil complex relation changes it is called critical dry spell. Similarly the interval between the onset of effective monsoon and commencement of first critical dry spell is called the first wet spell. Subsequent dry and wet spells are defined accordingly.

### 3.7.3. Mean Date of Onset of Effective Monsoon

After indentifying the date of onset of effective monsoon  $X_i$  (  $i = 1, 2, 3, \dots, n$  ) in the  $i$ th year for a particular rain gauge station, the mean date  $m$  is calculated as follows.

$$m = \frac{\sum_{i=1}^n X_i}{n} \quad \dots (3.24)$$

Where 'n' is the number of years.

#### 3.7.4. Standard Deviation(SD) of Onset of Effective Monsoon

The standard deviation of  $X$  ( $i = 1, 2, \dots, n$ ) dates of onset of effective monsoon is calculated as follows.

$$(SD) = \left[ \frac{\sum_{i=1}^n X_i^2 - \left( \frac{\sum_{i=1}^n X_i}{n} \right)^2}{n-1} \right]^{1/2} \dots (3.35)$$

#### 3.7.5. Median Date of Onset of Effective Monsoon

The median date is the middle value of the onset of effective monsoon when arranged in ascending or descending order for  $n$ -years and  $n$  is odd number of years. If  $n$  is even number of years then the median date is taken as the average date of the two middle dates.

#### 3.7.6. Quartile Deviation (Q)

The quartile deviation (Q) or the semi-interquartile range is defined as follows.

$$Q = \frac{Q_3 - Q_1}{2} \dots (3.36)$$

Where  $Q_1$  and  $Q_3$  are first and third quartiles and the median is the second quartile  $Q_2$ .

### 3.7.7. Earliest and Latest Probable Date of Onset of Effective Monsoon

If a variate  $x$  which takes the value  $X_1, X_2, \dots, X_n$  follows a normal distribution with mean 'm' and standard deviation (SD), then the probability density function of the variate is given by

$$p(x) = \frac{1}{(SD) \sqrt{2\pi}} \exp \frac{-(x-m)^2}{2 (SD)^2} \dots (3.37)$$

The probability that  $x$  lies between  $m-(SD)$  and  $m+(SD)$  is given by the relation

$$p(m-(SD) \leq X \leq m+(SD)) = \int_{m-(SD)}^{m+(SD)} p(x) dx \dots (3.38)$$

As  $x$  follows a normal distribution with mean 'm' and standard deviation (SD), the standardised normal variate

$$Z = \frac{x - m}{(SD)} \dots (3.39)$$

follows normal distribution with mean  $m$  and standard deviation 1. The probability that  $x$  lies between  $(m - (SD))$  and  $(m + (SD))$  is the same as that of 'Z' lying between -1 and 1 which is given by the relation

$$\begin{aligned}
 p(-1 \leq z \leq 1) &= \int_{-1}^1 \phi(z) dz \\
 &= 2 \int_0^1 \phi(z) dz \text{ because of symmetry} \\
 &= 2 \times 0.3413 \text{ ( from table )} \\
 &= 0.6826
 \end{aligned}$$

Thus if it is assumed that the dates of onset of effective monsoon  $X_i$  ( $i=1,2,3,\dots,n$ ), follow a normal distribution with mean 'm' and standard deviation (SD), then the least value,  $X_i$  can take with a probability of 0.68 is  $m - (SD)$  and the highest value is  $m + (SD)$  with the same probability. These values  $m - (SD)$  and  $m + (SD)$  are taken as the earliest and latest probable dates with a probability 0.68. Similarly as  $X_i$ , the dates of onset of effective monsoon, are assumed to be normal, the earliest probable date of onset of effective monsoon based on median is  $Q_2 - Q$  and the latest probable date is  $Q_2 + Q$  with probability 0.50. With this computer programme has been developed by Ashok Raj (1979) in Fortran-IV language. For the purpose of this study a modified Computer programme in Fortran-77 has been developed for UNIX - system. It has three sub-routines.

Rainfall data of 42 years have been collected on daily basis. For Bhubaneswar the average daily evaporation is calculated to be 4.98 mm/day (Senapati etal.

1985). The duration which makes the dryspell critical is considered 5 days under dryland situation in red lateritic soil. The 120 th day of each year is considered to be the approximate date in which rains likely to start. These data are fed to the computer for analysis.

### 3.8. Forecasting of Dry and Wet Spells

The procedure followed for the forecasting of dry and wet spells is discussed below.

The method applied in this study is based on first order Markov chain model ( Pandarinath, 1991).

Basing on experience it is considered that less than 20 mm. rainfall in a week as dry week and 20 mm. or more rainfall in a week as a wet week. The formula adopted for the calculation is as follows;

$$(i) P(d) = F(d)/n \quad \dots(3.40)$$

$$(ii) P(dd) = F(dd)/f(d) \quad \dots(3.41)$$

$$(iii) 2D = P(dw1) \times P(ddw2) \quad \dots (3.42)$$

$$(iv) 3D = P(dw1) \times p(ddw2) \times p(ddw3) \quad \dots(3.43)$$

$$(v) p(w) = F(w) /n \quad \dots(3.44)$$

Where  $p(d)$  = probability of the week being dry

$n$  = Number of years data used

$F(d)$  = Frequency of dry weeks

$P(dd)$  = Probability of the dry weeks preceded by another dry week ( conditional)

$F(dd)$  = Frequency of dry weeks preceded by another dry week

2D = Probability of two consecutive dry weeks

$P(dw1)$  = Probability of the week being dry ( 1st week)

$P(ddw2)$  = Probability of the 2nd consecutive dry week,  
given the preceding week being dry

3D = Probability of the three consecutive dry weeks

$P(ddw3)$  = Probability of the 3rd week being dry,  
given the preceding week being dry

$P(w)$  = Probability of the week being wet

$F(w)$  = Frequency of the wet week

$P(ww)$ , 2W and 3W are calculated in the same way as the  $P(dd)$ , 2D and 3D and the notations used are having the same meaning except the weeks being wet.

The daily rainfall data have been fed to the computer and through a simple Fortran - 77 Computer programme the daily data are converted to weekly data. To make the process easy the wet and dry weeks are first marked by '+' and '-' signs respectively. Counting the '+' and '-' signs separately gives the frequency of the wet weeks  $F(w)$  and frequency of the dry weeks  $F(d)$  respectively. Similarly '+' preceded by '+' and '-' preceded by '-' are counted to get the frequency of wet weeks preceded by wet weeks  $F(ww)$  and frequency of dry weeks preceded by dry weeks  $F(dd)$ .

Using the above formula, probabilities of dry weeks and wet weeks, conditional probabilities of the dry weeks and wet weeks preceded by <sup>dry weeks and</sup> wet weeks

and probability of consecutive 2 and 3 dry or wet weeks starting with the week dry or wet have been calculated.

### 3.9 Forecasting of Commencement of Sowing Rain

The procedure adopted for the forecasting of commencement of sowing rain is detailed below.

For this study we need to calculate the forward and backward accumulation of the weekly rainfall. To make the calculation easy the following method is taken into account.

The daily rainfall data for 42 years are fed to the computer. Through a simple Fortran - 77 Computer programme the daily data are converted to weekly data. The weekly rainfalls are arranged in columns and the years arranged in rows. The weekly rainfalls are added from 1st week onward i.e. ( 1st week + 2nd week + ....) to find the corresponding week number in which the cumulative rainfall has reached a sum total of 75 mm and 200 mm. Similarly the weekly rainfall of 52nd week is added backwardly i.e. ( 52nd week + 51st week + ...) to get 100 mm , 300mm and 500mm total and the corresponding week numbers are noted. Then the years are arranged with rank number i.e. 1950 to 1991 as 1 to 42. The probability of each rank is calculated by the following simple statistical formula.

$$P = ( 1/m + 1 ) \times 100 \quad \dots (3.45)$$

Where m is the year number

For forward accumulation the rank order and the probability level are arranged in ascending order and the corresponding week numbers are arranged in the same manner. Similarly for backward accumulation rank order and the probability level are arranged in descending order and the corresponding week numbers for 500 mm , 300 mm and 100 mm respectively are arranged in descending order. The corresponding probability level and the week number at which 75 mm , 200 mm for forward accumulation and 500 mm, 300 mm, and 100 mm for backward accumulation will occur at certain probability level can be judged.

### 3.10 Estimation of Reference Crop Evapotranspiration ( ETo)

The water requirement of different crops on weekly basis is determined by using modified Blaney - Criddle method, modified Radiation method and modified Penman method as proposed by Doorenbos and Pruitt ( 1977).

#### 3.10.1. Modified Blaney - Criddle Method

The recommended relationship is given as

$$ETo = c [ p (0.46 T + 8) ] \quad \dots(3.46)$$

Where ETo = reference crop evapotranspiration in mm/day for the month considered

T = Mean daily temperature in  $^{\circ}$ C over the month considered

P = Mean daily percentage of total annual day time hours

and C = Adjustment factor which depends on minimum relative humidity, sunshine hours and day time wind estimates. Value of C considered by Allen et al. (1991) is given as

$$c = 0.908 - .00483 RH_{\min} + 0.7949 n/N + 0.0768 [ \ln(Ud + 1) ] - 0.0038 RH_{\min} n/N - 0.000433 RH_{\min} Ud + 0.281 \ln(Ud + 1) \ln(n/N + 1) - .00975 [ \ln(RH_{\min} + 1) ] \ln(Ud + 1) \ln(n/N + 1) \dots(3.47)$$

Where  $RH_{\min}$  = Mean daily minimum relative humidity over the month considered

n = Mean daily sunshine hour over the month considered

N = Daily duration of maximum possible sunshine hours

Ud = Mean daily day time wind velocity over the month considered in m/sec

### 3.10.2. Modified Radiation Method

The relationship recommended is expressed as

$$ET_0 = c[W Rs] \dots(3.48)$$

$$Rs = ( 0.25 + 0.50 n/N ) Ra \dots(3.49)$$

Where  $ET_0$  = Reference crop evapotranspiration in mm/day

W = Temperature and altitude related weighting factor

Rs = Solar radiation in equivalent evaporation in mm/day

P = Mean daily percentage of total annual day time hours

and C = Adjustment factor which depends on minimum relative humidity, sunshine hours and day time wind estimates. Value of C considered by Allen et al; (1991) is given as

$$c = 0.908 - .00483 RH + 0.7949 n/N + 0.0768 [ \ln(Ud + 1) ] - 0.0038 RH \quad n/N - 0.000433 RH \quad ud + 0.281 \ln(Ud + 1) \ln (n/N + 1 ) - .00975 [ \ln( RH_{\min} + 1) ] \ln(Ud + 1) \ln( n/N + 1) ] \dots(3.47)$$

Where  $RH_{\min}$  = Mean daily minimum relative humidity over the month considered

n = Mean daily sunshine hour over the month considered

N = Daily duration of maximum possible sunshine hours

Ud = Mean daily day time wind velocity over the month considered in m/sec

### 3.10.2. Modified Radiation Method

The relationship recommended is expressed as

$$ET_0 = c[W Rs] \dots(3.48)$$

$$Rs = ( 0.25 + 0.50 n/N) Ra \dots(3.49)$$

Where  $ET_0$  = Reference crop evapotranspiration in mm/day

W = Temperature and altitude related weighting factor

Rs = Solar radiation in equivalent evaporation in mm/day

N = Mean daily sunshine hour over the month considered  
 Ra = Extra terrestrial radiation expressed in equivalent evaporation in mm/day and depends on latitude

C = Adjustment factor which depends on mean humidity and day time wind conditions and is given as follows (Allen et al. 1991)

$$C = 1.066 - 0.00128 RH_{mean} + 0.045 U_d - 0.0002 RH_{mean} U_d - 0.0000315 (RH_{mean})^2 - 0.001133 (U_d)^2 \dots\dots(3.50)$$

Where  $RH_{mean}$  = average daily relative humidity over the month considered

$U_d$  = Mean daily day time wind velocity over the month considered in m/sec

### 3.10.3. Modified Penman Method

The form of the equation used in this method to calculate reference crop evapotranspiration is

$$ET_o = c [ w.R_n + (1-w) f(u) (e_a - e_d) ] \dots(3.51)$$

$$f(u) = 0.27 \left( 1 + \frac{u}{100} \right) \dots\dots(3.52)$$

$$e_d = e_a \times RH_{mean} \dots(3.53)$$

$$R_n = R_{ns} - R_{nl} \dots(3.54)$$

$$R_{ns} = (1 - L) R_s \dots(3.55)$$

$$Rn_l = F(T) \cdot F(ed) \cdot F(n/N) \quad \dots(3.56)$$

$$f(T) = (T_k) \quad \dots(3.57)$$

$$f(ed) = 0.34 - 0.44 \sqrt{ed} \quad \dots(3.58)$$

$$F(n/N) = 0.1 + 0.9 n/N \quad \dots(3.59)$$

Where  $E_{To}$  = reference crop evapotranspiration in mm/day

$W$  = temperature and altitude related weighting factor

$R_n$  = net radiation in equivalent evaporation in mm/day

$f(u)$  = wind - related function

$u$  = 24 hours wind velocity in km/day at 2m height, an appropriate correction factor 0.93 has been multiplied as the velocity measured is at 3m height.

$e_d$  = mean actual water vapour pressure in mbav

$e_a$  = mean saturation water vapour pressure in mbav

$RH_{\text{mean}}$  = average daily relative humidity over the month

considered

$R_n$  = net radiation

$R_{ns}$  = net shortwave radiation

$L$  = correction factor for reflectiveness of the crops, generally for most crops  $L = 0.25$

$R_s$  = net solar radiation in equivalent evaporation in mm/day

$R_{nl}$  = net longwave radiation

$F(t)$  = function related to effect of temperature on longwave radiation

-9

$\sigma$  = Boltzmen's constant =  $2.01 \times 10$

T = temperature in degree Kelvin

f(ed) = function related to effect of vapour pressure on longwave radiation

f(n/N) = function related to effect of the ratio of actual and maximum bright sunshine hours on longwave radiation

n = mean daily sunshine hour over the month considered

N = daily duration of maximum possible sunshine hours

(ea - ed) = difference between the saturation vapour pressure at mean air temperature and the mean actual

vapour pressure of the air, both in m bar

c = adjustment factor to compensate for the effect of day and night weather condition and is given by Allen et al. (1991) as given below

$$C = 0.892 - 0.0781 U_d + 0.00219 U_d R_s + 0.000402 R_{H_{max}} R_s + 0.000196 (U_d/U_n) U_d R_{H_{max}} + 0.0000198 (U_d/U_n) U_d R_{H_{max}} R_s + 0.00000236 (U_d)^2 R_{H_{max}} R_s - 0.0000086$$

$$(U_d/U_n)^2 U_d R_{H_{max}} - 0.0000000292 (U_d/U_n) (U_d)^2 (R_{H_{max}})^2 R_s - 0.0000161 R_{H_{max}} (R_s)^2 \dots (3.60)$$

Where  $U_d$  = Mean daily day time wind velocity over the month considered in m/sec

$R_{H_{max}}$  = Mean daily maximum relative humidity over the month considered in per cent

(Ud/Un) = Ratio of the day time wind velocity to night

(Ud/Un) = Ratio of the day time wind velocity to night

time wind velocity. In absence of night time wind velocity ( $U_d/U_n$ ) is considered as 2.

A Fortran 77 Computer programme has been developed for UNIX - system to compute the reference crop evapotranspiration for all the above three methods. The daily maximum and minimum relative humidity, maximum and minimum temperature, sunshine hour, day time wind velocity for 32 years from 1960 to 1991 are fed to the computer for the above analysis.

### 3.11. Crop Evapotranspiration

The three methods described under the article 3.10 predict the effect of climate on reference crop evapotranspiration ( $E_{To}$ ). To account for the effect of the crop characteristics on crop water requirements, crop coefficients need to be estimated.

Crop coefficient for different crops are estimated using the procedure given by Doorenbos and Pruitt (1977).

Water requirement of the crops for which the crop coefficients are developed, are calculated using the equation given below.

$$ET_{\text{crop}} = K_c \cdot E_{To} \quad \dots(3.61)$$

Where  $ET_{crop}$  = crop evapotranspiration or water  
 requirement of crop, mm/day

$K$  = crop coefficient

$ET_0$  = reference crop evapotranspiration, mm/day

### 3.12 Forecasting of Crop Yield Based on Growing Degree Days

For the purpose of forecasting the yield depending on the growing degree days, the procedure adopted is detailed below.

The growing degree days are calculated by the following formula as suggested by Ratnam and Kavi (1990)

$$\text{Growing degree days (GDD)} = E \cdot \left[ \frac{T_{\max} + T_{\min}}{2} \right] - 10^{\circ} \quad \dots (3.62)$$

Where  $T_{\max}$  = daily maximum temperature in deg. C.

and  $T_{\min}$  = daily minimum temperature in deg. C.

The temperature of ten degree is considered as the base temperature, which is subtracted from the average temperature below which the plant will not develop.

A Fortran 77 Computer programme is developed with the above formula for the UNIX - system. Daily maximum and minimum temperatures are fed to the computer for 16 years from 1976 to 1991 to calculate the growing degree days for the periods given below. These periods relate to different growth phase of the crops such as arhar, groundnut, maize and upland paddy. The durations are given in Table 3.1

Table 3.1 Duration of different growth phase of crops under consideration.

Crops	Initial stage	Crop development stage	Mid season stage	Late season stage
Arhar	25th July - 18th August	19th August - 22nd September	23rd Sept.- 21st Nov.	22nd Nov.- 30th Dec.
Groundnut	10th July- 3rd August	4th August - 2nd September	3rd Sept.- 2nd October	3rd Oct.- 17th Oct.
Maize	10th July - 29th July	30th July - 28th Aug.	29th Aug.- 2nd Oct.	3rd. Oct.- 27th Oct.
Upland paddy	1st July - 20th July	21st July - 19th August	20th Aug.- 8th Sept.	19th Sept.- 8th Oct.

The yield data of the above crops are correlated with the growing degree days of different duration to obtain the simple linear regression relationship. The following regression models are fitted to find the correlation coefficients. The models are as follows ;

$$Y = a + bx \quad \dots(3.63)$$

$$Y = a + b \ln x \quad \dots( 3.64)$$

$$Y = ae^{bx} \quad \dots(3.65)$$

$$Y = ax^b \quad \dots(3.66)$$

Where Y is yield of the crops in quintals per hectare, a and b are constants and X is the growing degree days.

### 3.13. Crop-Weather Model

For the purpose of developing a crop weather model considering the weather parameters like rainfall, average temperature, average relative humidity, sunshine hour and wind velocity the procedure adopted is detailed below.

The method suggested by Shankar and Gupta ( 1987) is adopted for this study.

The daily data of the above meteorological parameters are fed to the computer for 16 years from 1976 to 1991. The sum total of the above parameters for different growth phase have been computed for the crops such as arhar, groundnut, maize, and upland paddy. The duration of different growth phase are given in Table 3.1.

For this study the yield data of the above crops are correlated with the rainfall, average temperature, average relative humidity, sunshine hours and wind velocity for each growth phase. Period which gives the highest correlation for a particular weather parameter is called as "sensitive period". The data pertaining to these sensitive periods are taken into consideration for multiple regression analysis. The multiple regression equation used is of the form

$$Y = a + b_1 x_1 + b_2 x_2 + b_3 x_3 + \dots + b_k x_k \dots (3.68)$$

$a, b_1, b_2, \dots, b_k$  are constants  $x_1, x_2, \dots, x_k$  are

weather parameters during different growth phase of the crop under consideration and  $Y$  is the yield of the crop under consideration.

The following assumptions are made for adopting this method.

(i) High level farm technology on different crops are used.

(ii) The crop yield in quintals per hectare is used as dependent variable and weather parameters as independent variables.

(iii) The crop yield is assumed to be directly related to the weather elements.

(iv) It is also assumed that the effect of weather elements <sup>on</sup> yield in each period is independent of the effect of weather elements in other time period.

## CHAPTER IV

### RESULTS AND DISCUSSION

This chapter is devoted to presentation and discussion of results obtained from various analysis of meteorological data and specific models employed in this study. Discussions on meteorological data analysis, forecasting of models, water requirement of crops and crop-weather models have been presented in this chapter.

#### Persistence Test and Serial Correlation Coefficient

With a view to studying the statistical properties of all the time series  $r^{(j)}$  with  $j=1,2,\dots,52$  individually, some statistical parameters like the mean  $\mu$  as a measure of central tendency, the variance  $(SD)^2$ , the standard deviation  $(SD)$ , coefficient of variation  $C_v$  as dispersion parameters, the coefficient of skewness  $C_s$  as descriptor of asymmetry and the coefficient of Kurtosis  $C_k$  as a descriptor of flatness have been estimated. The above parameters have also been calculated for the modular coefficients, square root and cube root transforms of original weekly rainfall data series. The values of  $\mu$ ,  $\lambda$ ,  $C_v$ ,  $C_s$ , and  $C_k$  for original data and its modular data, square root and cube root data for 1st to 52nd week are given in Appendix A.

The above statistical characteristics have also been evaluated for all twenty six fortnightly and twelve monthly rainfall time series of original, modular, square root and cube root data. The values of  $\mu$ ,  $\lambda$ ,  $C_v$ ,  $C_s$ , and  $C_k$  are given for 1st to 26th fortnight and 1st to 12th month in Table A-2 and A-3 respectively.

It is observed that in all the 52 weeks the coefficients of dispersion, coefficients of skewness and coefficients of kurtosis are the same for original and modular data series. The degree of dispersion is high from 1st to 24th week for the original data series and modular data series. For square root data series it is high upto 21st week. The cube root data series have low dispersion in all the 52 weeks. The original, modular and square root data series again show a high degree of dispersion from 45th week to 52nd week. But the 40th week and 42nd week also have a high coefficient of dispersion for original & modular data series. This signifies that the fluctuation in the actual rainfall values are more in these two weeks. However, the statistical parameter values of transformed data indicate that the dispersion and skewness tendency of the actual data have been nullified to a large degree.

The values of coefficient of variation and coefficients of skewness showed positive skewness for original and modular data series of weekly period. But

the square root data series of 30th, 32nd, 33rd, 39th, 41st and 43rd weeks and the cube root data series of 25th, 28th, 29th, 34th, 35th, and 42nd weeks show a negative skewness. The fortnightly & monthly data series for original and modular data show a positive skewness except the 17th fortnight. The 14th, 15th, 17th, 20th, 21st fortnights and 7th, 8th and 9th months for square root and cube root data series show a negative skewness.

The serial correlation coefficients for the original data, transformed modular, square root and cube root data series for the 1st, 5th, 10th, 15th, 20th, 25th, 30th, 35th, 40th, 45th, 50th and 52nd weeks have been given in Table A-4 .

It is observed that in the original and modular data series all the weeks have lag one serial correlation coefficient well within the tolerance limits  $\pm 2/\sqrt{N}$  where  $N=42$  years i.e.  $\pm 0.3086$  except the 2nd, 7th, 11th, 14th, 16th, 26th and 40th weeks. However, the whole series can be considered as a random series. It is important to note that the original and transformed modular coefficients time series have yielded identical values of serial correlation coefficients. The test of significance on the lag one serial correlation coefficients, as detailed above, have also been performed on transformed weekly rainfall series. All the series have been found to be random in nature.

The fortnightly and monthly rainfall time series and their transformed time series, as discussed above, have also been tested for randomness individually and are found to be serially independent except 8th, 11th, 15th, 20th, 25th and 26th fortnightly and 1st monthly original and modular coefficient data series. Similarly the transformed square root and cube root data series are found to be random except 11th, 15th, 20th, 22nd and 26th fortnightly and 3rd and 4th monthly data series. The serial correlation coefficients of 1st, 5th, 10th, 15th, 20th, 25th, and 26th fortnightly and 1st, 5th, and 10th and 12th monthly original rainfall series along with transformed data series are presented in Table A-5 and A-6 respectively.

2

### Probability Distribution Function

Weekly rainfall data series  $\{ r^{(j)} \}$ ,  $j=1,2,3,\dots, 52$  for all 52 weeks for 42 year period from 1950 to 1991 have been considered individually to find out the best suitable probability distribution among the normal, lognormal-2 and the log normal-3 distributions to suit the data series. The analysis has been carried out on original data, modular coefficient data, square root data and cube root data separately by adopting the procedure detailed in chapter -III.

The values of the maximum likelihood estimate of lower boundary parameter of the lognormal-3 distribution  $\hat{X}_0$  are calculated to be either zero or marginally negative. From the physical point of view however, precipitation can never be negative, while from the mathematical point of view lognormal-3 distribution is defined only for positive range of an independent variable. Therefore all the negative values of  $X_0$  for different weekly series, have been treated as equal to zero. The chi-square values, considered as a measure of goodness of fit in this study for all the three probability density functions for original and transformed weekly rainfall data are given in Table A-7 for 1st, 5th, 10th, 15th, 20th, 25th, 30th, 35th, 40th, 45th, 50th and 52nd weeks.

A similar procedure has been followed in calculating the parameters of normal probability, lognormal-2 and lognormal-3 distributions along with chi-square values considering fortnightly and monthly data series respectively. The same has also been calculated for transformed data series. The values of chi-square for 1st, 5th, 10th, 15th, 20th, 25th and 26th fortnights are presented in Table A-8. The same for 1st, 5th, 10th and 12th month are presented in Table A-9.

The chi-square values of the table A-7, A-8 and A-9 which are significant at 95% level of significance

are marked by asterisks. The table value of 95% significance is 58.16.

It is evident from the Table A-7 , A-8 and A-9 that power transformations of the actual data have yielded promising results. The normal distribution and lognormal distribution with two parameters have in no case indicated better applicability . Lognormal-3 distribution with square root or cube root transformed data can be fitted well to the sampled precipitation data . This may be due to the values of coefficient of skewness and coefficient of variation reduced significantly which may be seen from statistical parameters (Table A 1). Therefore the lognormal-3 density function for square root and cube root transformed values of actual data is accepted to find out the probable weekly rainfall at a 95 per cent level of significance .

In the case of fortnight and monthly data series lognormal-3 distribution for square root and cube root transformed values of actual data yield the best probability function.

In the analysis of all the data series i.e. weekly rainfall, the chi-sqaure values for actual data and its modular coefficient transformation worked out to be the same for all the three distributions.

## Forecasting of Weekly Cumulative Rainfall by Moving Average Method

All the rainfall time series,  $r^{(j)}$  with  $j=1,2,3,4,\dots,52$  weeks have been analysed individually by the moving average method considering 3,5,7 and 9 year-periods according to the procedure described in the previous chapter.

A sample calculation of forecasting of weekly cumulative rainfall for the year 1966 by using 3,5,7 and 9 years moving average method over all the 52 weeks is given in Table A-10.

It is evident from Table A-10 that 3 year moving average yields a forecasted value of 1501.42 mm against an actual rainfall of 1418.90 mm which is very high and hence cannot be accepted. The 5 year moving average method yields a forecasted value of 1405.70 mm against the actual value of 1418.90mm, which is little less and is negligible. The 7 year and 9 year moving average methods predicted the weekly cumulative rainfall of 1382.55 mm and 1352.51 mm respectively which are much lower than the actual. Hence it is clear that the 5 year moving average method prediction is much more closure value than other methods.

The total cumulative rainfall over all the years i.e. 1953-91 are presented in Table A-11. It is evident from Table A-11 that there are over estimation and under estimation of rainfall in certain years. It is clear that all the methods predict the values either high or low. But in case of 5 year moving average it is seen that the difference is much less in comparison to other methods.

Considering the case of the year 1991 it is seen that <sup>the</sup> predicted values are 1570.73 mm, 1555.44 mm, 1575.87 mm and 1594.00 mm by using 3, 5, 7 and 9 year -moving average methods respectively against the actual rainfall of 1411.70 mm. Hence it is clear that 5 year moving average yields the best result.

The cumulative weekly rainfall forecasted for the years 1992 by 3, 5, 7 and 9 year-moving average is presented in Table A-12. the predicted values at the end of the year is 1576.07 mm, 1449.56 mm, 1559.50 mm and 1577.64mm.

### **Forecasting of Weekly Cumulative Rainfall by Exponential Smoothing Method**

All the rainfall time series,  $r^{(j)}$  with  $j=1,2,3,\dots,52$  weeks have been analysed individually by the exponential smoothing technique according to the procedure described in the Chapter-III.

The forecasting of weekly cumulative rainfall values over all the 52 weeks for the year 1966 by using exponential smoothing technique is presented in Table A-13.

By carefully studying Table A-13 , it is clear that the cumulative weekly rainfall for the whole year is forecasted as 1437.89 mm which is slightly higher than the actual rainfall 1418.90 mm. Hence it is clear that the forecasting value is very close to the actual value .

The predicted and actual annual rainfall for the period from 1952 to 1991 is presented in Table A-14 . It is evident that in ceratin years the predicted value is higher or lower than the observed rainfall. But the difference is not too high . Hence this method is acceptable for forecsting of annual rainfall . But in the year 1957 there is a large difference between the predicted and observed values to the tune of 1186 mm perhaps due to the change of factors affecting the rainfall.

The cumulative weekly rainfall forecasted for the year 1992 is presented in Table A-15. The forecasted values at the end of the year is 1463.93 mm. The predicted value of the rainfall by 5 year-moving average method is 1449.56mm which is close to the value predicted

by exponential smoothing techniques . Hence , it is concluded that both the methods can be adopted for prediction of yearly rainfall.

## 5 Forecasting of Onset of Effective Monsoon and Critical Dry Spells.

The daily rainfall data of 42 years are processed through the computer programme with the method described in the Chapter -III.

The results of the analysis are presented in Appendix B (Table B-1 to B-4). Table B-1 gives the dates of onset of effective monsoon (OEM) in individual years, the dates of withdrawal of monsoon, the dates and duration of the first three critical dry spells (CDS) .Table B-2 gives the information regarding earliest probable date of onset of effective monsoon, the latest probable date of onset of effective monsoon at 68% and 50% probability , mean and median dates of OEM, the average date on which the effective monsoon ends , average number of critical dry spells , average date on which the first CDS starts and average rainfall during the wet spells for the year 1992 . Table B-3 gives the weekly observed maximum, minimum, normal rainfall and the probability of the weekly normal rainfall. Table B-4 gives the monthly rainfall and number of rainy days for the year 1992.

It is observed from Table B-2 that the earliest date of onset of effective monsoon at 68% probability is 31st May 1992 and the same at 50% probability is 8th June 1992. Similarly the latest date of onset of effective monsoon at 68% probability is 4th July 1992 and the same at 50% is 25th June 1992. The mean date of onset of effective monsoon is forecasted on 17th June 1992, which happens to be the exact date on which the effective monsoon broke in Bhubaneswar. The average predicted date on which the effective monsoon will end is 29th October 1992. It is also forecasted that the average number of critical dry spells over the year 1992 is 3. The average dates and durations of the critical dry spells during 1992 are 7th July for 11 days, 7th August for 9 days and 2nd September for 11 days respectively. The first dry spell of 11 days coincides with the actual observed dry period starting from 7th July '92. It is forecasted that the 1st wet spell continues from 17th June to 6th July amounting to a total rainfall of 317.07 mm. The duration of 2nd, 3rd, and 4th wet spells are 20th July to 6th August, 18th August to 26th August and 14th September to 25th September respectively. In these wet spells the rainfall of 264.28 mm, 211.89 mm and 143.41 mm are expected to occur.

From the Table B-3 it is seen that heighest weekly observed maximum rainfall of 340.3 mm occurs in the 25th week. The weekly normal rainfall till 21st week and from 45th to 52nd weeks is negligible and quite insufficient for crop production. The heighest weekly normal rainfall of 87.9 mm is observed during the 31st and 32nd week and the probability that in any particular year the weekly rainfall equals or exceeds this rainfall of 87.9 mm in 31st and 32nd week is about 48 per cent.

Table B-4 indicates that the annual rainfall forecasted for 1992 is 1491.87mm and the total number of rainy days are 79.2 or 79 days.

The above information are valuable for all the activities particularly to crop planning. The forecasting of the onset of effective monsoon on 8th June will help the farmers to go for their seed bed preparation and other primary tillage operations. The prediction of average date on which the effective monsoon ends i.e. 29th October 1992 will enable the farmers to select the variety relating to its duration and they will also know the date for the harvest of their crop. Depending on these information the farmers will make their crop planning. The irrigation scheduling can be prepared depending on the length of critical dry spells

with maximum water use efficiency. The predicted rainfall during the months of the year (Table B-4) will be beneficial to the farmers to choose their crops depending upon the water requirement during different cropping seasons. The crop management with effective water use efficiency will definitely increase the crop-production.

## 6 Forecasting of Dry and Wet Spells

Weekly rainfall data are analysed for the forecasting of dry and wet spells as per the method described in the Chapter- III. The result of the analysis is illustrated in Appendix- C.

It is clear from the result as given in Table C-1 that , the probability of occurrence of a dry week is high i.e. 52% to 100% in the first 24 weeks of the year. But it falls in subsequent weeks and maintain an average of 25% upto 43rd week of the year . Again it increases rapidly from the 44th week to 52nd week of the year. i.e. 71% to 100% . The conditional probability of dry week preceded by a dry week is also high upto 24th week but the probability of occurrence of two consecutive dry week is high upto 21st week. The probability of occurrence of three consecutive dry week is high only upto 18th week of the year. These probabilities of occurrence also increase remarkably from 44th week to 52nd week.

Similarly the probability of occurrence of wet week is very less upto 22nd week. It starts increasing gradually upto 33rd week i.e. 43% to 93% and then starts decreasing gradually till 43rd week i.e. 93% to 52%. From 44th week of the year it reduces even to the level of 0%. The conditional probability of occurrence of wet week preceded by wet week is moderate in the first two weeks of the year i.e. 33%, but it increases substantially from 24th week to 33rd week <sup>and</sup> then decreases gradually. The probability of occurrence of two consecutive wet weeks is significant in 25th week i.e. 45% and increases upto 77% by 32nd week of the year. It starts decreasing suddenly from 40th week. The probability of three consecutive wet weeks is very poor till 26th week of the year. Its maximum probability of occurrence is 71% at 31st week. Thereafter it decreases to a level of 6% by 43rd week of the year.

### **Forecasting of Commencement of Sowing Rain**

Weekly rainfall data are analysed for the forecasting of commencement of sowing rain as per the method described in the Chapter-III and the result is illustrated in Table C-2.

As described the forecasting of sowing rain is calculated by making forward and backward accumulation of rainfall. Table C-2 illustrates the results of the

analysis. From the result it is evident that at 75% probability at least 75mm rainfall can be expected at 22nd week and 200mm at 26th week of the year, taking forward accumulation into account. Similarly at least 500 mm rainfall can be expected at 34th week, 300 mm at 37th week and 100 mm at 40th week respectively taking backward accumulation of rain water into account. These are illustrated in form of graphs in Figure 4.1.

It is clear from the graph that at 75% probability level it takes four weeks to accumulate from 75mm to 200mm. On the other hand it takes only three weeks at the end of the rainy season to drop from an expected 300mm to 100mm. From 22nd week to 36th week of the year the rainfall is adequate to take rice crop. But the probability curve of two consecutive dry weeks having less than 20 mm rainfall shows there is 40% chance of occurring dry weeks at the 22nd week.

If a farmer starts his sowing in 22nd week, he may take a risk to a level of 40 percent. But if he starts planting in 25th week he can have a chance of failure of only 7.5%. Therefore it is suggested that a farmer can start his farming activities in 25th week instead of 22nd week to avoid crop failure.

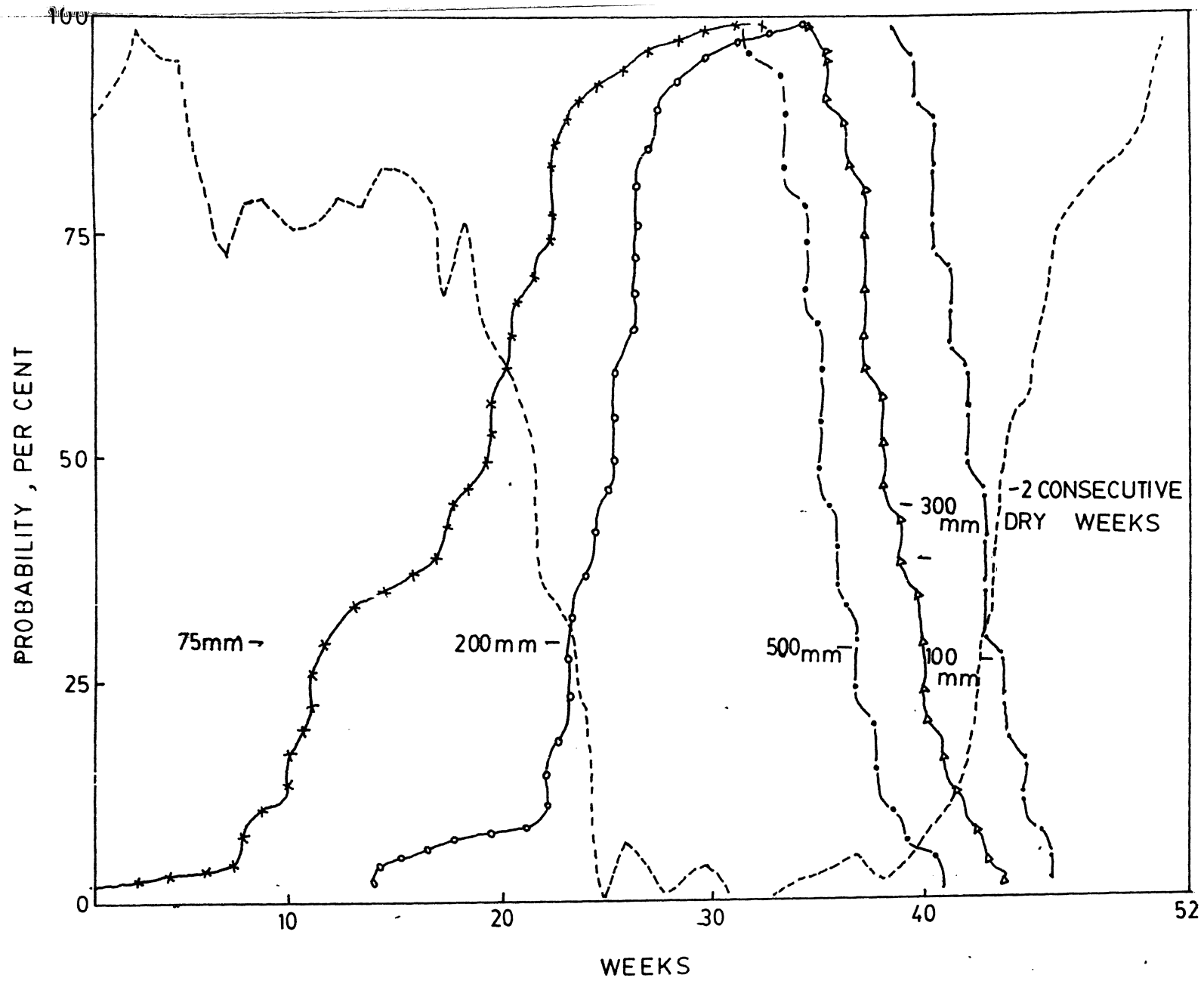


Fig. 4.1 Cumulative probability of having 75mm , 100mm , 200mm , 300mm , 500mm rainfall and probability of having 2 consecutive dry weeks

### Estimation of Crop Evapotranspiration

Reference crop evapotranspiration,  $ET_0$  is estimated using the computer programme developed on the equations described in the Chapter -III. The weekly values of reference crop evaporation<sup>calculated</sup> for the period from 1960 to 1991 using the methods such as modified Blaney-Criddle method, modified Radiation method and modified Penman method are given in Appendix D (Table D-1, D-2, D-3).

Comparing the values of reference crop evapotranspiration obtained by using the above three methods it is seen that the modified Penman method gives the lower values as compared to other two methods.

Under dryland situations, the water requirement of crops is limited to the soil moisture availability, thus modified Penman method has been considered to estimate the water requirement of crops such as arhar, groundnut, maize and upland paddy. The weekly values of reference crop evapotranspiration based on modified Penman method is given in Table D-4.

The values of crop coefficient are affected mainly by the crop characteristics, crop planting or sowing date, rate of crop development, length of growing season and climatic conditions. Thus crop coefficient curves for arhar, groundnut and maize are developed as per the guidelines given by Doorenhos and

Pruitt (1977) and are presented in Fig 4.2 , 4.3 , 4.4.

The crop evapotranspiration has been calculated using the equation 3.61. The weekly values of crop evapotranspiration for arhar, groundnut, maize and upland paddy are shown in Table D-5 , D-6 , D-7 and D-8 . It is evident from these tables that the consumptive use of water for arhar, groundnut, maize and upland paddy are 572.50 mm , 296.93 mm , 372.95 mm and 485.16 mm respectively.

#### **Forecasting of Crop Yields based on Growing Degree Days**

The growing degree days are calculated for different growth phase for crops such as arhar, groundnut, maize and upland paddy using the equation 3.62.

The yeild of different crops as mentioned above for 16 years from 1976 to 1991 along with the calculated growing degree days for diffrent growth phases such as initial stage , crop development stage, mid season stage and late season stage are presented in Appendix E in Table E-1 , E-2 , E-3 & E-4.

To obtain a simple linear regression relationship in respect of yield and accumulated growing degree days for a particular growth phase, the diffrent models described in equation 3.63 to 3.66 are fitted . The

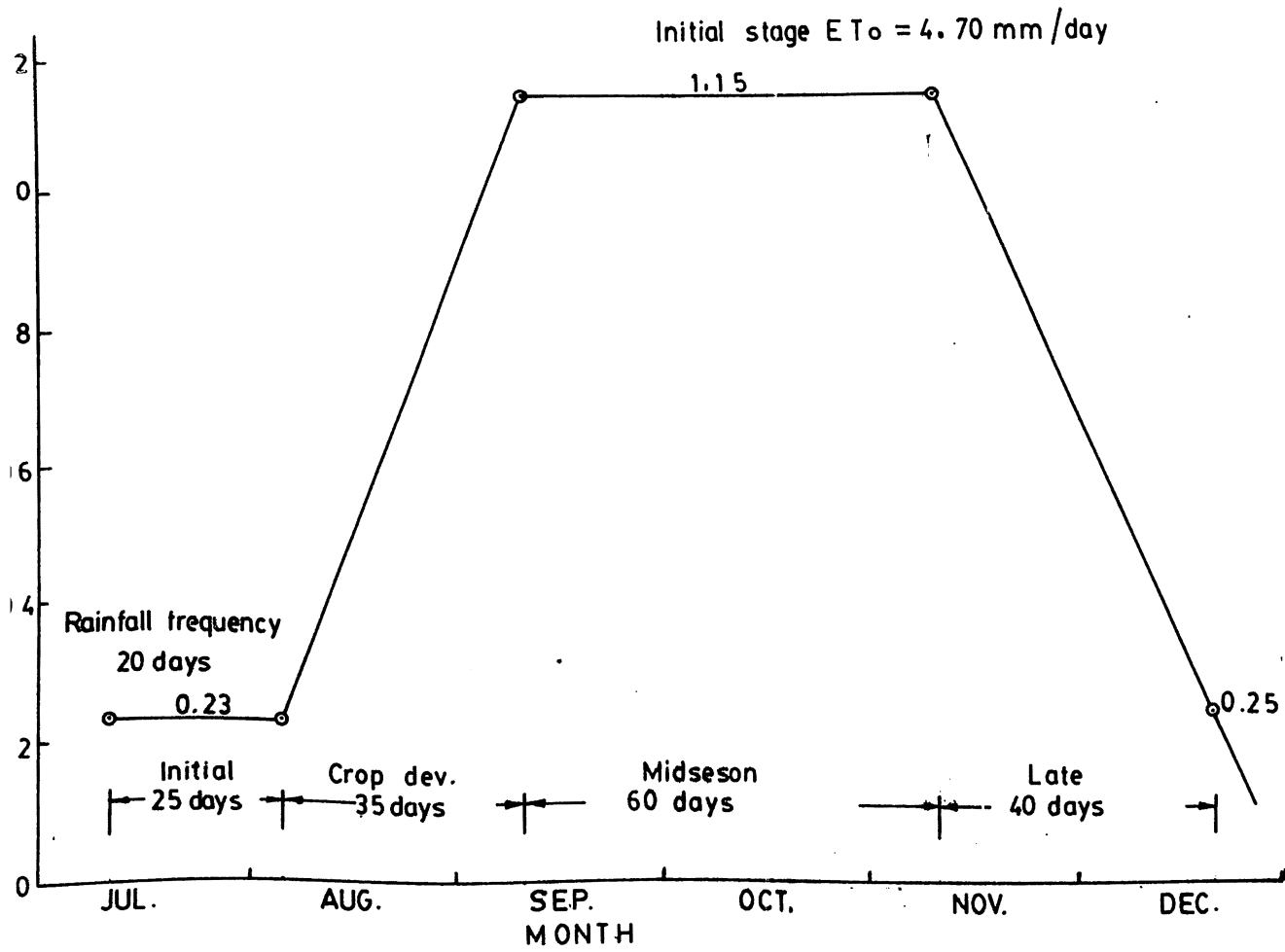


Fig. 4.2 Crop coefficient curve for Arhar

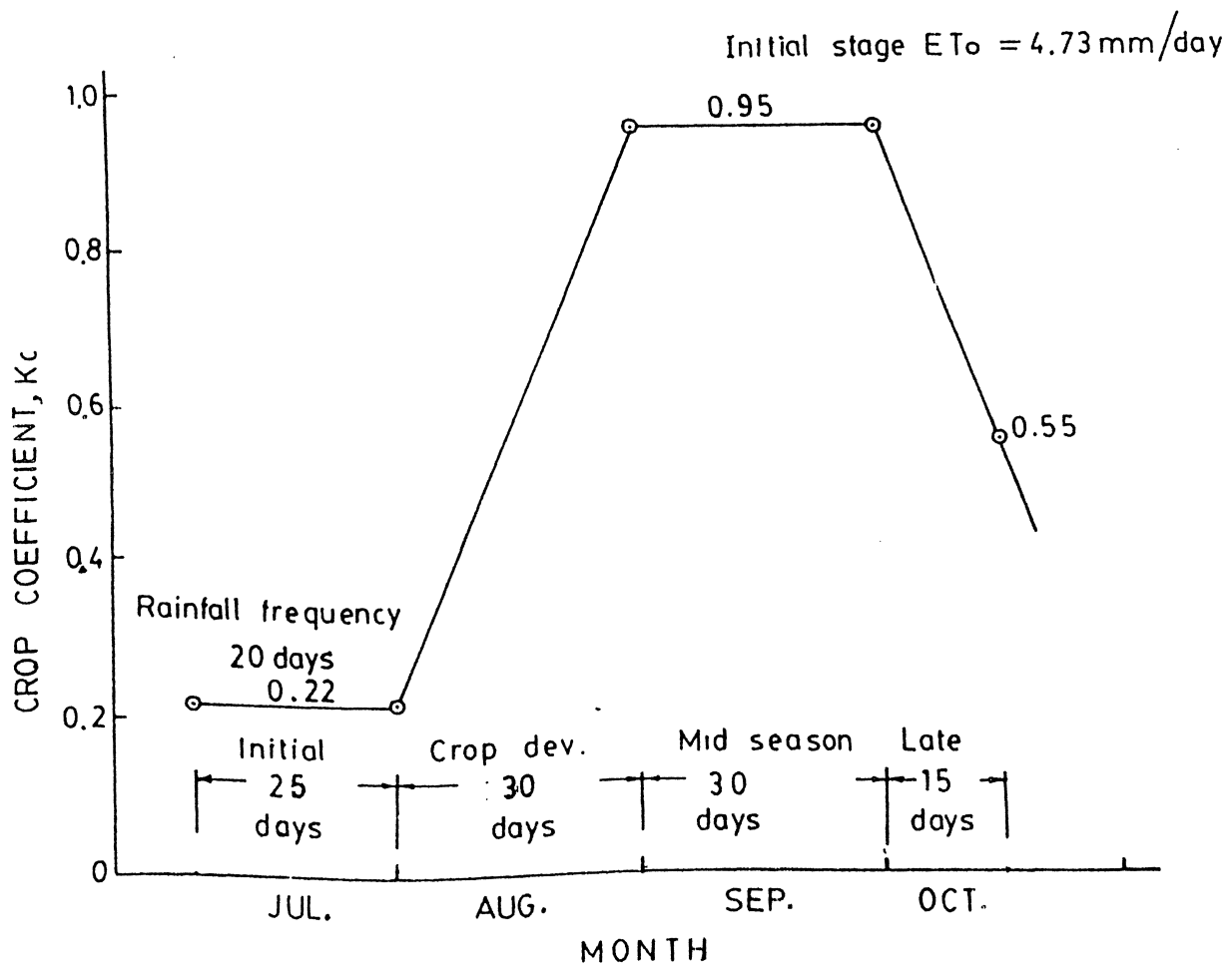


Fig. 4.3 Crop coefficient curve for Groundnut

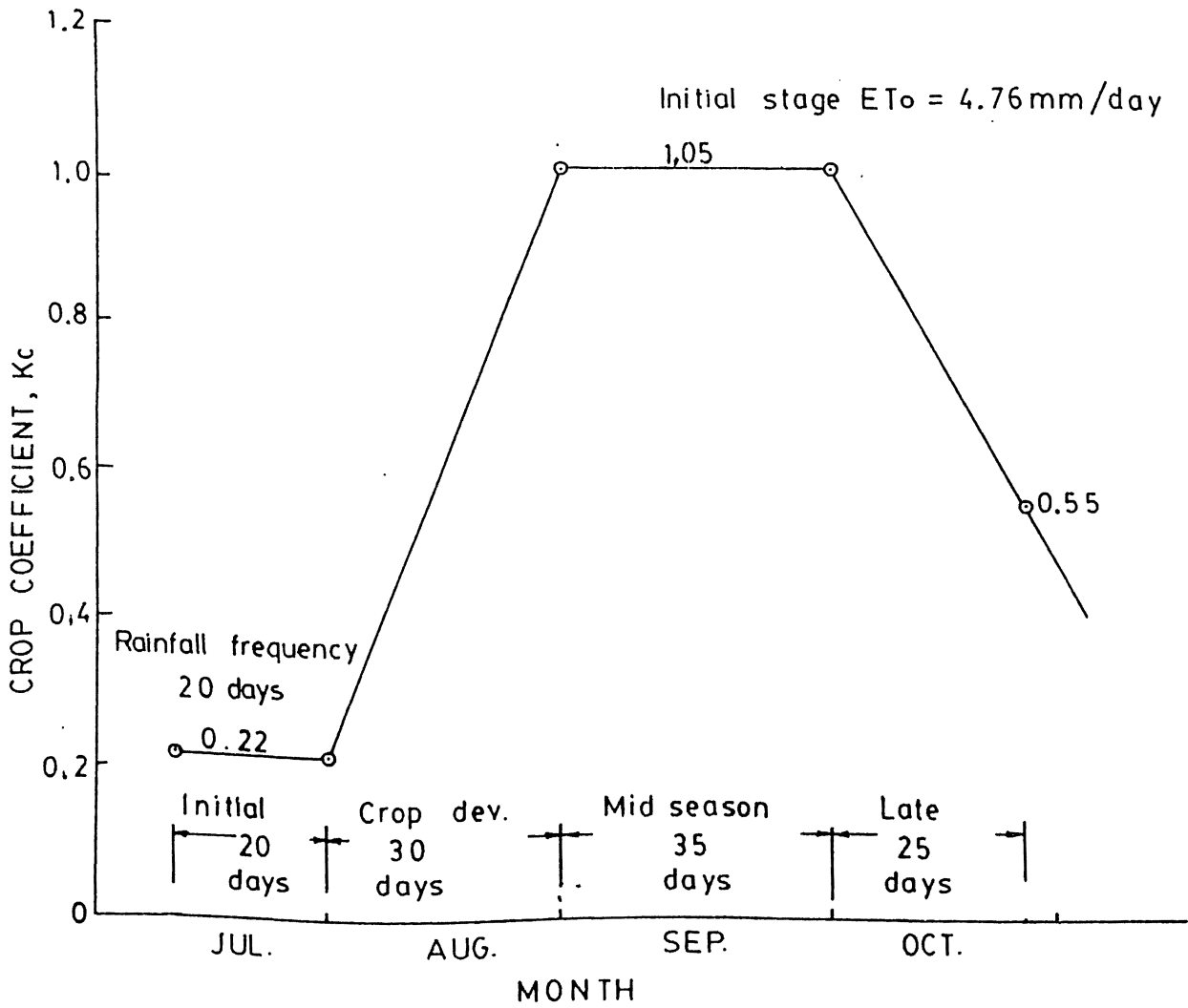


Fig. 4.4 Crop coefficient curve for Maize

regression equations and correlations coefficients obtained between crop yield and growing degree days for arhar , groundnut , maize and upland paddy are presented in Table 4-1 to 4.4. respectively.

The correlation coefficients of arhar (Table 4.1) during the initial stage varies from -0.91 to -0.95 . But it is interesting that the models  $Y = ae^{bx}$  and  $Y = ax^b$  yields the same correlation coefficient as -0.95. In the crop development stage the correlation coefficients ranges from 0.94 to 0.95 and the model  $Y = ae^{bx}$  yields the value 0.94 and all other models yield the same correlation coefficients i.e. 0.95 . All the models have the same correlation coefficient for mid season i.e. 0.97 whereas in late season the first two models give the correlation coefficient of 0.96 and the last two models give the same as 0.97.

Table 4.2 shows that for groundnut the mid season growth phase has the lowest correlation coefficient of -0.86 to -0.87 as compared, to other three phases . For maize, during the mid season stage, the correlation coefficient estimated by four models is the same. In the first two growth phase the last two models give low correlation coefficient of 0.85 as indicated in Table 4.3 . From Table 4.4. it is evident that the mid season and late season of upland paddy has the same correlation coefficients of 0.89 and 0.91 respectively as estimated by all the four models. The

Table 4.1 Regression models relating yield and growing degree days for arhar

Standard models considered	Models developed for different stage			
	Initial stage	Crop dev. stage	Mid season	Late season
a+bX	Y=101.4-0.19X r=-0.91	Y=-77.19+0.13X r=0.95	Y=40.02-0.026X r=-0.97	Y=-17.35+0.054X r=0.96
a+b lnX	Y=584.15-93.26 lnX r=-0.92	Y=-545.08+85.51 lnX r=0.95	Y=220.28-29.88 lnX r=-0.97	Y=-156.25+26.75 lnX r=0.96
a e <sup>bX</sup>	Y=1.36x10 <sup>5</sup> e <sup>-0.02X</sup> r=-0.95	Y=1.93x10 <sup>-3</sup> e <sup>0.01X</sup> r=0.94	Y=207.59 e <sup>-26.7X</sup> r=-0.97	Y=0.59 e <sup>5.6x10<sup>-3</sup>X</sup> r=0.97
aX <sup>b</sup>	Y=5.278X <sup>-9.62</sup> r=-0.95	Y=5x10 <sup>-24</sup> X <sup>8.62</sup> r=0.95	Y=1.67x10 <sup>10</sup> X <sup>-3</sup> r=-0.97	Y=3.63x10 <sup>-7</sup> X <sup>2.76</sup> r=0.97

Table 4.2 Regression models relating yield and growing degree days for groundnut

Standard models considered	Models developed for different stage			
	Initial stage	Crop dev. stage	Mid season	Late season
a+bX	Y=-93.03+0.02X r=0.96	Y=-70.9+0.14X r=0.93	Y=91.99-0.14X r=-0.86	Y=-26.99+0.14X r=0.94
a+b lnX	Y=-632.2+104.5 lnX r=0.96	Y=-515.9+83.2 lnX r=0.93	Y=521.6-80.5 lnX r=-0.86	Y=-206.7+38.84 lnX r=0.94
a e <sup>bX</sup>	Y=1.5x10 <sup>-3</sup> e <sup>0.02</sup> r=0.97	Y=0.01 e <sup>0.01</sup> r=0.93	Y=11187 e <sup>-0.01</sup> r=-0.87	Y=0.432 e <sup>0.01</sup> r=0.94
aX <sup>b</sup>	Y=1.54x10 <sup>-23</sup> X <sup>8.9</sup> r=0.97	Y=4.95x10 <sup>-19</sup> X <sup>7.0</sup> r=0.93	Y=1.02x10 <sup>20</sup> X <sup>-6.8</sup> r=-0.87	Y=9.84x10 <sup>-8</sup> X <sup>3.3</sup> r=0.94

Table 4.3 Regression models relating yield and growing degree days for maize

Standard models considered	Models developed for different stage			
	Initial stage	Crop dev. stage	Mid season	Late season
$Y=a+bX$	$Y=222.3-0.54X$ $r=-0.90$	$Y=-211.1+0.4X$ $r=0.90$	$Y=276.5-0.4x$ $r=-0.90$	$Y=149.7-0.3X$ $r=-0.94$
$Y=a+b\ln X$	$Y=1229.2-203.9 \ln X$ $r=-0.90$	$Y=-1445.7+230.8 \ln X$ $r=0.90$	$Y=1702.6-259.8 \ln X$ $r=-0.90$	$Y=825.16-132.3 \ln X$ $r=-0.94$
$Y=ae^{bX}$	$Y=5.9 \times 10^6 e^{-0.03X}$ $r=-0.85$	$Y=1.13 \times 10^5 e^{0.03X}$ $r=0.85$	$Y=385.5 \times 10^6 e^{-0.03X}$ $r=-0.90$	$Y=2.84 \times 10^{11} e^{-0.02X}$ $r=-0.93$
$Y=aX^b$	$Y=9.9 \times 10^{33} X^{-12.7}$ $r=-0.85$	$Y=4.5 \times 10^{-39} X^{14.4}$ $r=0.85$	$Y=1.4 \times 10^{49} X^{-16.9}$ $r=-0.90$	$Y=1.2 \times 10^{24} X^{-8.6}$ $r=-0.93$

Table 4.4 Regression models relating yield and growing degree days for upland paddy

Standard models considered	Models developed for different stage			
	Initial stage	Crop dev. stage	Mid season	Late season
$Y=a+bX$	$Y=50.2-0.09X$ $r=-0.83$	$Y=116.9-0.18X$ $r=-0.86$	$Y=93.9-0.15X$ $r=-0.89$	$Y=-66.6+0.21X$ $r=0.91$
$Y=a+b\ln X$	$Y=243.2-38.4 \ln X$ $r=-0.83$	$Y=675.6-104.5 \ln X$ $r=-0.86$	$Y=522.7-80.9 \ln X$ $r=-0.89$	$Y=-460.6+79.8 \ln X$ $r=0.91$
$Y=ae^{bX}$	$Y=239.9 e^{-7.3X}$ $r=-0.86$	$Y=42840.1 e^{-0.01X}$ $r=-0.89$	$Y=6401.1 e^{-0.01X}$ $r=-0.89$	$Y=0.03 e^{0.02X}$ $r=0.91$
$Y=aX^b$	$Y=890.1 \times 10^6 X^{-3.0}$ $r=0.91$	$Y=3.7 \times 10^{23} X^{-8.2}$ $r=0.91$	$Y=1.2 \times 10^{18} X^{-6.2}$ $r=0.91$	$Y=4.8 \times 10^{-15} X^{6.0}$ $r=0.91$

coefficients obtained by the models  $Y = a + bX$  and  $Y = a + b \ln X$  for the initial growth phase is the lowest of all and is -0.83.

From all the values of correlation coefficients it is clear that the model  $Y = aX^b$  yields the best result in comparison to others models for the four growth phases of all the four crops under consideration.

These equations can be used to predict the crop yield of arhar, groundnut, maize and upland paddy using growing degree days.

4.10

#### Development of Crop-Weather Model

Multiple regression analyses are made to develop relationship among variables such as crop yield, rainfall, average temperature, average relative humidity, sunshine hour and wind velocity.

The yield of crops such as arhar, groundnut, maize and upland paddy are correlated individually through simple regression model <sup>of the form  $y = a + bx$</sup>  with accumulated rainfall, average temperature, average relative humidity, sunshine hour and wind velocity for 16 years from 1976 to 1991 for the initial growth stage, crop development stage, mid season and late season separately. The coefficients of correlation thus ob-

tained for different crops are presented in Tables 4.5, 4.6, 4.7 and 4.8.

Table 4.5 presents the correlation coefficient of the relationship between different weather parameters under consideration and crop yield of arhar in different growth phase. It is clear that rainfall, sunshine hour and wind velocity have higher correlation coefficients with yield only during initial growth stage but average temperature and average relative humidity have the higher correlation coefficients during the mid season. From Table 4.6 it is clear that rainfall, average relative humidity and sunshine hour have higher correlation coefficients during the late season with yield of groundnut whereas average temperature is highly correlated with yield during crop development stage and wind velocity during mid season of crop growth. Table 4.7 indicates that wind velocity has the best correlation with yield of maize during initial growth stage, rainfall during mid season and all other parameters in the late season of crop growth. In case of upland paddy it is evident from table 4.8 that wind velocity is highly correlated with the yield during initial growth stage, average temperature during mid season and all other parameters during the late season of crop growth. All the correlation coefficients which are significant are star marked in all the tables.

The weather elements those are highly correlated

Table 4.5 Coefficient of correlation between arhar yield and weather parameter

Weather element	Stages of crop growth			
	Initial stage	Crop development stage	Mid season	Late season
Rainfall	-0.52*	-0.40	0.29	-0.22
Average temperature	-0.57	-0.96	-0.97*	0.73
Average relative humidity	-0.15	-0.40	0.59*	0.23
Sunshine hour	0.39*	0.27	-0.25	-0.03
Wind velocity	-0.29*	-0.17	0.03	0.10

Table 4.6 Coefficient of correlation between groundnut yield and weather parameter

Weather element	Stages of crop growth			
	Initial stage	Crop development stage	Mid season	Late season
Rainfall	-0.24	-0.08	0.07	0.26*
Average temperature	0.64	0.93*	-0.85	0.92
Average relative humidity	-0.05	-0.21	0.16	-0.27*
Sunshine hour	-0.05	0.22	-0.15	-0.36*
Wind velocity	-0.01	0.38	0.40*	0.02

Table 4.7 Coefficient of correlation between maize yield and weather parameter

Weather element	Stages of crop growth			
	Initial stage	Crop development stage	Mid season	Late season
Rainfall	-0.04	0.13	-0.47*	0.39
Average temperature	-0.90	-0.91	-0.90	-0.97*
Average relative humidity	-0.14	0.03	-0.37	0.48*
Sunshine hour	-0.08	0.04	0.07	-0.34*
Wind velocity	-0.23*	-0.20	0.21	0.03

Table 4.8 Coefficient of correlation between upland paddy yield and weather parameter

Weather element	Stages of crop growth			
	Initial stage	Crop development stage	Mid season	Late season
Rainfall	0.03	0.06	0.11	0.64*
Average temperature	-0.82	-0.86	-0.89*	-0.20
Average relative humidity	0.53	-0.03	-0.03	0.55*
Sunshine hour	-0.33	0.14	-0.08	-0.44*
Wind velocity	-0.47*	-0.29	-0.10	0.14

with yield are taken into consideration for the development of crop-weather model. The weather elements along with yield data for 16 years for crops under consideration from 1976 to 1991 are presented in Table 4.9 to 4.12. By applying multiple regression technique the models are formulated as given below .

For Arhar

$$Y = 0.191 + 0.065X_1 - 0.06X_2 + 0.015X_3 + 0.24X_4 + 0.008X_5 \dots (4.1)$$

For Gorundnut

$$Y = -5.163 + 1.06X_1 + 1.09X_2 - 1.15X_3 + 2.30X_4 + 0.55X_5 \dots (4.2)$$

For Maize

$$Y = 0.53 - 0.01X_1 - 0.53X_2 + 0.15X_3 + 0.43X_4 + 0.17X_5 \dots (4.3)$$

For Upland paddy

$$Y = 0.65 + 0.04X_1 - 0.12X_2 + 0.02X_3 + 0.28X_4 + 0.24X_5 \dots (4.4)$$

For all the above four models

Y = Yield of crops in Quintal/hectare

X<sub>1</sub> = Rainfall in mm during the period

X<sub>2</sub> = Average temperature in °C during the period

X<sub>3</sub> = Average relative humidity in per cent during the period

X<sub>4</sub> = Sunshine hour in hours during the period

X<sub>5</sub> = Wind velocity in km/hr during the period

Table 4.9 Different weather elements during sensitive periods of arhar along with yield data from 1976 to 1991

Year	Yield in q/ha	Rainfall in mm	Av.Temp. in deg.cent.	Av.Rh. in per cent	Sunshine in hour	Wind velocity in km/hour
1976	8.20	271.0	1795.6	4432.0	117.6	242.5
1977	9.05	305.5	1781.8	4357.5	112.1	249.2
1978	9.38	115.3	1761.8	4684.5	121.9	138.9
1979	12.11	324.6	1692.0	4581.0	141.6	200.1
1980	9.77	289.2	1758.4	4413.0	116.6	172.7
1981	9.93	360.0	1731.8	4221.0	129.6	258.5
1982	9.44	509.0	1767.7	4371.5	79.2	215.3
1983	10.00	384.4	1711.8	4427.0	99.8	200.0
1984	7.11	404.0	1852.6	4195.0	131.0	221.2
1985	7.22	360.4	1841.3	4440.0	128.6	197.5
1986	11.89	154.0	1674.1	1764.5	140.3	193.3
1987	13.56	139.8	1607.0	4739.0	159.8	157.2
1988	10.22	208.0	1702.3	4189.5	94.7	172.0
1989	9.93	331.5	1731.8	4436.5	94.3	63.2
1990	11.22	144.8	1701.0	4726.5	132.2	43.7
1991	9.38	344.4	1779.3	4660.5	68.5	101.1

Table 4.10 Different weather elements during sensitive periods of groundnut along with yield data from 1976 to 1991

Year	Yield in q/ha	Rainfall in mm	Av.Temp. in deg.cent.	Av.Rh. in per cent	Sunshine in hour	Wind velocity in km/hour
1976	10.28	2.0	858.5	1051.0	137.3	171.9
1977	10.97	33.0	864.2	1160.5	132.3	146.3
1978	11.11	66.8	865.5	1226.0	107.8	168.5
1979	13.84	82.5	883.1	1184.5	117.1	150.0
1980	12.19	5.7	868.4	1139.0	136.0	185.8
1981	13.94	3.2	886.7	1049.0	147.7	209.4
1982	13.80	67.2	877.5	1141.0	112.9	188.8
1983	13.80	129.8	869.9	1141.0	90.8	198.7
1984	13.47	27.0	853.9	1249.5	92.2	116.4
1985	9.78	197.4	853.3	1176.0	89.1	184.1
1986	9.72	195.2	854.3	1269.5	95.2	151.2
1987	10.00	93.0	868.6	1287.5	116.8	123.8
1988	13.47	65.9	866.5	1003.0	150.4	143.7
1989	11.94	68.0	861.7	1221.5	118.9	28.4
1990	10.78	151.5	859.2	1204.0	83.5	52.7
1991	10.44	100.0	859.2	1231.5	63.4	19.6

Table 4.11 Different weather elements during sensitive periods of maize along with yield data from 1976 to 1991

Year	Yield in q/ha	Rainfall in mm	Av.Temp. in deg.cent.	Av.Rh. in per cent	Sunshine in hour	Wind velocity in km/hour
1976	22.93	277.6	683.6	1764.0	228.2	180.7
1977	9.14	404.7	724.8	1584.0	243.0	144.8
1978	19.14	231.2	690.5	1918.0	186.9	129.7
1979	11.11	357.6	714.6	1861.5	237.9	170.9
1980	9.59	59.2	721.9	1843.0	211.5	132.6
1981	16.05	3.2	705.5	1670.5	241.9	132.4
1982	11.51	77.4	703.9	1825.5	207.3	187.6
1983	12.39	149.8	713.6	1880.5	187.2	173.7
1984	19.60	66.4	687.6	1869.5	181.3	142.9
1985	23.01	197.4	673.8	1950.0	231.9	143.6
1986	19.44	206.4	688.8	1929.5	195.3	189.5
1987	18.46	115.2	689.5	1889.0	215.4	128.4
1988	15.28	109.5	709.4	1693.0	242.9	152.2
1989	17.38	68.0	702.4	1864.0	204.6	92.5
1990	22.90	153.2	684.5	1942.0	151.1	34.9
1991	17.76	101.4	700.2	1951.0	134.5	106.4

Table 4.12 Different weather elements during sensitive periods of upland paddy along with yield data from 1976 to 1991

Year	Yield in q/ha	Rainfall in mm	Av.Temp. in deg.cent.	Av.Rh. in per cent	Sunshine in hour	Wind velocity in km/hour
1976	11.58	52.1	851.8	1477.0	191.3	168.2
1977	13.66	165.0	844.2	1633.5	164.2	137.4
1978	14.77	115.2	877.1	1674.0	123.2	112.3
1979	11.03	176.9	853.6	1652.5	164.8	195.2
1980	12.63	126.6	842.9	1639.5	155.8	153.3
1981	12.46	189.8	844.8	1603.0	158.9	138.0
1982	10.21	6.4	864.7	1492.0	177.2	176.9
1983	14.10	204.6	851.3	1753.5	110.5	161.3
1984	14.16	11.0	841.5	1486.5	183.3	168.0
1985	14.44	238.1	830.1	1675.0	141.1	146.1
1986	14.72	335.4	827.9	1725.5	101.0	161.2
1987	10.30	0.0	862.0	1599.0	143.7	154.6
1988	11.72	263.2	850.8	1681.0	139.4	177.4
1989	12.00	41.8	845.0	1640.0	145.4	115.1
1990	12.72	341.7	825.4	1789.0	110.2	57.1
1991	10.89	73.2	885.2	1673.0	107.7	80.2

The above models given in equation 4.1, 4.2, 4.3 & 4.4 have correlation coefficients of 0.84 ,0.91,0.98, and 0.85 respectively which indicate that there exist high relationships among the parameters .

## CHAPTER V

### SUMMARY AND CONCLUSION

#### 5.1 Summary

Agriculture is the main source of income of people of Orissa, which depends mainly on rainfall. As rainfall distribution is quite erratic and uneven the agricultural production is thus highly unstable. Even during the monsoon season the state suffers from simultaneous problems of draught and flood. For this reason, the study of variation of weather parameters is of prime importance for crop planning. Development <sup>of</sup> reliable crop - weather models are needed to predict the yield and for the determination of climatic risks in crop production.

Forecasting of rainfall is essential for proper planning of crop production. Different agricultural operations depend on rainfall under dryland situation. By about 70 % of cultivable land of Orissa depends on rainfall for crop production. Prediction of rainfall in advance helps to accomplish the agricultural operations in time..

Statistical analysis of rainfall data of Bhubaneswar for 42 years from 1950 to 1991 has been carried out in order to find out the distribution of weekly, fortnightly and monthly values. Three probability distribution functions have been considered to find out the best fit of the data series. Different statistical models have been tried to forecast the weekly rainfall, dry weeks and wet weeks, critical dry spells and commencement of sowing rain for the year 1992.

Crop yield models have been developed basing on growing degree days for crops such as arhar, groundnut, maize and upland paddy.

Crop-weather models have been developed by multiple regression technique relating yield and weather parameters such as rainfall, average temperature, average relative humidity, sunshine hour and wind velocity for the above said crops.

## 2. Conclusion

The following are the salient conclusions that can be drawn from the investigation reported in the text of this dissertation.

- 1.- Rainfall data series of any particular week,

fortnight or month over a period of 1950 to 1991 have been found serially independent.

2. Most of the rainfall time series of actual data are found to be positively skewed. The dispersion and skewness of the actual data are nullified to a large extent when the square root and cube root transformed data are considered.
3. In case of original and transformed data, the chi-square values for the time series under normal distribution and log normal 2 distribution are found to be non-significant in most of the weeks, fortnights and months. In case of cube root transformed data, the chi-square values for the lognormal - 3 distribution are found to be significant at 95 per cent level.
4. The five year-moving average forecasting technique gave better results than the three, seven and nine year periods. The exponential smoothing technique also gives satisfactory result.
5. Prediction models for the year 1992 show that

seedbed preparation is to be taken up in the 23rd week as effective monsoon breaks towards 8th of June. As the effective monsoon ceases on 29th October 1992, the crops of duration about 140 days can be selected. Dry spells have been indicated, so that provision for irrigation facilities can be made available during those periods.

6. It is suggested that the planting of crops may be taken up in 25th week at Bhubaneswar as 200 mm. rainfall is expected at 75 percent probability level.
7. Modified Penman method yields lower values of mean weekly reference crop evapotranspiration as compared to modified Blaney-Criddle method and modified Radiation method. Crop evapotranspiration values for the crops of arhar, groundnut, maize and upland paddy are 572.50 mm., 296.93 mm., 372.95 mm. and 485.16 mm. respectively.
8. The power regression models of the form  $Y = aX^b$  shows that the best relationship between crop yield and growing degree days for the crops such as arhar, groundnut, maize and upland paddy for all the growth stages.

9. The crop weather models developed among the parameters such as yield (Y) in q/hect, rainfall (X<sub>1</sub>) in mm, temperature (X<sub>2</sub>) in °C, relative humidity (X<sub>3</sub>) in per cent, sunshine hour (X<sub>4</sub>) in hour and wind velocity (X<sub>5</sub>) in Km./hour are given below for different crops with their correlation coefficient values.

For Arhar

$$Y = 0.191 + 0.065 X_1 - 0.06 X_2 + 0.015 X_3 + 0.024 X_4 + 0.008 X_5$$

$$r = 0.84$$

For Groundnut

$$Y = -5.163 + 1.06 X_1 + 1.09 X_2 - 1.15 X_3 + 2.30 X_4 + 0.55 X_5$$

$$r = 0.91$$

For Maize

$$Y = 0.53 - 0.01 X_1 - 0.53 X_2 + 0.15 X_3 + 0.43 X_4 + 0.17 X_5$$

$$r = 0.98$$

For Upland paddy

$$Y = 0.65 + 0.04 X_1 - 0.12 X_2 + 0.02 X_3 + 0.28 X_4 + 0.24 X_5$$

$$r = 0.85$$

## L I T E R A T U R E   C I T E D

- grewal, R., Jain, R.C., Jha, M.P. and Singh, D. 1980.  
Forecasting of rice yield using climatic variables.  
Indian Journal of Agricultural Science. 50(9):680-684
- grewal, R., Jain, R.C. and Jha, M.P. 1983. Joint effects of weather  
variables on rice yields, Mausam. 34(2) : 189 - 194
- grewal, R., Jain, R.C. and Jha, M.P. 1986. Models for studying rice  
crop - weather relations. Mausam. 37(1) : 67 - 70
- grewal, R., and Jain, R.C. 1990. Studies to develop models for  
obtaining pre-harvest forecast of wheat yield on the  
basis of weather parameters. Indian Agricultural  
Statistics Research Institute, ICAR.
- Allen, G.R. and Pruitt, W.O. 1991. FAO- 24 reference  
evapotranspiration factors. Journal of Irrigation and  
Drainage Engineering. ASCE. 117(5):758-773
- Anderson, O.D. 1942. Distribution of serial correlation  
coefficient. Annals<sup>of</sup> Mathematical Statistics. 13:1-13
- Anderson, O.D. 1976. Time series analysis and forecasting, the  
Box- Jenkin approach. Butler Worth. London.
- Chok Raj, P.C. 1979. Onset of effective monsoon and critical dry  
spells. IARI. Research Bulletin No. 11.

- Bartlett, M.S. 1935. Some aspects of time correlation problem in regard to test of significance. Journal of Royal Statistical Society. 98 : 536 - 543
- Bartlett, M.S. 1946. On the theoretical specification of sampling properties of auto correlated time series. Journal of Royal Statistical Society. 88: 27-41
- Basu, G.C. and Khamuri, S.R. 1989. The quantitative rainfall forecasts through statistical synoptic model and its application in forecasting daily rainfall over Maurakshi basin area. Mausam. 40(4) : 421 - 424
- Beer, A., Drummond, A.J. and Furth, R. 1946. Sequences of wet and dry months and the theory of probability. Quarterly Journal of Royal Meteorological Society. 72 : 74 - 86
- Beson, M.A. 1962 . Evaluation of Methods for evaluating the occurrence of floods. U.S. Geological Survey. Water supply paper. 1580 -A.
- Beura, R.N. 1991. Modelling runoff and soil loss from interterrace treated lands. <sup>unpublished</sup> M.Sc. Theis. C.A.E.T. O.U.A.T.
- Biswas, B.C. 1990, Forecasting <sup>for</sup> agricultural application. Mausam. 41(2) : 329-334
- Blackman, R.B. and Tukey, J.W. 1959. The measurement of power spectra. Dover publication incorporated. Sanfrancisco.
- Brittan, M.R. 1961. Past and probable future variation in stream flow in upper Colorado River. University of Colorado. Bureau of Economic Research.

- Brooks, C.E.P. and Corruthers, N. 1953. Hand book of statistical methods in meteorology. Great Britain Meteorological Office. Her Majesty's Stationery Office, London.
- Chow, V.T. 1964. Hand book of applied hydrology. Mc-Graw Hill Book Company. New York.
- Chow, V.T. 1954. The log-probability law and its engineering applications. Proceeding of American Society of Civil Engineers. 80 : 1- 25
- Clarke, R.T. 1973, Mathematical models in hydrology. Irrigation and Drainage paper. 19. FAO. United Nations.
- Doorenbos, J. and Pruitt, W.O. 1977. Crop water requirements. Irrigation and Drainage paper. 24. FAO. United Nation.
- Feyerhern, A.M. and Bark, L.D. 1965. Statistical methods for persistent precipitation patterns. Journal of Applied Meteorology. 4: 320-328.
- Franz, D.D. 1970. Hourly rainfall synthesis for a network of stations. Technical report no. 126. Dept. of Civil Engineering. University of Stanford.
- Frevert, D.K., Hill, R.W. and Braten, B.C. 1983. Estimation of FAO evapotranspiration coefficients. Journal of Irrigation and Drainage Engineering. ASCE. 109(2) : 256 -270
- Ganesan G.S., Ahobala Rao, H.R. and Mathur Butheswaran. 1985. A study of the influence of selected weather parameters on biomass production in ragi. Mausam. 39(2) :197-200

- Gilcrisht, W. 1976. Statistical forecasting. John Willey and Sons. London.
- Gowarikar, V., Thapliyal, V., Kulsrestha, S.M., Mandal, G.S., Ray, N.S. and Sikka, D.R. 1991. A power regression model for long-range forecast of southwest monsoon rainfall over India. Mausam. 92(2) : 125-130
- Gumbel, E.J. 1954. Statistical theory of droughts. Proceedings of ASCE. 80(439) : 1-19
- Gupta, S.C. and Kapoor, V.K. 1983. Fundamentals of Mathematical Statistics. S. Chand and Sons. New Delhi.
- Hall, W.A. and David, T.H. 1963. Estimating Flood probabilities within specific time intervals. Journal of Hydrology 1 : 265 - 274
- Harshfield, D.M. and Kohler, M.A. 1960. An emperical appraisal of the Gumbel extreme procedure. Journal of Geophysics Research. 65 : 1737 - 1746
- Harshfield, D.M. 1962. An emperical comparison of the productive value of three extreme value procedures. Journal of Geophysics Research. 65 : 1535 - 1542
- Jain, R.C. , Agrawal, R. and Jha, M.P. 1980. Effect of climatic variables on rice yield and its forecast. Mausam . 31(4) : 591 - 596

- Kendall, G.M. and Stuart, A. 1968. The advanced theory of Statistics. 3. Charle Griffin and Company Ltd. London.
- Kotz, S. and Neuman, J. 1955. Autocorrelation in precipitation and runoff. Colorado State University. Hydrological paper No. 8. Fort Collins.
- Lober, M. and Haith, A.D. 1981. A corn yield model for operational planning and management. Transaction of ASAE. 24(6) : 1520 - 1525
- Markovic, R.D. 1965. Probability functions of best fit to distribution of annual precipitation and runoff. Colorado State University. Hydrological paper No. 8. Fort Collins.
- Mohapatra, J. 1991. Planning for a river lift irrigation project M.Sc. Thesis, CAET, O.U.A.T.
- Mutreja, K.N. 1986. Applied hydrology. Tata McGrawhill publishing Company Limited. New Delhi.
- Namias, J. 1952. The annual course of month to month persistence in climate anomallies. Bulletin of American Meteorologal Society. 33(7) : 279 -285
- Nelson, L.W. and Dale, R.F. 1978. Effect of trend or technology variables and record period on prediction of corn yields with weather variables . Journal of Applied Meteorology. 17 : 926 - 933

- Pandarinath, N. 1991. Markov chain model probability of dry, wet weeks during monsoon period over Andhra Pradesh. Mausam. 42 (4) : 493 - 400
- Pandit, K.N. 1990. Goal programming approach to irrigation planning for optimal cropping pattern. M.Sc. Thesis. CAET, O.U.A.T..
- Pattison, A. 1965. Synthesis of hourly rainfall data. Water Resources Research. 1: 489 - 498
- Prasad, R. and D. dhane, S.N. 1989. Forecasting rice yields in Gengetic West Bengal using rainfall and agricultural technology. Mausam 40 (4) : 441 - 446
- Raman, C.R.V. 1974, Analysis of commencement of monsoon rains over Maharashtra State for agricultural planning. Scientific Report No. 216. India Meteorological Department, Poona.
- Ramlingam, P. 1976, System analysis for managerial decisions : A computer approach. Johnwiley and Sons, New York.
- Ratnam, B.P. and Kavi, P.S. 1990. Study of growing degree days in Karnatana and its significance to the crops . Mausam. 41 : 214

- Runge, E.C.A. 1968. Effects of rainfall and temperature interactions during growing season on crop yield. *Agronomy Journal*. 60 : 503
- Salas, J.D. and Benyeden, E. 1978. Probability distribution functions. : computer workshop in statistical hydrology. Department of Civil engineering, Colorado State University. Fort Collins.
- Senapati, P.C., Mishra, N. and Lal, R. 1985. Relationship between pan evaporation and meteorological parameters at Bhubaneswar (Orissa). *Journal of Indian Water Resources Society*. 5 : 27-32
- Shane, R.M. and Lynn, W.R. 1964. Mathematical models for flood risk evaluation. *Proceeding of ASCE. Journal of Hydraulics Division*. HY6 : 1-20
- Shankar, U. and Gupta, B.R.O. 1987. Forecasting the yield of paddy at Chinsurah in West Bengal using multiple regression technique. *Mausam*. 38 ( 4 ) : 415 - 418
- Singh, J.K. 1979. Application of forecasting models for developing integrated irrigation and drainage system; A case study. Ph.D. Thesis. IIT, Kharagpur.
- Slade, J.J.Jr. 1936. An anymatric probability function . *Tranction ASCE* . 101 : 1-37
- Stacy, S.V. , Stenson, D., Jones, L.S. and Foreman, J. 1957 Joint effects of maximum temperatures and rainfall on cop yield. *Agronomy Journal* . 49 : 26 - 28

- Stern, R.d. 1982. Computing a probability distribution for the start of the rains from a markov chain model for precipitation. Journal of Applied Meteorology. 21 (3) : 420 - 423
- Stidd, C.K. 1953. Cube-root normal precipitation distributions. Transaction American Geophysical Union. 34(1) : 31-35
- Thom, H.C.S. 1940. On the statistical analysis of rainfall data. Transaction American Geophysics Union. 21(2) : 490
- Todorovic, P. and Yevjevich, V. 1969. Stochastic process of precipitation. Colorado State University. Hydrological paper No. 35. Fort Collins.
- Tice, T.F. and Closure, R.L. 1982. Determination of the value of weather information to individual corn producers. Journal of Applied Meteorology . 21 (4) : 447 - 452
- Upadhya, D.S., Apte, N.Y., Kaur, S. and Singh, S.P. 1986. A dynamic approach to quantitative precipitation forecast. Mausam. 37 (3) : 369 - 372
- Victor, U.S. and Sastry, P.S.N. 1979. Dry spell probability by markov chain model and its application to crop development stage. Mausam. 30 : 479 - 484
- Whitcomb, M. 1940. A statistical study of rainfall data. M.S. Thesis. Massachusetts Institute of Technology.
- W.M.O. 1982. A study of agroclimatology of the humid tropics of South East Asia. Technical Report No. 179

- Stern, R.d. 1982. Computing a probability distribution for the start of the rains from a markov chain model for precipitation. Journal of Applied Meteorology. 21 (3) : 420 - 423
- Stidd, C.K. 1953. Cube-root normal precipitation distributions. Transaction American Geophysical Union. 34(1) : 31-35
- Thom, H.C.S. 1940. On the statistical analysis of rainfall data. Transaction American Geophysics Union. 21(2) : 490
- Todorovic, P. and Yevjevich, V. 1969. Stochastic process of precipitation. Colorado State University. Hydrological paper No. 35. Fort Collins.
- Tice, T.F. and Closure, R.L. 1982. Determination of the value of weather information to individual corn producers. Journal of Applied Meteorology . 21 (4) : 447 - 452
- Upadhya, D.S., Apte, N.Y., Kaur, S. and Singh, S.P. 1986. A dynamic approach to quantitative precipitation forecast. Mausam. 37 (3) : 369 - 372
- Victor, U.S. and Sastry, P.S.N. 1979. Dry spell probability by markov chain model and its application to crop development stage. Mausam. 30 : 479 - 484
- Whitcomb, M. 1940. A statistical study of rainfall data. M.S. Thesis. Massachusetts Institute of Technology.
- W.M.O. 1982. A study of agroclimatology of the humid tropics of South East Asia. Technical Report No. 179

- Yevjevich, V. 1963, Fluctuations of wet and dry years, Part -1  
: Research Data Assembly and Mathematical Models.  
Colorado State University, Paper No. 1 Fort Collins.
- Yevjevich, V. and Karplus, A.K. 1973. Area -time structure  
of the monthly precipitation process. Colorado  
State University, Hydrology paper No. 64.  
Fort Collins.
- Yule, G.U. 1945. On a method of studying time series based  
on their internal correlation. Journal of Royal  
Statistical Society. Vol. 108.
-

## APPENDIX - A

Table A-1 Statistical parameters of weekly data series

Week no.	mean	sd	cv	cs	ck	
1	2	3	4	5	6	
Week 1	4.10405	15.22780	3.71043	4.61108	24.48504	(o.d)
	1.00000	3.71043	3.71043	4.61108	24.48504	(m.d)
	0.65211	1.94127	2.97690	3.48901	14.88757	(s.d)
	1.23279	0.72296	0.58644	3.54324	15.02652	(c.d)
Week 2	2.92810	8.03156	2.74293	3.20926	12.42902	
	1.00000	2.74293	2.74293	3.20926	12.42901	
	0.68758	1.58594	2.30655	2.40273	7.82366	
	1.24867	0.59631	0.47756	2.57942	8.71286	
Week 3	1.11405	5.26849	4.72914	5.97038	38.97640	
	1.00000	4.72914	4.72914	5.97038	38.97640	
	0.27003	1.03273	3.82446	4.58292	24.56510	
	1.08426	0.39359	0.36300	4.61341	25.88204	
Week 4	1.33929	5.50799	4.11264	5.06774	28.79024	
	1.00000	4.11264	4.11264	5.06774	28.79030	
	0.34247	1.11884	3.26697	3.92914	18.44306	
	1.11234	0.41550	0.37354	4.37720	21.73681	
Week 5	1.58857	4.52804	2.85038	3.16361	12.08983	
	1.00000	2.85038	2.85038	3.16361	12.08982	
	0.48081	1.17919	2.45249	2.56088	8.39965	
	1.14744	0.44828	0.39068	2.62499	9.24119	
Week 6	4.26119	9.06250	2.12675	2.89797	11.72539	
	1.00000	2.12675	2.12675	2.89797	11.72539	
	1.11618	1.75752	1.57459	1.62256	4.96527	
	1.37305	0.66798	0.48649	1.86150	5.70037	
Week 7	5.70214	11.29171	1.98026	2.13159	6.72757	
	1.00000	1.98026	1.98026	2.13159	6.72757	
	1.21674	2.07958	1.70913	1.47664	3.85620	
	1.44066	0.79999	0.55530	1.52930	3.99480	
Week 8	7.74905	17.11509	2.20367	2.58348	9.02451	
	1.00000	2.20867	2.20367	2.58348	9.02451	
	1.40641	2.43142	1.72382	1.76203	5.07199	
	1.48982	0.93019	0.62437	1.81512	5.14588	
Week 9	3.61000	8.53949	2.36551	3.29216	14.80178	
	1.00000	2.36551	2.36551	3.29216	14.80177	
	0.92738	1.67841	1.80984	1.90643	6.02060	
	1.31113	0.63785	0.48649	2.08141	6.71812	

Week no.	mean	sd	cv	cs	ck
1	2	3	4	5	6
Week 10	9.73595	20.64648	2.12064	2.44060	7.92213
	1.00000	2.12064	2.12064	2.44060	7.92214
	1.62935	2.69330	1.65299	1.64680	4.69061
	1.59017	1.01316	0.63714	1.69158	4.73668
Week 11.	6.64357	15.14267	2.27930	2.50675	8.44805
	1.00000	2.27930	2.27930	2.50675	8.44805
	1.22325	2.29625	1.87717	1.86612	5.26375
	1.42656	0.88126	0.61775	1.93308	5.39922
Week 12	4.93405	9.51202	1.92783	2.42715	8.42536
	1.00000	1.92783	1.92783	2.42714	8.42535
	1.27249	1.84274	1.44814	1.38409	4.03900
	1.42565	0.70943	0.49762	1.58234	4.53102
Week 13	5.52929	11.87332	2.14735	2.86810	11.47260
	1.00000	2.14735	2.14735	2.86810	11.47261
	1.21547	2.03734	1.67618	1.64466	4.90052
	1.43325	0.77531	0.54095	1.74364	5.15850
Week 14	6.21476	15.44956	2.48595	3.30204	14.52910
	1.00000	2.48595	2.48595	3.30203	14.52909
	1.19267	2.21567	1.85774	2.07638	6.66220
	1.40580	0.84457	0.60078	2.15941	6.76433
Week 15	4.69429	9.86566	2.10163	2.95686	12.21110
	1.00000	2.10163	2.10163	2.95686	12.21111
	1.15990	1.85219	1.59685	1.57680	4.80515
	1.38482	0.72272	0.52189	1.59314	5.02995
Week 16	4.79310	11.89670	2.48205	3.63811	17.71467
	1.00000	2.48205	2.48205	3.63810	17.71466
	1.08117	1.92680	1.78214	2.04489	6.84581
	1.35090	0.74312	0.55009	2.13574	7.04740
Week 17	8.76214	15.39589	1.75709	1.90423	5.54553
	1.00000	1.75709	1.75709	1.90423	5.54553
	1.76076	2.40831	1.36777	1.17777	3.22807
	1.61222	0.94082	0.58355	1.22688	3.29169
Week 18	7.27167	14.90481	2.04971	2.45330	8.44428
	1.00000	2.04971	2.04971	2.45330	8.44428
	1.49106	2.27410	1.52516	1.56868	4.48992
	1.49377	0.88775	0.59430	1.65531	4.59148

Week no.	mean	sd	cv	cs	ck
1	2	3	4	5	6
Week 19					
	10.54714	23.38463	2.21715	3.70299	18.64091
	1.00000	2.21715	2.21715	3.70298	18.64091
	1.88083	2.67967	1.42473	1.73280	6.10211
	1.64523	1.02150	0.62088	1.63876	5.42918
Week 20					
	10.29452	18.19634	1.76757	2.30348	8.42005
	1.00000	1.76757	1.76757	2.30348	8.42005
	1.96592	2.56642	1.30546	1.17590	3.50254
	1.67794	1.00742	0.60039	1.15551	3.33717
Week 21					
	11.28190	15.18976	1.34638	1.43075	4.34396
	1.00000	1.34638	1.34638	1.43075	4.34396
	2.37756	2.40134	1.01000	0.57908	2.23943
	1.83915	0.95605	0.51983	0.63190	2.17213
Week 22					
	19.00714	25.53443	1.34341	1.82857	6.05065
	1.00000	1.34341	1.34341	1.82857	6.05065
	3.27641	2.91102	0.88848	0.63275	2.81459
	2.18451	1.12644	0.51565	0.56712	2.52556
Week 23					
	29.71382	37.46766	1.26095	1.80459	6.78716
	1.00000	1.26095	1.26095	1.80459	6.78716
	4.15832	3.56723	0.85785	0.47203	2.59675
	2.48729	1.38268	0.55590	0.25915	2.20938
Week 24					
	32.22929	34.95876	1.08469	1.58885	5.85041
	1.00000	1.08469	1.08469	1.58885	5.85041
	4.73127	3.17560	0.67119	0.32347	2.78112
	2.73447	1.20813	0.44182	0.13496	2.41596
Week 25					
	49.95357	47.59565	0.95280	1.30033	4.58930
	1.00000	0.95280	0.95280	1.30033	4.58930
	6.19731	3.43927	0.55496	0.28376	2.72991
	3.25793	1.27640	0.39178	-0.07877	2.65251
Week 26					
	63.04834	56.57632	0.89735	2.24451	10.36608
	1.00000	0.89735	0.89735	2.24451	10.36608
	7.20553	3.37640	0.46858	0.46758	4.41640
	3.64395	1.17717	0.32305	-0.06945	3.90019
Week 27					
	50.49952	46.30501	0.91694	1.36158	4.48530
	1.00000	0.91694	0.91694	1.36158	4.48530
	6.37035	3.18748	0.50036	0.44486	2.97125
	3.35071	1.13672	0.33925	0.17060	2.74237

Week no.	mean	sd	cv	cs	ck
1	2	3	4	5	6
Week 28	64.83500	54.23111	0.83645	2.01628	9.21170
	1.00000	0.83645	0.83645	2.01628	9.21171
	7.40287	3.20582	0.43305	0.47788	4.07779
	3.71532	1.11722	0.30071	-0.02437	3.51005
Week 29	79.76070	53.21072	0.66713	1.31053	6.25248
	1.00000	0.66713	0.66713	1.31053	6.25248
	8.41787	3.01948	0.35870	0.08797	3.61728
	4.07401	1.02246	0.25097	-0.34491	3.64673
Week 30	66.19380	48.25587	0.72901	1.02919	4.32578
	1.00000	0.72901	0.72901	1.02919	4.32577
	7.51547	3.15410	0.41968	-0.10730	3.24426
	3.76303	1.10518	0.29370	-0.43683	3.32514
Week 31	85.99404	83.05820	0.96586	1.61976	5.91452
	1.00000	0.96586	0.96586	1.61976	5.91452
	8.22378	4.33721	0.52740	0.47352	3.31241
	3.96433	1.42122	0.35850	0.11209	3.12201
Week 32	73.61571	50.77190	0.68969	0.82131	3.58439
	1.00000	0.68969	0.68969	0.82131	3.58438
	7.99678	3.14691	0.39352	-0.11645	2.98873
	3.91954	1.10745	0.28255	-0.55631	3.54991
Week 33	95.45882	55.02969	0.57648	0.79899	5.24565
	1.00000	0.57648	0.57648	0.79899	5.24565
	9.26334	3.14401	0.33940	-0.59621	4.38975
	4.35337	1.04770	0.24066	-0.98540	4.97116
Week 34	73.52142	59.67350	0.81165	1.06121	3.81056
	1.00000	0.81165	0.81165	1.06121	3.81056
	7.80978	3.58251	0.45872	0.15580	2.77303
	3.83339	1.25416	0.32717	-0.26451	2.99851
Week 35	74.38334	56.90853	0.76507	1.26668	4.79196
	1.00000	0.76507	0.76507	1.26668	4.79196
	7.99617	3.27098	0.40907	0.30909	3.06928
	3.92140	1.10922	0.28286	-0.03849	2.90750
Week 36	63.36905	51.51385	0.81292	1.69083	7.85057
	1.00000	0.81292	0.81292	1.69083	7.85057
	7.33890	3.12115	0.42529	0.45895	3.39267
	3.69958	1.07847	0.29151	0.11699	2.85593

Week no.	mean	sd	cv	cs	ck
1	2	3	4	5	6
Week 37	80.78382	60.90250	0.75389	1.69967	7.08364
	1.00000	0.75389	0.75389	1.69967	7.08364
	8.40443	3.22443	0.38366	0.51313	3.79696
	4.06567	1.06286	0.26142	0.11984	3.34869
Week 38	57.55286	52.93235	0.91972	2.73661	14.19811
	1.00000	0.91972	0.91972	2.73661	14.19812
	6.96496	3.04348	0.43697	0.98486	5.22370
	3.57364	1.04362	0.29203	0.50610	3.87579
Week 39	52.75618	43.28552	0.82048	1.13615	4.48707
	1.00000	0.82048	0.82048	1.13615	4.48707
	6.44734	3.38540	0.52509	-0.28424	3.22932
	3.39629	1.20889	0.35594	-0.52771	3.25354
Week 40	46.90833	49.30293	1.05105	1.88247	8.43463
	1.00000	1.05105	1.05105	1.88247	8.43462
	5.69071	3.85726	0.67782	0.14629	2.91615
	3.07373	1.42909	0.46494	-0.14252	2.46600
Week 41	57.35691	51.20225	0.89270	0.83016	3.08330
	1.00000	0.89270	0.89270	0.83016	3.08330
	6.52665	3.88842	0.59578	-0.13765	2.40149
	3.39009	1.39314	0.41095	-0.31102	2.33025
Week 42	36.96810	39.14032	1.05876	1.16391	3.93716
	1.00000	1.05876	1.05876	1.16391	3.93716
	4.91309	3.62527	0.73788	0.12384	2.23333
	2.80026	1.36233	0.48650	-0.00867	2.01879
Week 43	28.88476	27.99241	0.96911	0.86180	3.45705
	1.00000	0.96911	0.96911	0.86180	3.45705
	4.35659	3.18536	0.73116	-0.12230	2.04045
	2.62227	1.21783	0.46442	-0.18407	1.91091
Week 44	34.01905	71.49874	2.10173	2.82330	10.99610
	1.00000	2.10173	2.10173	2.82330	10.99609
	3.29144	4.87350	1.48066	1.61963	4.97747
	2.15503	1.69937	0.78856	1.43367	4.15624
Week 45	21.26286	49.32313	2.31968	3.35566	14.43480
	1.00000	2.31968	2.31968	3.35566	14.43480
	2.49866	3.92248	1.56983	1.86634	6.24338
	1.89259	1.40171	0.74063	1.68666	5.28581

Week no.	mean	sd	cv	cs	ck
1	2	3	4	5	6
Week 46	15.05833	35.83433	2.37970	3.01209	11.73845
	1.00000	2.37970	2.37970	3.01209	11.73847
	1.93914	3.40200	1.75439	1.95654	6.12928
	1.69305	1.24014	0.73249	1.88440	5.68432
Week 47	4.67786	17.04244	3.64322	4.15799	19.19557
	1.00000	3.64322	3.64322	4.15799	19.19557
	0.75717	2.05053	2.70813	3.47509	14.41081
	1.21118	0.77847	0.64273	3.52141	14.58734
Week 48	7.55476	20.60404	2.72729	3.38997	14.57633
	1.00000	2.72729	2.72729	3.38997	14.57632
	1.13387	2.53417	2.23496	2.37295	7.79336
	1.41613	0.94522	0.66746	2.37074	7.60888
Week 49	0.35000	1.56848	4.48136	5.61962	35.35452
	1.00000	4.48137	4.48137	5.61962	35.35448
	0.14918	0.57943	3.88404	4.33873	21.87103
	1.04375	0.18917	0.18124	5.29048	31.73482
Week 50	2.02310	8.14330	4.02517	5.07755	29.43943
	1.00000	4.02517	4.02517	5.07755	29.43944
	0.40624	1.37963	3.39606	3.83009	17.54946
	1.15072	0.51947	0.45143	3.93598	18.39447
Week 51	1.30714	4.46796	3.41811	4.07269	18.97550
	1.00000	3.41811	3.41811	4.07268	18.97550
	0.38053	1.09119	2.86753	3.18208	12.45104
	1.12136	0.40827	0.36408	3.38973	14.21169
Week 52	0.24452	1.14957	4.70124	5.95608	38.90521
	1.00000	4.70125	4.70125	5.95608	38.90516
	0.12266	0.48484	3.95264	4.55255	24.20964
	1.02929	0.14687	0.14269	6.19224	41.19417

sd = standard deviation.  
cv = coefficient of variance.  
cs = coefficient of skewness.  
ck = coefficient of curtosis.

o.d - original data.  
m.d - modular data.  
s.d - squareroot data.  
c.d - cuberoot data.

Week no.	mean	sd	cv	cs	ck
1	2	3	4	5	6
Week 46	15.05833	35.83433	2.37970	3.01209	11.73845
	1.00000	2.37970	2.37970	3.01209	11.73847
	1.93914	3.40200	1.75439	1.95654	6.12928
	1.69305	1.24014	0.73249	1.88440	5.68432
Week 47	4.67786	17.04244	3.64322	4.15799	19.19557
	1.00000	3.64322	3.64322	4.15799	19.19557
	0.75717	2.05053	2.70813	3.47509	14.41081
	1.21118	0.77847	0.64273	3.52141	14.58734
Week 48	7.55476	20.60404	2.72729	3.38997	14.57633
	1.00000	2.72729	2.72729	3.38997	14.57632
	1.13387	2.53417	2.23496	2.37295	7.79336
	1.41613	0.94522	0.66746	2.37074	7.60888
Week 49	0.35000	1.56848	4.48136	5.61962	35.35452
	1.00000	4.48137	4.48137	5.61962	35.35448
	0.14918	0.57943	3.88404	4.33873	21.87103
	1.04375	0.18917	0.18124	5.29048	31.73482
Week 50	2.02310	8.14330	4.02517	5.07755	29.43943
	1.00000	4.02517	4.02517	5.07755	29.43944
	0.40624	1.37963	3.39606	3.83009	17.54946
	1.15072	0.51947	0.45143	3.93598	18.39447
Week 51	1.30714	4.46796	3.41811	4.07269	18.97550
	1.00000	3.41811	3.41811	4.07268	18.97550
	0.38053	1.09119	2.86753	3.18208	12.45104
	1.12136	0.40827	0.36408	3.38973	14.21169
Week 52	0.24452	1.14957	4.70124	5.95608	38.90521
	1.00000	4.70125	4.70125	5.95608	38.90516
	0.12266	0.48484	3.95264	4.55255	24.20964
	1.02929	0.14687	0.14269	6.19224	41.19417

sd = standard deviation.  
cv = coefficient of variance.  
cs = coefficient of skewness.  
ck = coefficient of curtosis.

o.d - original data.  
m.d - modular data.  
s.d - squareroot data.  
c.d - cuberoot data.

Table A-2 Statistical parameters of fortnightly data series

Fortnight no.	mean	sd	cv	cs	ck
1	2	3	4	5	6
Fortnight 1	7.03214	18.27672	2.59903	3.23180	13.42423 (o.d)
	1.00000	2.59903	2.59902	3.23180	13.42425 (m.d)
	1.15078	2.41807	2.10125	2.21710	7.07682 (s.d)
	1.42110	0.90739	0.63851	2.23514	7.02550 (c.d)
Fortnight 2	2.45333	7.41877	3.02395	3.67455	15.81304
	1.00000	3.02395	3.02395	3.67455	15.81303
	0.61250	1.45906	2.38213	2.71830	9.75705
	1.19660	0.55512	0.46392	2.90622	10.91947
Fortnight 3	5.84976	9.96692	1.70382	2.13166	7.99837
	1.00000	1.70382	1.70382	2.13166	7.99837
	1.43724	1.96885	1.36988	1.07473	3.05313
	1.50544	0.75955	0.50453	1.18551	3.23894
Fortnight 4	13.45119	22.90906	1.70313	2.46522	9.89192
	1.00000	1.70313	1.70312	2.46522	9.89192
	2.35648	2.84444	1.20707	1.08584	3.49206
	1.82913	1.10281	0.60291	1.03528	3.14581
Fortnight 5	13.34595	23.06926	1.72856	1.83848	5.10968
	1.00000	1.72856	1.72856	1.83849	5.10968
	2.22171	2.93514	1.32112	1.14153	3.18018
	1.80956	1.10787	0.61223	1.18102	3.19279
Fortnight 6	11.57762	18.46625	1.59500	1.88146	5.98440
	1.00000	1.59500	1.59500	1.88147	5.98440
	2.26310	2.57167	1.13635	0.97669	2.98663
	1.78148	1.01290	0.56857	1.02158	2.89752
Fortnight 7	11.74405	22.78678	1.94028	2.64991	9.92838
	1.00000	1.94028	1.94028	2.64991	9.92837
	2.02041	2.80159	1.38665	1.39886	4.29278
	1.71951	1.06227	0.61778	1.39684	4.06527
Fortnight 8	9.48738	14.82435	1.56253	2.12390	7.39846
	1.00000	1.56253	1.56253	2.12390	7.39846
	2.08977	2.29022	1.09592	0.90158	3.09829
	1.71535	0.91427	0.53299	0.90749	3.00735
Fortnight 9	16.03381	22.82224	1.42338	1.43891	4.05173
	1.00000	1.42338	1.42338	1.43891	4.05173
	2.80070	2.89649	1.03420	0.73543	2.40109
	1.97538	1.15049	0.58241	0.71626	2.26873

Fortnight no.	mean	sd	cv	cs	ck
1	2	3	4	5	6
Fortnight 10	20.84167	31.78818	1.52522	2.01570	6.87379
	1.00000	1.52522	1.52522	2.01570	6.87379
	3.16176	3.33308	1.05418	0.86938	3.00695
	2.12488	1.27821	0.60155	0.75503	2.64375
Fortnight 11	30.28905	34.08954	1.12547	1.48975	5.45071
	1.00000	1.12547	1.12547	1.48975	5.45071
	4.45487	3.27076	0.73420	0.32112	2.49529
	2.61594	1.26370	0.48308	0.16388	2.14839
Fortnight 12	61.94310	60.82291	0.98192	1.18286	3.98789
	1.00000	0.98192	0.98192	1.18286	3.98789
	6.80163	4.00791	0.58926	0.26960	2.50641
	3.46293	1.41922	0.40983	0.01434	2.32625
Fortnight 13	113.00191	81.76653	0.72359	1.57132	5.69584
	1.00000	0.72359	0.72359	1.57133	5.69584
	9.98412	3.69380	0.36997	0.42346	4.10635
	4.56082	1.17524	0.25768	-0.21707	4.71913
Fortnight 14	115.33452	67.98451	0.58946	0.76555	4.13893
	1.00000	0.58946	0.58946	0.76555	4.13894
	10.21617	3.35141	0.32805	-0.21237	3.34868
	4.64562	1.07542	0.23149	-0.59261	3.72612
Fortnight 15	145.95454	69.24004	0.47439	0.01286	2.70269
	1.00000	0.47439	0.47439	0.01286	2.70269
	11.65664	3.21297	0.27563	-0.73412	3.67831
	5.09064	1.00364	0.19715	-1.08553	4.67901
Fortnight 16	159.60979	94.65244	0.59302	0.78826	3.65013
	1.00000	0.59302	0.59302	0.78827	3.65013
	12.04784	3.84865	0.31945	0.00812	2.99002
	5.19265	1.14644	0.22078	-0.28893	3.12778
Fortnight 17	168.98022	75.12686	0.44459	-0.05609	2.50331
	1.00000	0.44459	0.44459	-0.05609	2.50331
	12.61298	3.18344	0.25239	-0.66633	3.36906
	5.37587	0.95427	0.17751	-0.92205	3.94575
Fortnight 18	137.75237	74.73383	0.54252	0.93581	4.04297
	1.00000	0.54252	0.54252	0.93581	4.04297
	11.30226	3.20240	0.28334	0.10066	3.50192
	4.98970	0.96931	0.19426	-0.25219	3.80259

Fortnight no.	mean	sd	cv	cs	ck
1	2	3	4	5	6
Fortnight 19	138.33667	81.25194	0.58735	1.02796	4.66890
	1.00000	0.58735	0.58735	1.02796	4.66890
	11.24266	3.49722	0.31107	0.07097	3.48143
	4.96175	1.06574	0.21479	-0.29542	3.63605
Fortnight 20	99.66455	59.67454	0.59875	0.55493	3.68035
	1.00000	0.59875	0.59875	0.55493	3.68035
	9.31963	3.62236	0.38868	-0.91350	4.52955
	4.34719	1.25294	0.28822	-1.37618	5.47787
Fortnight 21	94.32500	63.35838	0.67170	0.35091	2.54452
	1.00000	0.67170	0.67170	0.35091	2.54452
	8.92867	3.86781	0.43319	-0.59120	3.09906
	4.21239	1.31722	0.31270	-0.86736	3.49395
Fortnight 22	62.90382	78.54150	1.24860	2.01855	7.08048
	1.00000	1.24860	1.24860	2.01855	7.08048
	6.43022	4.69913	0.73079	0.66033	3.34310
	3.30369	1.63355	0.49446	0.29358	2.75180
Fortnight 23	36.32119	60.43034	1.66378	2.18809	7.32823
	1.00000	1.66378	1.66378	2.18809	7.32823
	3.99785	4.56447	1.14173	1.06404	3.43676
	2.44074	1.62079	0.66406	0.89289	2.92342
Fortnight 24	12.23262	25.80158	2.10924	2.31742	7.47700
	1.00000	2.10924	2.10924	2.31742	7.47701
	1.76360	3.05693	1.73334	1.64732	4.48101
	1.62071	1.15754	0.71422	1.62402	4.31188
Fortnight 25	2.37310	8.33393	3.51184	4.74636	26.45635
	1.00000	3.51184	3.51184	4.74636	26.45637
	0.52723	1.46500	2.77867	3.21569	13.38980
	1.19061	0.54704	0.45947	3.39962	14.64442
Fortnight 26	1.55167	4.61292	2.97288	3.65576	16.07208
	1.00000	2.97288	2.97288	3.65576	16.07208
	0.47870	1.16395	2.43147	2.65882	9.34502
	1.14900	0.43318	0.37701	2.92051	11.07941

sd = standard deviation.  
 cv = coefficient of variance.  
 cs = coefficient of skewness.  
 ck = coefficient of kurtosis.

o.d - original data.  
 m.d - modular data.  
 s.d - squareroot data.  
 c.d - cuberoot data.

Table A-3 Statistical parameters for monthly data series

Month no.	mean	sd	cv	cs	ck
1	2	3	4	5	6
Month 1	9.48548	19.29774	2.03445	2.61161	9.96395 (o.d)
	1.00000	2.03445	2.03445	2.61161	9.96395 (m.d)
	1.66508	2.62235	1.57491	1.51794	4.38701 (s.d)
	1.60037	0.99486	0.62165	1.54815	4.30437 (c.d)
Month 2	19.30095	27.18406	1.40843	2.51704	11.17227
	1.00000	1.40843	1.40843	2.51704	11.17227
	3.24130	3.00157	0.92604	0.67942	3.22752
	2.18541	1.14543	0.52413	0.57578	2.70892
Month 3	24.92357	28.29357	1.13521	1.20255	4.06290
	1.00000	1.13521	1.13521	1.20255	4.06290
	3.92552	3.12184	0.77527	0.27261	2.15987
	2.43267	1.20812	0.47662	0.21709	1.95216
Month 4	21.23143	28.38456	1.33691	2.12940	7.97794
	1.00000	1.33691	1.33691	2.12940	7.97794
	3.55356	2.96876	0.83543	0.66159	3.21270
	2.30010	1.12810	0.49045	0.56601	2.79576
Month 5	36.87547	39.61240	1.07422	1.12125	3.65946
	1.00000	1.07422	1.07422	1.12125	3.65946
	4.91231	3.61324	0.73555	0.19157	2.17389
	2.75769	1.40951	0.51112	-0.00882	1.97831
Month 6	92.23215	73.91199	0.80137	1.04439	4.18124
	1.00000	0.80137	0.80137	1.04439	4.18124
	8.72181	4.06895	0.46653	0.01639	2.84580
	4.13219	1.36082	0.32932	-0.31454	2.88980
Month 7	228.33646	103.92408	0.45514	0.12209	2.83775
	1.00000	0.45514	0.45514	0.12209	2.83775
	14.62315	3.85402	0.26356	-0.82804	4.61235
	5.92462	1.12840	0.19046	-1.33250	6.34032
Month 8	305.56427	111.72810	0.36565	0.12749	2.99008
	1.00000	0.36565	0.36565	0.12749	2.99008
	17.16609	3.33998	0.19457	-0.37095	3.12266
	6.62552	0.88087	0.13295	-0.54609	3.30324
Month 9	306.73264	111.07384	0.36212	0.49812	3.62470
	1.00000	0.36212	0.36212	0.49812	3.62470
	17.22208	3.22176	0.18707	-0.08978	3.50238
	6.64270	0.84175	0.12672	-0.30481	3.67347

```

~~~~~
Month no.  mean      sd      cv      cs      ck
~~~~~
      1          2          3          4          5          6
~~~~~
Month 10
 238.00119  96.95374  0.40737  0.46624  3.01928
   1.00000   0.40737  0.40737  0.46624  3.01928
  15.10434   3.17817  0.21041  0.03096  2.63852
   6.08034   0.86329  0.14198 -0.10970  2.59075

Month 11
 157.22879 102.90873  0.65452  1.72831  6.95441
   1.00000   0.65452  0.65452  1.72831  6.95441
  11.97566   3.76157  0.31410  0.84610  4.07244
   5.18062   1.07561  0.20762  0.56805  3.50566

Month 12
  48.55381  62.27452  1.28259  1.51962  5.08758
   1.00000   1.28259  1.28259  1.51962  5.08758
   5.14130   4.76029  0.92589  0.48455  2.30180
   2.83869   1.71668  0.60474  0.32309  1.98170

```

sd = standard deviation.

cv = coefficient of variance.

cs = coefficient of skewness.

ck = coefficient of kurtosis.

o.d - original data.

m.d - modular data.

s.d - squareroot data.

c.d - cuberoot data.

---

Table A - 4 Serial correlation coefficients of different weeks for original and transformed data

Week 1													
1	0.176	2	-0.049	3	-0.059	4	-0.061	5	-0.050	6	-0.003	7	-0.062
8	-0.064	9	-0.065	10	-0.067	11	-0.069	12	-0.070	13	-0.072	14	-0.074
15	-0.076	(original data)											
1	0.176	2	-0.049	3	-0.059	4	-0.061	5	-0.050	6	-0.003	7	-0.062
8	-0.064	9	-0.065	10	-0.067	11	-0.069	12	-0.070	13	-0.072	14	-0.074
15	-0.076	(modular data)											
1	0.312	2	-0.033	3	-0.096	4	-0.083	5	-0.028	6	-0.088	7	-0.093
8	-0.096	9	-0.099	10	-0.102	11	-0.104	12	-0.102	13	-0.105	14	-0.108
15	-0.111	(squareroot data)											
1	0.299	2	-0.036	3	-0.087	4	-0.085	5	-0.070	6	0.073	7	-0.083
8	-0.086	9	-0.089	10	-0.091	11	-0.094	12	-0.095	13	-0.097	14	-0.100
15	-0.103	(cuberoot data)											
Week 5													
1	-0.097	2	0.172	3	-0.122	4	-0.141	5	-0.143	6	0.191	7	-0.113
8	0.020	9	-0.102	10	-0.078	11	-0.071	12	-0.077	13	-0.041	14	-0.073
15	0.054	(o.d)											
1	-0.097	2	0.172	3	-0.122	4	-0.141	5	-0.143	6	0.191	7	-0.113
8	0.020	9	-0.102	10	-0.078	11	-0.071	12	-0.077	13	-0.041	14	-0.073
15	0.054	(m.d)											
1	-0.082	2	0.215	3	-0.081	4	-0.191	5	-0.177	6	0.100	7	-0.104
8	0.062	9	-0.148	10	-0.055	11	-0.084	12	-0.112	13	-0.009	14	-0.100
15	0.140	(s.d)											
1	-0.075	2	0.241	3	-0.298	4	-0.124	5	-0.193	6	0.170	7	-0.102
8	0.076	9	-0.087	10	-0.078	11	-0.059	12	-0.073	13	-0.049	14	-0.065
15	0.096	(c.d)											
Week 10													
1	-0.130	2	0.092	3	0.159	4	-0.145	5	0.090	6	-0.171	7	-0.204
8	-0.022	9	-0.095	10	-0.005	11	-0.051	12	-0.035	13	0.059	14	-0.096
15	-0.065	(o.d)											
1	-0.130	2	0.092	3	0.159	4	-0.145	5	0.090	6	-0.171	7	-0.204
8	-0.022	9	-0.095	10	-0.005	11	-0.051	12	-0.035	13	0.059	14	-0.096
15	-0.065	(m.d)											
1	-0.082	2	0.058	3	0.136	4	-0.143	5	0.044	6	-0.159	7	-0.294
8	-0.011	9	-0.041	10	-0.011	11	-0.064	12	0.031	13	0.105	14	-0.076
15	-0.031	(s.d)											
1	-0.096	2	0.063	3	0.131	4	-0.156	5	0.039	6	-0.165	7	-0.284
8	0.003	9	-0.056	10	0.012	11	-0.046	12	0.044	13	0.109	14	-0.067
15	-0.038	(c.d)											
Week 15													
1	-0.003	2	-0.090	3	-0.129	4	0.001	5	-0.008	6	0.046	7	0.150
8	0.025	9	-0.098	10	-0.105	11	-0.128	12	-0.100	13	0.110	14	0.048
15	-0.047	(o.d)											
1	-0.003	2	-0.090	3	-0.129	4	0.001	5	-0.008	6	0.046	7	0.150
8	0.025	9	-0.098	10	-0.105	11	-0.128	12	-0.100	13	0.110	14	0.048
15	-0.047	(m.d)											
1	0.029	2	-0.157	3	-0.157	4	0.044	5	0.006	6	0.049	7	0.093
8	0.088	9	-0.115	10	-0.156	11	-0.140	12	-0.074	13	0.142	14	-0.001
15	-0.082	(s.d)											
1	0.039	2	-0.146	3	-0.105	4	0.029	5	0.006	6	0.083	7	0.090
8	0.023	9	-0.108	10	-0.136	11	-0.141	12	-0.171	13	0.131	14	0.064
15	-0.158	(c.d)											

## Week 20

1	-0.155	2	0.262	3	-0.134	4	0.108	5	0.027	6	-0.088	7	0.249
8	0.138	9	-0.080	10	0.007	11	-0.158	12	0.181	13	-0.109	14	0.030
15	0.190	(o.d)											
1	-0.155	2	0.262	3	-0.134	4	0.108	5	0.027	6	-0.088	7	0.249
8	0.138	9	-0.080	10	0.007	11	-0.158	12	0.181	13	-0.109	14	0.030
15	0.190	(m.d)											
1	-0.093	2	0.281	3	-0.211	4	-0.052	5	0.048	6	-0.080	7	0.362
8	0.169	9	-0.025	10	-0.004	11	-0.200	12	0.105	13	-0.097	14	0.083
15	0.231	(s.d)											
1	-0.083	2	0.250	3	-0.218	4	-0.084	5	0.022	6	-0.069	7	0.376
8	0.155	9	-0.031	10	-0.052	11	-0.197	12	0.130	13	-0.092	14	0.108
15	0.198												

## Week 25

1	0.007	2	-0.142	3	0.048	4	0.123	5	0.098	6	0.247	7	-0.002
8	-0.227	9	0.160	10	0.139	11	-0.146	12	-0.099	13	0.035	14	-0.002
15	0.036	(o.d)											
1	0.007	2	-0.142	3	0.048	4	0.123	5	0.098	6	0.247	7	-0.002
8	-0.227	9	0.160	10	0.139	11	-0.146	12	-0.099	13	0.035	14	-0.002
15	0.036	(m.d)											
1	0.076	2	-0.219	3	0.090	4	0.161	5	0.109	6	0.255	7	0.021
8	-0.240	9	0.124	10	0.169	11	-0.092	12	-0.090	13	-0.061	14	-0.000
15	0.115	(s.d)											
1	0.091	2	-0.250	3	0.098	4	0.161	5	0.098	6	0.226	7	0.028
8	-0.207	9	0.098	10	0.152	11	-0.077	12	-0.059	13	-0.098	14	-0.012
15	0.138	(c.d)											

## Week 30

1	0.110	2	-0.225	3	0.211	4	0.078	5	-0.035	6	0.062	7	0.118
8	-0.010	9	-0.172	10	0.022	11	-0.023	12	-0.206	13	0.094	14	0.106
15	-0.026	(o.d)											
1	0.110	2	-0.225	3	0.211	4	0.078	5	-0.035	6	0.062	7	0.118
8	-0.010	9	-0.172	10	0.022	11	-0.023	12	-0.206	13	0.094	14	0.106
15	-0.026	(m.d)											
1	0.171	2	-0.295	3	0.045	4	0.034	5	-0.045	6	0.140	7	0.202
8	-0.009	9	-0.168	10	-0.000	11	-0.053	12	-0.173	13	0.100	14	0.140
15	0.020	(s.d)											
1	0.183	2	-0.315	3	-0.012	4	0.016	5	-0.046	6	0.165	7	0.225
8	-0.007	9	-0.167	10	-0.011	11	-0.060	12	-0.161	13	0.096	14	0.147
15	0.029	(c.d)											

## Week 35

1	0.015	2	0.067	3	0.011	4	-0.172	5	-0.105	6	0.080	7	0.219
8	0.012	9	0.019	10	0.116	11	0.085	12	0.031	13	0.017	14	0.133
15	-0.102	(o.d)											
1	0.015	2	0.067	3	0.011	4	-0.172	5	-0.105	6	0.080	7	0.219
8	0.012	9	0.019	10	0.116	11	0.085	12	0.031	13	0.017	14	0.133
15	-0.102	(m.d)											
1	-0.009	2	0.092	3	-0.078	4	-0.228	5	-0.117	6	0.055	7	0.212
8	-0.013	9	0.027	10	0.071	11	0.081	12	0.036	13	0.076	14	0.063
15	-0.029	(s.d)											
1	-0.024	2	0.099	3	-0.102	4	-0.246	5	-0.119	6	0.037	7	0.198
8	-0.028	9	0.025	10	0.046	11	0.076	12	0.040	13	0.090	14	0.038
15	0.001	(c.d)											

## Week 40

1	-0.157	2	-0.068	3	-0.177	4	0.262	5	-0.068	6	-0.037	7	-0.020
8	0.345	9	0.003	10	-0.087	11	-0.119	12	0.147	13	-0.089	14	0.095
15	-0.263	(o.d)											
1	-0.157	2	-0.068	3	-0.177	4	0.262	5	-0.068	6	-0.037	7	-0.020
8	0.345	9	0.003	10	-0.087	11	-0.119	12	0.147	13	-0.089	14	0.095
15	-0.263	(m.d)											
1	-0.201	2	0.010	3	-0.116	4	0.285	5	0.068	6	-0.116	7	-0.019
8	0.207	9	0.033	10	-0.076	11	-0.107	12	0.053	13	-0.036	14	0.096
15	-0.230	(s.d)											
1	-0.201	2	0.024	3	-0.104	4	0.259	5	0.094	6	-0.129	7	-0.048
8	0.166	9	0.029	10	-0.064	11	-0.125	12	0.025	13	-0.016	14	0.085
15	-0.219	(c.d)											

## Week 45

1	0.080	2	-0.123	3	-0.035	4	0.078	5	0.029	6	0.116	7	-0.066
8	-0.071	9	-0.027	10	-0.065	11	-0.043	12	-0.025	13	-0.024	14	-0.059
15	0.100	(o.d)											
1	0.080	2	-0.123	3	-0.035	4	0.078	5	0.029	6	0.116	7	-0.066
8	-0.071	9	-0.027	10	-0.065	11	-0.043	12	-0.029	13	0.116	14	-0.066
15	0.100	(m.d)											
1	0.115	2	-0.252	3	-0.061	4	0.040	5	0.063	6	0.130	7	-0.112
8	-0.131	9	-0.034	10	-0.067	11	-0.006	12	0.038	13	-0.028	14	-0.054
15	0.238	(s.d)											
1	0.126	2	-0.259	3	-0.097	4	0.047	5	0.073	6	0.141	7	-0.103
8	-0.133	9	-0.023	10	-0.063	11	-0.003	12	0.035	13	-0.024	14	-0.076
15	0.241	(c.d)											

## Week 50

1	-0.047	2	-0.068	3	-0.069	4	-0.071	5	0.339	6	-0.074	7	-0.076
8	-0.077	9	-0.079	10	-0.074	11	-0.071	12	-0.072	13	0.044	14	0.083
15	-0.059	(o.d)											
1	-0.047	2	-0.068	3	-0.069	4	0.071	5	0.339	6	-0.074	7	-0.076
8	-0.077	9	-0.079	10	-0.074	11	-0.071	12	-0.072	13	0.044	14	0.083
15	-0.059	(m.d)											
1	0.001	2	-0.095	3	-0.097	4	-0.100	5	0.332	6	-0.104	7	-0.106
8	-0.108	9	-0.110	10	-0.098	11	-0.086	12	-0.088	13	0.142	14	0.187
15	-0.069	(s.d)											
1	-0.010	2	-0.093	3	-0.095	4	-0.097	5	0.349	6	-0.101	7	-0.103
8	-0.105	9	-0.107	10	-0.096	11	-0.085	12	-0.088	13	0.123	14	0.174
15	-0.068	(c.d)											

## Week 52

1	-0.049	2	-0.050	3	-0.051	4	-0.052	5	-0.047	6	-0.040	7	-0.041
8	-0.042	9	-0.043	10	-0.045	11	0.127	12	-0.047	13	-0.048	14	-0.049
15	-0.050	(o.d)											
1	-0.049	2	-0.050	3	-0.051	4	-0.052	5	-0.047	6	-0.040	7	-0.041
8	-0.042	9	-0.043	10	-0.045	11	0.127	12	-0.047	13	-0.048	14	-0.049
15	-0.050	(m.d)											
1	-0.069	2	-0.070	3	-0.070	4	-0.074	5	-0.060	6	-0.045	7	-0.046
8	-0.048	9	-0.049	10	-0.051	11	0.269	12	-0.054	13	-0.056	14	-0.057
15	-0.059	(s.d)											
1	-0.043	2	-0.044	3	-0.045	4	-0.046	5	-0.044	6	-0.038	7	-0.039
8	-0.040	9	-0.041	10	-0.042	11	0.047	12	-0.044	13	-0.045	14	-0.046
15	-0.046	(c.d)											

o.d - original data. m.d - modular data.  
s.d - squareroot data. c.d - cuberoot data.

Table A - 5 Serial correlation coefficients of different fortnights for original and transformed data

## Fortnight 1

1	0.466	2	0.148	3	-0.097	4	-0.107	5	-0.132	6	-0.091	7	-0.141
8	-0.104	9	0.020	10	-0.013	11	-0.083	12	-0.144	13	-0.132	14	-0.125
15	-0.113	(o.d)											
1	0.466	2	0.148	3	-0.097	4	-0.107	5	-0.132	6	-0.091	7	-0.141
8	-0.104	9	0.020	10	-0.013	11	-0.083	12	-0.144	13	-0.132	14	-0.125
15	-0.113	(m.d)											
1	0.430	2	0.176	3	-0.119	4	-0.065	5	-0.169	6	-0.053	7	-0.183
8	-0.108	9	-0.003	10	0.033	11	-0.079	12	-0.198	13	-0.141	14	-0.128
15	-0.113	(s.d)											
1	0.442	2	0.186	3	-0.103	4	-0.098	5	-0.193	6	-0.076	7	-0.193
8	-0.094	9	0.009	10	0.043	11	-0.062	12	-0.192	13	-0.139	14	-0.128
15	-0.117	(c.d)											

## Fortnight 5

1	-0.112	2	0.066	3	0.069	4	-0.182	5	-0.042	6	-0.127	7	-0.280
8	-0.022	9	-0.023	10	0.054	11	0.120	12	0.074	13	0.075	14	-0.080
15	0.026	(o.d)											
1	-0.112	2	0.066	3	0.069	4	-0.182	5	-0.042	6	-0.127	7	-0.280
8	-0.022	9	-0.023	10	0.054	11	0.120	12	0.074	13	0.075	14	-0.080
15	0.026	(m.d)											
1	-0.134	2	0.106	3	0.037	4	-0.160	5	-0.113	6	-0.069	7	-0.311
8	-0.018	9	0.023	10	0.012	11	0.219	12	0.030	13	0.121	14	-0.112
15	-0.024	(s.d)											
1	-0.144	2	0.105	3	0.036	4	-0.158	5	-0.112	6	-0.061	7	-0.313
8	-0.001	9	0.015	10	0.012	11	0.225	12	0.025	13	0.117	14	-0.097
15	-0.025	(c.d)											

## Fortnight 10

1	0.122	2	-0.073	3	-0.238	4	-0.127	5	-0.127	6	0.026	7	0.050
8	0.176	9	0.077	10	-0.039	11	-0.123	12	-0.068	13	0.033	14	0.164
15	0.155	(o.d)											
1	0.122	2	-0.073	3	-0.238	4	-0.127	5	-0.127	6	0.026	7	0.050
8	0.176	9	0.077	10	-0.039	11	-0.123	12	-0.068	13	0.033	14	0.164
15	0.155	(m.d)											
1	0.079	2	0.061	3	-0.261	4	-0.133	5	-0.104	6	-0.024	7	0.156
8	0.218	9	0.153	10	0.091	11	-0.207	12	-0.113	13	-0.040	14	0.108
15	0.139	(s.d)											
1	0.042	2	0.079	3	-0.263	4	-0.156	5	-0.123	6	-0.053	7	0.174
8	0.181	9	0.151	10	0.076	11	-0.195	12	-0.074	13	-0.070	14	0.078
15	0.128	(c.d)											

## Fortnight 15

1	0.432	2	0.046	3	-0.176	4	-0.142	5	-0.091	6	0.143	7	0.213
8	0.006	9	-0.283	10	-0.067	11	0.008	12	0.046	13	0.189	14	0.204
15	0.112	(o.d)											
1	0.442	2	0.046	3	-0.176	4	-0.142	5	-0.091	6	0.143	7	0.213
8	0.006	9	-0.283	10	-0.067	11	0.008	12	0.046	13	0.189	14	0.204
15	0.112	(m.d)											
1	0.351	2	-0.004	3	-0.218	4	-0.170	5	-0.064	6	0.194	7	0.270
8	0.022	9	-0.276	10	-0.059	11	0.015	12	0.053	13	0.226	14	0.221
15	0.128	(s.d)											
1	0.308	2	-0.021	3	-0.229	4	-0.175	5	-0.049	6	0.219	7	0.289
8	0.029	9	-0.256	10	-0.055	11	0.011	12	0.049	13	0.228	14	0.214
15	0.125	(c.d)											

## Fortnight 20

1	-0.343	2	-0.037	3	-0.051	4	-0.034	5	0.076	6	-0.017	7	-0.029
8	0.056	9	0.164	10	-0.059	11	-0.054	12	0.003	13	0.003	14	0.043
15	-0.108	(o.d)											
1	-0.343	2	-0.037	3	-0.051	4	-0.034	5	0.076	6	-0.017	7	-0.029
8	0.056	9	0.164	10	-0.059	11	-0.054	12	0.003	13	0.003	14	0.043
15	-0.018	(m.d)											
1	-0.349	2	0.085	3	-0.034	4	-0.028	5	0.215	6	-0.061	7	0.029
8	0.022	9	0.097	10	-0.024	11	-0.024	12	-0.032	13	0.006	14	0.053
15	-0.094	(s.d)											
1	-0.332	2	0.133	3	-0.026	4	-0.031	5	0.257	6	-0.067	7	0.037
8	-0.002	9	0.085	10	-0.020	11	-0.021	12	-0.037	13	0.001	14	0.050
15	-0.097	(c.d)											

## Fortnight 25

1	-0.057	2	0.052	3	0.102	4	-0.093	5	0.330	6	-0.097	7	-0.099
8	-0.101	9	-0.103	10	-0.099	11	-0.095	12	-0.097	13	0.014	14	0.055
15	-0.074	(o.d)											
1	-0.057	2	0.052	3	0.102	4	-0.093	5	0.330	6	-0.097	7	-0.099
8	-0.101	9	-0.103	10	-0.099	11	-0.095	12	-0.097	13	0.014	14	0.055
15	-0.074	(m.d)											
1	0.009	2	0.181	3	0.207	4	-0.149	5	0.248	6	-0.155	7	-0.159
8	-0.162	9	-0.165	10	-0.151	11	-0.139	12	-0.142	13	0.061	14	0.107
15	-0.067	(s.d)											
1	-0.014	2	0.151	3	0.186	4	-0.140	5	0.278	6	-0.146	7	-0.149
8	-0.152	9	-0.155	10	-0.142	11	-0.131	12	-0.134	13	0.055	14	0.107
15	-0.078	(c.d)											

Fortnight 26													
1	-0.085	2	-0.121	3	-0.127	4	-0.019	5	0.111	6	-0.017	7	-0.113
8	0.507	9	-0.119	10	-0.122	11	-0.074	12	0.007	13	0.108	14	-0.013
5	-0.091	(o.d)											
1	-0.085	2	-0.121	3	-0.127	4	-0.019	5	0.111	6	-0.017	7	-0.113
8	0.507	9	-0.119	10	-0.122	11	-0.074	12	0.007	13	0.108	14	-0.013
5	-0.091	(m.d)											
1	-0.079	2	-0.139	3	-0.190	4	0.053	5	0.089	6	0.052	7	-0.154
8	0.422	9	-0.163	10	-0.167	11	-0.074	12	0.032	13	0.112	14	0.050
5	-0.107	(s.d)											
1	-0.054	2	-0.195	3	-0.133	4	0.051	5	0.134	6	-0.060	7	-0.111
8	0.479	9	-0.117	10	-0.120	11	-0.077	12	0.040	13	0.141	14	-0.066
5	-0.093	(c.d)											

.d - original data.  
 .d - modular data.  
 .d - squareroot data.  
 .d - cuberoot data.

Table A - 6 Serial correlation coefficients of different months for original and transformed data

Month 1													
1	0.353	2	0.042	3	-0.184	4	-0.089	5	0.010	6	-0.108	7	-0.151
8	-0.133	9	-0.027	10	-0.011	11	-0.139	12	-0.161	13	0.034	14	0.005
5	0.003	(o.d)											
1	0.353	2	0.042	3	-0.184	4	-0.089	5	0.010	6	-0.108	7	-0.151
8	-0.133	9	-0.027	10	-0.011	11	-0.139	12	-0.161	13	0.034	14	0.005
5	0.003	(m.d)											
1	0.301	5	0.001	3	-0.226	4	0.015	5	0.078	6	-0.017	7	-0.217
3	-0.148	9	-0.023	10	-0.013	11	-0.191	12	-0.202	13	-0.010	14	0.042
5	0.022	(s.d)											
1	0.300	2	0.022	3	-0.221	4	-0.034	5	0.040	6	-0.033	7	-0.205
3	-0.128	9	-0.031	10	0.004	11	-0.162	12	-0.180	13	0.016	14	0.033
5	0.013	(c.d)											
Month 5													
1	0.115	2	-0.065	3	-0.212	4	0.047	5	-0.174	6	-0.072	7	0.082
3	0.148	9	0.132	10	-0.063	11	-0.073	12	-0.047	13	0.055	14	0.036
5	0.177	(o.d)											
1	0.115	2	-0.065	3	-0.212	4	0.047	5	-0.174	6	-0.072	7	0.082
3	0.148	9	0.132	10	-0.063	11	-0.073	12	-0.047	13	0.055	14	0.036
5	0.177	(m.d)											
1	0.104	2	-0.018	3	-0.235	4	0.036	5	-0.088	6	-0.121	7	0.105
3	0.155	9	0.127	10	0.038	11	-0.103	12	-0.148	13	-0.077	14	0.007
5	0.206	(s.d)											
1	0.066	2	0.048	3	-0.253	4	0.057	5	-0.081	6	-0.117	7	0.070
3	0.140	9	0.118	10	0.025	11	-0.110	12	-0.152	13	-0.088	14	0.011
5	0.193	(c.d)											

Fortnight 26													
1	-0.085	2	-0.121	3	-0.127	4	-0.019	5	0.111	6	-0.017	7	-0.113
8	0.507	9	-0.119	10	-0.122	11	-0.074	12	0.007	13	0.108	14	-0.013
15	-0.091	(o.d)											
1	-0.085	2	-0.121	3	-0.127	4	-0.019	5	0.111	6	-0.017	7	-0.113
8	0.507	9	-0.119	10	-0.122	11	-0.074	12	0.007	13	0.108	14	-0.013
15	-0.091	(m.d)											
1	-0.079	2	-0.139	3	-0.190	4	0.053	5	0.089	6	0.052	7	-0.154
8	0.422	9	-0.163	10	-0.167	11	-0.074	12	0.032	13	0.112	14	0.050
15	-0.107	(s.d)											
1	-0.054	2	-0.195	3	-0.133	4	0.051	5	0.134	6	-0.060	7	-0.111
8	0.479	9	-0.117	10	-0.120	11	-0.077	12	0.040	13	0.141	14	-0.066
15	-0.093	(c.d)											

o.d - original data.  
m.d - modular data.  
s.d - squareroot data.  
c.d - cuberoot data.

Table A - 6 Serial correlation coefficients of different months for original and transformed data

Month 1													
1	0.353	2	0.042	3	-0.184	4	-0.089	5	0.010	6	-0.108	7	-0.151
8	-0.133	9	-0.027	10	-0.011	11	-0.139	12	-0.161	13	0.034	14	0.005
15	0.003	(o.d)											
1	0.353	2	0.042	3	-0.184	4	-0.089	5	0.010	6	-0.108	7	-0.151
8	-0.133	9	-0.027	10	-0.011	11	-0.139	12	-0.161	13	0.034	14	0.005
15	0.003	(m.d)											
1	0.301	5	0.001	3	-0.226	4	0.015	5	0.078	6	-0.017	7	-0.217
8	-0.148	9	-0.023	10	-0.013	11	-0.191	12	-0.202	13	-0.010	14	0.042
15	0.022	(s.d)											
1	0.300	2	0.022	3	-0.221	4	-0.034	5	0.040	6	-0.033	7	-0.205
8	-0.128	9	-0.031	10	0.004	11	-0.162	12	-0.180	13	0.016	14	0.033
15	0.013	(c.d)											
Month 5													
1	0.115	2	-0.065	3	-0.212	4	0.047	5	-0.174	6	-0.072	7	0.082
8	0.148	9	0.132	10	-0.063	11	-0.073	12	-0.047	13	0.055	14	0.036
15	0.177	(o.d)											
1	0.115	2	-0.065	3	-0.212	4	0.047	5	-0.174	6	-0.072	7	0.082
8	0.148	9	0.132	10	-0.063	11	-0.073	12	-0.047	13	0.055	14	0.036
15	0.177	(m.d)											
1	0.104	2	-0.018	3	-0.235	4	0.036	5	-0.088	6	-0.121	7	0.105
8	0.155	9	0.127	10	0.038	11	-0.103	12	-0.148	13	-0.077	14	0.007
15	0.206	(s.d)											
1	0.066	2	0.048	3	-0.253	4	0.057	5	-0.081	6	-0.117	7	0.070
8	0.140	9	0.118	10	0.025	11	-0.110	12	-0.152	13	-0.088	14	0.011
15	0.193	(c.d)											

Month 10

1	-0.250	2	-0.271	3	0.132	4	-0.119	5	0.159	6	0.019	7	-0.046
8	0.025	9	-0.090	10	-0.060	11	0.110	12	-0.211	13	0.198	14	0.157
15	-0.225	(o.d)											
1	-0.250	2	-0.271	3	0.132	4	-0.119	5	0.159	6	0.019	7	-0.046
8	0.025	9	-0.090	10	-0.060	11	0.110	12	-0.211	13	0.198	14	0.157
15	-0.225	(m.d)											
1	-0.255	2	-0.249	3	0.141	4	-0.145	5	0.177	6	0.041	7	-0.069
8	0.018	9	-0.089	10	-0.065	11	0.108	12	-0.234	13	0.205	14	0.154
15	-0.229	(s.d)											
1	-0.255	2	-0.241	3	0.143	4	-0.151	5	0.180	6	0.046	7	-0.027
8	0.014	9	-0.090	10	-0.065	11	0.107	12	-0.241	13	0.208	14	0.154
15	-0.230	(c.d)											

Month 12

1	0.028	2	-0.108	3	0.040	4	0.068	5	-0.059	6	-0.057	7	-0.070
8	-0.096	9	-0.017	10	-0.020	11	0.011	12	-0.123	13	0.190	14	-0.106
15	0.049	(o.d)											
1	0.028	2	-0.108	3	0.040	4	0.068	5	-0.059	6	-0.057	7	-0.070
8	-0.096	9	-0.017	10	-0.020	11	0.011	12	-0.123	13	0.190	14	-0.106
15	0.049	(m.d)											
1	-0.045	2	-0.167	3	0.001	4	0.011	5	0.022	6	-0.104	7	-0.072
8	-0.025	9	-0.073	10	-0.082	11	0.027	12	-0.169	13	0.173	14	-0.149
15	0.079	(s.d)											
1	-0.032	2	-0.167	3	-0.017	4	-0.0089	5	0.052	6	-0.110	7	-0.067
8	-0.018	9	-0.091	10	-0.086	11	0.018	12	-0.168	13	0.158	14	-0.163
15	0.078	(c.d)											

o.d - original data.  
m.d - modular data.  
s.d - squareroot data.  
c.d - cuberoot data.

---

Table A-8 Chi-square values of different fortnights for different probability distribution for original and transformed data

Normal distribution				
Fortnight no.	o.d	m.d	s.d	c.d
1	173.86	173.86	236.05	28.80*
5	407.49	407.49	56.80*	41.33*
10	110.06	110.06	169.22	27.36*
15	565.16	565.16	314.30	74.96
20	123.58	123.58	103.74	29.65*
25	510.97	510.97	149.50	123.40
26	503.52	503.52	463.07	47.43*
Lognormal 2 distribution				
Fortnight no.	o.d	m.d	s.d	c.d
1	135.97	135.95	180.47	22.58*
5	321.83	321.83	45.51*	33.39*
10	94.47	94.47	143.73	23.73*
15	536.00	536.00	300.72	71.92
20	122.17	122.17	103.25	29.62*
25	516.36	516.36	150.49	124.13
26	505.92	505.92	463.83	47.48*
Lognormal 3 distribution				
Fortnight no.	o.d	m.d	s.d	c.d
1	135.97	135.97	139.91	10.67*
5	278.43	278.43	47.53*	5.01*
10	40.65*	40.65*	20.22*	9.01*
15	109.33	109.33	56.26*	8.84*
20	149.35	149.35	11.83*	2.88*
25	287.34	287.34	81.02	6.39*
26	246.73	246.73	20.27*	2.12*

o.d - original data.  
s.d - squareroot data.

m.d - modular data.  
c.d - cuberoot data.

Table A-7 Chi-square values of different weeks for different probability distribution for original and transformed data Y

Normal distribution

Week no.	o.d	m.d	s.d	c.d
1	184.99	184.99	28.61*	36.74*
5	310.00	310.00	145.60	16.66*
10	287.72	287.72	343.53	243.62
15	142.21	142.21	386.17	322.02
20	127.05	127.05	133.05	88.73
25	175.98	175.98	281.14	101.60
30	218.39	218.39	267.96	85.30
35	638.98	638.98	574.72	163.74
40	113.69	113.69	151.52	52.66*
45	175.80	175.80	398.18	173.89
50	223.54	223.54	66.06	54.27*
52	86.79	86.79	43.94*	51.63*

Lognormal 2 distribution

Week no.	o.d	m.d	s.d	c.d
1	159.02	159.02	24.70*	32.31*
5	277.19	277.19	129.81	14.86*
10	235.94	235.94	280.58	198.64
15	113.88	113.88	306.94	255.72
20	99.89	99.89	104.86	69.62
25	147.92	147.92	238.69	86.56
30	194.07	194.07	239.84	76.63
35	598.23	598.23	538.81	153.70
40	108.75	108.75	145.27	50.61*
45	172.70	172.70	389.68	169.87
50	215.21	215.21	63.57	52.24*
52	83.46	83.46	42.25*	49.65*

Lognormal 3 distribution

Week no.	o.d	m.d	s.d	c.d
1	159.02	159.02	5.14*	1.39*
5	43.09*	43.09*	16.82*	1.65*
10	85.18	85.18	84.58	6.62*
15	172.56	172.56	43.26*	4.05*
20	85.26	85.26	84.48	6.63*
25	110.74	110.74	18.67*	5.60*
30	99.07	99.07	12.89*	3.26*
35	176.80	176.80	154.10	3.92*
40	26.82*	26.82*	41.30*	13.21*
45	236.68	236.68	49.26*	27.45*
50	32.49*	32.49*	93.50	7.20*
52	12.13*	12.13*	5.61*	2.81*

o.d - original data.

s.d - squareroot data.

m.d - modular data.

c.d - cuberoot data.

Table A-8 Chi-square values of different fortnights for different probability distribution for original and transformed data

Normal distribution

Fortnight no.	o.d	m.d	s.d	c.d
1	173.86	173.86	236.05	28.80*
5	407.49	407.49	56.80*	41.33*
10	110.06	110.06	169.22	27.36*
15	565.16	565.16	314.30	74.96
20	123.58	123.58	103.74	29.65*
25	510.97	510.97	149.50	123.40
26	503.52	503.52	463.07	47.43*

Lognormal 2 distribution

Fortnight no.	o.d	m.d	s.d	c.d
1	135.97	135.95	180.47	22.58*
5	321.83	321.83	45.51*	33.39*
10	94.47	94.47	143.73	23.73*
15	536.00	536.00	300.72	71.92
20	122.17	122.17	103.25	29.62*
25	516.36	516.36	150.49	124.13
26	505.92	505.92	463.83	47.48*

Lognormal 3 distribution

Fortnight no.	o.d	m.d	s.d	c.d
1	135.97	135.97	139.91	10.67*
5	278.43	278.43	47.53*	5.01*
10	40.65*	40.65*	20.22*	9.01*
15	109.33	109.33	56.26*	8.84*
20	149.35	149.35	11.83*	2.88*
25	287.34	287.34	81.02	6.39*
26	246.73	246.73	20.27*	2.12*

o.d - original data.  
s.d - squareroot data.  
m.d - modular data.  
c.d - cuberoot data.

Table A-9 Chi-square values of different months for different probability distribution of original and transformed data

Normal distribution

Month no.	o.d	m.d	s.d	c.d
1	294.42	294.42	289.28	186.04
5	748.65	748.65	231.43	107.45
10	978.65	978.65	225.45	38.82*
12	639.02	639.02	560.14	97.90

Lognormal 2 distribution

Month no.	o.d	m.d	s.d	c.d
1	285.66	285.66	280.22	180.13
5	730.67	730.67	226.22	105.11
10	968.02	968.02	223.01	38.40*
12	632.13	632.13	554.12	96.90

Lognormal 3 distribution

Month no.	o.d	m.d	s.d	c.d
1	118.10	118.10	10.65	7.85*
5	405.55	405.55	22.76*	5.03*
10	412.84	412.84	89.44	1.11*
12	270.01	270.01	19.24*	4.08*

o.d - original data.  
s.d - squareroot data.

m.d - modular data.  
c.d - cuberoot data.

Table A-10 Forecasting of weekly cumulative rainfall by 3,5,7 and 9 year moving average method of 1966

Week no.	3	5	7	9	
Actual	Forecast	Forecast	Forecast	Forecast	
1	2	3	4	5	6
1	84.00	1.27	1.05	0.75	0.59
2	86.60	5.53	3.61	2.58	4.72
3	86.60	5.53	3.61	3.85	5.70
4	86.60	5.53	4.37	4.39	6.13
5	86.60	10.27	7.24	6.44	9.89
6	86.60	11.40	9.61	8.13	11.27
7	102.40	11.40	9.71	8.21	11.46
8	102.40	15.27	12.03	9.87	20.26
9	102.40	17.07	15.39	12.63	29.30
10	102.40	18.73	16.39	17.37	39.17
11	102.40	18.73	28.71	26.17	46.01
12	102.40	23.17	31.37	28.98	48.19
13	102.40	35.90	39.01	34.44	52.44
14	102.40	61.43	54.33	45.38	60.95
15	104.00	73.50	61.57	50.77	65.14
16	108.60	75.37	66.85	54.54	68.07
17	108.60	81.93	79.35	65.35	76.49
18	110.20	96.40	91.47	74.01	83.73
19	110.20	113.93	102.54	81.92	89.88
20	110.20	132.60	113.79	89.95	96.13
21	110.20	145.33	121.49	99.77	103.76
22	119.60	168.50	135.46	121.14	120.39
23	119.60	183.57	155.12	142.30	144.63
24	126.10	196.70	175.66	165.02	168.15
25	187.70	242.97	205.05	197.70	194.74
26	282.10	279.17	242.65	237.55	237.26
27	322.30	298.37	258.31	281.72	275.98
28	325.20	423.03	367.29	372.70	366.89
29	403.80	534.93	461.10	461.19	457.68
30	449.40	626.10	538.12	535.86	532.92
31	651.50	697.17	583.28	590.03	579.79
32	748.50	753.30	641.00	651.58	640.36
33	883.20	874.37	722.28	735.44	731.83
34	922.90	938.20	809.92	815.38	802.10
35	929.90	1020.13	881.06	884.59	864.60
36	1048.90	1101.93	952.10	957.25	927.89
37	1078.40	1154.47	1063.62	1057.44	1026.81
38	1153.70	1210.30	1114.64	1102.01	1067.43
39	1209.90	1282.20	1175.42	1152.76	1127.54
40	1212.60	1332.57	1212.58	1198.35	1174.82

contd.

Week no.	3	5	7	9	
	Actual	Forecast	Forecast	Forecast	
1	2	3	4	5	
				6	
41	1212.60	1348.63	1243.42	1241.17	1214.90
42	1315.80	1385.03	1278.90	1272.43	1244.83
43	1319.60	1449.73	1322.40	1312.96	1286.00
44	1319.60	1498.93	1381.00	1362.69	1329.17
45	1319.60	1498.93	1404.20	1379.41	1342.17
46	1319.60	1498.93	1404.20	1379.41	1346.04
47	1320.60	1498.93	1404.26	1379.45	1346.07
48	1418.90	1499.03	1404.26	1379.45	1350.11
49	1418.90	1499.03	1404.26	1379.45	1350.11
50	1418.90	1499.03	1404.26	1381.52	1351.71
51	1418.90	1499.03	1404.26	1381.52	1351.71
52	1418.90	1501.43	1405.70	1382.55	1352.51

Table A-11 Forecasting of total yearly rainfall by 3,5,7 and 9 year moving average method for the year 1953 - 1991

Year	Actual	Forecasted rainfall			
		3	5	7	9
1953	1339.93	1451.93	1451.93	1451.93	1451.93
1954	1612.11	1395.71	1395.71	1395.71	1395.71
1955	1836.42	1451.00	1461.57	1461.57	1461.57
1956	1934.71	1596.15	1527.13	1527.13	1527.13
1957	996.19	1794.41	1624.83	1582.71	1582.71
1958	1498.61	1589.11	1543.87	1509.51	1509.51
1959	1490.07	1476.50	1575.61	1516.99	1508.20
1960	1159.26	1328.29	1551.20	1529.72	1506.14
1961	1106.09	1382.65	1415.77	1503.91	1474.24
1962	1418.10	1251.81	1250.04	1431.62	1441.49
1963	1679.90	1227.82	1334.43	1371.86	1450.17
1964	1597.30	1401.36	1370.68	1335.46	1457.71
1965	1227.10	1565.10	1392.13	1421.33	1431.14
1966	1418.90	1501.43	1405.70	1382.55	1352.51
1967	1384.00	1414.43	1468.26	1372.38	1399.48
1968	1921.20	1343.33	1461.44	1404.48	1386.75
1969	1335.10	1574.70	1509.70	1520.93	1434.65
1970	1608.33	1546.77	1457.26	1509.07	1454.19
1971	1512.00	1621.54	1533.51	1498.85	1509.99
1972	1299.10	1485.14	1552.13	1486.66	1520.43
1973	1712.80	1473.14	1535.15	1496.95	1478.11
1974	1273.60	1507.97	1493.47	1538.93	1490.95
1975	1396.40	1428.50	1481.17	1523.16	1496.11
1976	1292.90	1460.93	1438.78	1448.19	1493.61
1977	1719.70	1460.93	1438.78	1442.16	1483.49
1978	1070.70	1320.97	1394.96	1442.16	1483.49
1979	1587.61	1469.67	1479.08	1458.07	1461.10
1980	1805.80	1469.67	1479.08	1458.07	1461.10
1981	1333.00	1361.10	1350.66	1395.03	1431.73
1982	1558.90	1459.34	1413.46	1436.24	1429.42
1983	1756.00	1459.34	1495.34	1449.53	1462.02
1984	1526.30	1488.04	1495.34	1449.53	1462.02
1985	1727.60	1575.47	1503.36	1458.02	1465.83
1986	1941.10	1575.47	1471.20	1481.23	1448.73
1987	1125.10	1565.90	1471.20	1481.23	1448.73
1988	1394.50	1565.90	1608.26	1547.39	1502.33
1989	1264.00	1549.30	1608.26	1547.39	1502.33
1990	2052.50	1549.30	1596.00	1519.76	1516.77
1991	1411.70	1613.73	1596.00	1519.76	1516.77

Table A-12 Forecasting of weekly cumulative rainfall by 3,5,7 and 9 year moving average method for the year 1992

Week no.	3yr	5yr	7yr	9yr
1	16.88	10.10	8.76	6.81
2	18.73	12.36	10.37	8.07
3	20.30	13.30	15.76	12.26
4	20.30	13.30	15.76	12.26
5	20.30	13.30	15.76	12.26
6	20.30	13.30	16.47	15.94
7	25.70	18.26	28.37	30.19
8	40.13	27.76	35.51	45.33
9	40.13	28.84	37.26	46.69
10	65.83	47.60	50.66	57.11
11	91.20	63.62	62.10	66.01
12	91.20	64.06	64.30	69.01
13	93.47	65.42	65.27	69.77
14	108.10	74.20	71.54	74.64
15	126.70	86.70	80.47	85.17
16	126.70	86.70	80.47	85.17
17	128.03	88.50	89.09	97.53
18	147.33	107.60	105.56	110.52
19	147.77	111.90	108.74	114.56
20	174.53	135.88	135.99	139.32
21	201.70	160.58	155.54	154.33
22	240.83	184.06	173.69	172.93
23	287.77	236.54	215.97	206.60
24	309.83	273.26	247.06	241.60
25	391.20	324.68	302.16	301.17
26	419.47	365.36	363.61	355.23
27	440.27	382.08	385.61	380.26
28	497.80	424.28	441.54	438.27
29	583.83	523.46	561.27	538.52
30	659.90	604.14	649.07	645.70
31	761.77	709.94	743.79	735.90
32	792.37	749.26	816.19	818.06
33	928.33	844.80	902.03	907.11
34	1001.77	917.22	986.33	1009.48
35	1151.83	1024.46	1073.70	1110.54
36	1187.07	1054.74	1101.51	1153.97
37	1237.53	1109.86	1165.00	1219.26
38	1271.57	1158.88	1219.43	1277.86
39	1351.30	1226.48	1299.34	1346.90
40	1356.37	1238.24	1323.76	1369.62
41	1422.80	1302.26	1403.77	1445.19
42	1461.00	1332.48	1439.19	1477.04
43	1464.87	1359.44	1468.39	1504.13
44	1465.90	1360.06	1468.33	1506.70
45	1570.47	1430.08	1529.44	1553.84

contd.

Week no.	3yr	5yr	7yr	9yr
46	1575.57	1433.14	1546.46	1567.08
47	1576.07	1448.20	1557.21	1575.44
48	1576.07	1448.88	1557.70	1576.24
49	1576.07	1448.88	1557.70	1576.24
50	1576.07	1448.88	1557.70	1576.24
51	1576.07	1449.56	1559.24	1577.44
52	1576.07	1449.56	1559.50	1577.44

Table A-13 Forecasting of weekly cumulative rainfall by exponential smoothing technique for the year 1966

Week.no	Actual	Forecasted	Week no.	Actual	forecasted
1	84.00	0.10	27	322.30	337.69
2	86.60	0.79	28	325.20	454.09
3	86.60	0.95	29	403.80	559.85
4	86.60	1.56	30	449.40	654.96
5	86.60	2.34	31	651.50	718.28
6	86.60	4.79	32	748.50	782.75
7	102.40	4.85	33	883.20	886.44
8	102.40	11.89	34	922.90	922.33
9	102.40	18.69	35	929.20	1004.39
10	102.40	23.77	36	1048.90	1099.30
11	102.40	28.72	37	1078.40	1163.08
12	102.40	31.41	38	1153.70	1195.17
13	102.40	35.20	39	1209.90	1283.15
14	102.40	41.79	40	1212.60	1310.27
15	104.00	51.48	41	1212.60	1333.59
16	108.60	85.87	42	1315.80	1337.97
17	108.60	85.87	43	1319.60	1406.00
18	110.20	88.18	44	1319.60	1437.89
19	110.20	112.89	45	1319.60	1437.89
20	110.20	126.06	46	1319.60	1437.89
21	110.20	134.39	47	1320.60	1437.89
22	119.60	152.75	48	1418.90	1437.89
23	119.60	178.32	49	1418.90	1437.89
24	126.10	203.44	50	1418.90	1437.89
25	187.70	238.42	51	1418.90	1437.89
26	282.10	284.31	52	1418.90	1437.89

Table A -14 Forecasting of total yearly rainfall by exponential smoothing method for the year 1952 - 1991

Year	Actual	Forecast	Year	Actual	Forecast
1952	1400.97	1041.29	1972	1299.10	1554.74
1953	1339.93	1487.69	1973	1712.80	1380.34
1954	1612.11	1615.35	1974	1273.60	1596.25
1955	1836.42	1827.91	1975	1396.40	1383.56
1956	1934.71	2048.52	1976	1292.90	1370.61
1957	996.19	2182.15	1977	1719.70	1294.13
1958	1498.61	1529.09	1978	1070.70	1569.94
1959	1490.07	1554.27	1979	1587.61	1235.04
1960	1159.26	1551.23	1980	1805.80	1448.74
1961	1106.09	1303.87	1981	1333.00	1711.37
1962	1418.10	1145.53	1982	1558.90	1490.76
1963	1679.90	1300.21	1983	1756.00	1542.60
1964	1597.30	1567.34	1984	1526.30	1707.86
1965	1227.10	1631.87	1985	1727.60	1616.41
1966	1418.90	1387.28	1986	1941.10	1712.20
1967	1384.00	1404.43	1987	1125.10	1907.16
1968	1921.20	1388.20	1988	1394.50	1403.89
1969	1335.10	1767.80	1989	1264.00	1355.59
1970	1608.33	1521.17	1990	2052.50	1246.89
1971	1512.00	1592.76	1991	1411.70	1772.30

Table A-15 Forecasting of weekly cumulative rainfall by exponential smoothing technique for the year 1992

Week no.	Forecasted rainfall	Week no.	Forecasted rainfall
1	2.72	27	422.03
2	4.45	28	472.56
3	5.27	29	572.42
4	6.02	30	666.97
5	6.95	31	780.61
6	15.23	32	834.58
7	22.15	33	937.03
8	36.14	34	992.45
9	43.16	35	1031.63
10	55.39	36	1050.42
11	60.88	37	1131.09
12	71.79	38	1150.31
13	76.43	39	1200.09
14	84.73	40	1233.31
15	96.59	41	1313.72
16	116.65	42	1314.66
17	116.65	43	1394.54
18	128.15	44	1394.54
19	133.78	45	1426.85
20	163.87	46	1432.77
21	184.23	47	1433.86
22	205.97	48	1455.72
23	257.50	49	1461.25
24	283.45	50	1463.93
25	351.57	51	1463.93
26	408.84	52	1463.93

## APPENDIX-B

Table B-1 Onset & withdrawal of effective monsoon & occurrence of  
Critical dry spells

\*\*\*\*\*

year	Effective monsoon		C R I T I C A L D R Y		S P E L L S (clds*)		
	onsets on	ends on	date & length of 1st cds	date & length of 2nd cds	date & length of 3rd cds	total no. of cds	
1950	06Jun	17Nov	16Aug 8	03Sep 6	25Sep 8	4	
1951	29Jun	27Nov	14Aug 9	31Aug 22	12Oct 45	3	
1952	22Jun	11Oct	09Jly 6	25Jly 5	31Jly 10	5	
1953	13Jun	15Nov	20Jun 19	21Jly 5	25Aug 11	6	
1954	08Jun	25Oct	15Jun 7	17Jly 12	21Aug 7	5	
1955	24Jun	09Nov	18Jly 20	11Sep 7	31Oct 8	3	
1956	24Jun	02Nov	08Jly 10	30Sep 5	19Oct 11	3	
1957	26May	17Oct	12Jun 15	05Jly 14	26Jly 5	5	
1958	05Jun	17Oct	17Jly 6	24Jly 11	10Aug 13	7	
1958	09Jly	22Oct	04Jun 6	17Jun 11	23Sep 7	4	
1959	28May	30Oct	17Jly 6	13Aug 8	31Aug 6	5	
1960	18Jun	10Oct	17Jly 6	13Aug 8	31Aug 6	5	
1961	18Jun	14Oct	08Aug 7	09Sep 12	22Sep 5	4	
1961	01Aug	31Oct	28Jly 27	25Aug 15	20Sep 33	3	
1962	06Jly	27Oct	19Jun 12	12Aug 5	13Sep 13	4	
1963	12Jun	26Oct	17Aug 6	30Aug 15	01Oct 18	3	
1964	26Jun	24Oct	27Jun 6	20Jly 7	29Jly 16	6	
1965	20Jun	23Nov	02Jly 10	18Aug 15	13Sep 9	5	
1966	16Jun	06Oct	12Jly 9	02Sep 7	16Sep 10	4	
1967	20Jun	15Nov	15Jun 7	08Jly 10	06Aug 5	9	
1968	08Jun	13Nov	20Aug 9	31Aug 5	22Sep 7	5	
1969	14Jly	07Oct	11Jun 5	17Jun 10	14Jly 6	7	
1970	01Jun	31Oct	23Jun 7	07Jly 5	06Sep 10	5	
1971	04Jun	12Oct	26Jly 7	30Aug 8	30Sep 5	3	
1972	27Jun	10Dec	29Aug 7	13Sep 8	02Oct 9	5	
1973	03Jly	29Oct	24Jly 15	15Aug 13	29Aug 11	5	
1974	12Jun	31Oct	02Jly 11	29Jly 6	20Aug 6	6	
1975	25Jun	28Nov	28Jun 5	27Jly 5	15Aug 10	5	
1976	17Jun	27Nov	10May 30	17Jun 5	17Jly 8	5	
1977	03May	22Oct	13Jly 6	26Jly 14	16Aug 6	6	
1978	06Jly	19Oct	21Jly 7	09Aug 11	21Aug 6	5	
1979	06Jly	26Oct	06Aug 14	28Aug 7	24Sep 25	3	
1980	17Jun	03Oct	23Jun 13	14Jly 17	22Aug 8	6	
1981	16Jun	15Oct	19Jun 27	29Aug 6	18Sep 26	3	
1982	12Jun	07Oct	27Jun 6	07Sep 9	17Sep 5	3	
1983	20Jun	24Oct	21Jun 9	18Sep 35	00 00 0	2	
1984	14Jun	17Oct	20Jly 9	24Sep 6	10Oct 5	3	
1985	22Jun	10Nov	21Aug 18	15Sep 7	08Oct 25	3	
1986	12Jun						

\*\*\*\*\*

contd.

\*\*\*\*\*

year	Effective monsoon		C R I T I C A L D R Y		S P E L L S (cds*)			total no. of cds
	onsets on	ends on	date & length of 1st cds	date & length of 2nd cds	date & length of 3rd cds			

\*\*\*\*\*

1987	11Jly	20Nov	28Jly 8	06Aug 9	01Sep 10	6	
1988	02Jun	22Oct	17Jun 6	28Jun 10	17Aug 18	4	
1989	13Jun	11Oct	20Jun 16	07Jly 6	28Jly 9	4	
1990	11May	05Nov	19May 15	04Jun 9	30Jun 7	7	
1991	02Jun	05Nov	09Jun 25	30Jly 6	12Aug 10	5	
mean	17Jun	29Oct	07Jly 11	07Aug 9	02Sep 11	4	

\*\*\*\*\*

\*critical dry spell(cds):when length of spell exceeds 5days

Table B-2 Detailed information on effective monsoon for the year 1992

-----

earliest probable date of oem(p=0.68):	31May
mean date of oem:	17Jun
latest probable date of oem(p=0.68):	04Jly
earliest probable date of oem(p=0.50):	08Jun
median date of oem:	16Jun
latest probable date of oem(p=0.50):	25Jun
standard deviation(days):	17
semi-inter-quartile range(days):	9

average date on which effective monsoon ends: 29Oct  
 average number of cds per year: 3

average date on which 1st cds starts:	07Jly	length(days):	11
average date on which 2nd cds starts:	07Aug	length(days):	9
average date on which 3rd cds starts:	02Sep	length(days):	11

average rain during the 1st wet spell( 17Jun to 06Jly):	317.07(mm)
average rain during the 2nd wet spell( 20Jly to 06Aug):	264.28(mm)
average rain during the 3rd wet spell( 18Aug to 26Aug):	211.89(mm)
average rain during the 4th wet spell( 14Sep to 25Sep):	143.41(mm)

---

Table B-3 weekly observed minimum, maximum &amp; normal rainfall and the probability of the weekly normal rainfall

week	minimum (mm)	maximum (mm)	normal (mm)	probability (%)
1	0.0	84.0	4.1	9.52
2	0.0	33.1	2.9	16.67
3	0.0	33.0	1.1	7.14
4	0.0	31.8	1.3	9.52
5	0.0	19.6	1.6	14.29
6	0.0	42.6	4.3	23.81
7	0.0	42.4	5.7	26.19
8	0.0	67.6	7.7	21.43
9	0.0	69.0	10.8	21.43
10	0.0	60.2	4.9	21.43
11	0.0	48.6	5.4	21.43
12	0.0	44.4	6.4	26.19
13	0.0	88.8	6.6	19.05
14	0.0	77.9	5.0	21.43
15	0.0	36.2	2.9	21.43
16	0.0	58.8	7.2	21.43
17	0.0	56.9	7.7	23.81
18	0.0	62.4	12.1	28.57
19	0.0	68.5	9.5	30.95
20	0.0	53.9	10.6	33.33
21	0.0	94.2	15.0	28.57
22	0.0	128.0	20.7	30.95
23	0.0	163.8	32.5	35.71
24	0.0	200.4	44.0	40.41
25	0.0	340.3	61.8	35.71
26	0.0	153.9	53.7	45.24
27	1.3	234.2	62.9	42.86
28	1.8	296.2	75.9	38.10
29	0.	195.2	73.7	47.62
30	0.2	212.0	71.4	45.24
31	7.7	288.5	87.9	47.62
32	0.2	281.3	87.9	47.62
33	0.	221.4	78.4	47.62
34	2.4	205.5	70.4	45.24
35	3.6	160.0	70.2	45.24
36	2.0	272.2	72.5	47.62
37	2.6	230.5	63.3	45.24
38	0.0	209.6	57.0	38.10
39	0.0	246.2	52.6	35.71

contd.

week	minimum (mm)	maximum (mm)	normal (mm)	probability (%)
40	0.0	179.4	60.9	40.48
41	0.0	150.4	38.7	42.86
42	0.0	152.9	29.8	40.48
43	0.0	311.4	30.6	19.05
44	0.0	254.6	29.2	21.43
45	0.0	163.3	15.3	21.43
46	0.0	82.0	4.4	16.67
47	0.0	99.3	6.9	11.90
48	0.0	43.2	2.2	9.52
49	0.0	47.5	2.0	9.52
50	0.0	21.8	1.3	11.90
51	0.0	7.2	0.2	7.14
52	0.0	15.2	0.6	4.76

Table B-4 Predicted monthly rainfall and number of rainy days for the year 1992

month	rainfall (mm)	rainy days	month	rainfall (mm)	rainy days
jan	9.98	0.6	jul	317.02	15.0
feb	22.05	1.5	aug	349.74	15.9
mar	30.35	2.1	sep	261.43	12.7
apr	26.31	1.8	oct	176.75	7.7
may	54.52	3.3	nov	41.19	1.7
jun	198.29	9.5	dec	4.24	0.3

No. of rainy days: 72.19 Annual rainfall(mm): 1491.87

Table C - 1 Probability of different dry and wet spells

Week no.	F (d)	F (dd) %	P (d) %	P (dd) %	2d %	3d	F (w) %	F (ww) %	P (w) %	P (ww) %	2w	3w
1	39	38	93	97	88	87	3	1	7	33	2	0
2	39	37	93	95	91	91	3	1	7	33	0	0
3	41	40	98	98	98	98	1	0	2	0	0	0
4	40	40	95	100	95	90	2	0	5	0	0	0
5	42	42	100	100	95	85	0	0	0	0	0	0
6	39	37	93	95	83	69	3	1	7	33	1	0.2
7	37	33	88	89	73	69	5	1	12	20	2	0
8	35	29	83	83	79	65	7	1	17	14	0	0
9	40	38	95	95	79	73	2	0	5	0	1	0.2
10	35	29	83	83	76	68	7	1	17	14	6	0
11	36	33	86	92	77	68	6	2	14	33	0	0
12	38	34	90	89	80	71	4	0	9	0	2	0
13	37	33	88	89	78	72	5	1	12	20	0	0
14	38	34	90	89	83	74	4	0	9	0	0	0
15	39	36	93	92	93	74	3	0	7	0	0	0
16	38	34	90	89	80	66	4	0	9	0	4	0
17	35	31	83	89	69	61	7	3	17	43	0	0
18	36	30	86	83	77	58	6	0	14	0	5	0
19	36	32	86	89	65	49	6	2	14	33	0	0
20	34	20	81	76	61	43	8	0	19	0	4	2
21	32	24	76	71	54	29	10	2	24	20	10	3
22	28	20	67	54	36	23	14	6	33	43	11	6
23	24	13	52	54	33	15	18	6	43	33	24	16
24	22	14	52	64	23	0	20	11	48	55	33	24
25	16	7	38	44	0	0	26	18	62	69	45	29
26	9	0	21	0	7	1	33	24	79	73	50	38
27	15	5	36	33	5	0	27	17	64	63	49	42
28	8	1	19	13	0	0	34	26	81	76	70	56
29	4	0	9	0	3	1	38	33	90	87	71	61
30	9	3	21	33	4	0	33	26	79	79	68	56
31	6	1	14	17	0	0	36	31	86	86	71	62
32	6	0	14	0	0	0	36	30	86	83	77	64
33	3	0	7	0	0	0	39	35	93	90	77	62
34	6	0	14	0	2	0.2	36	30	86	83	69	52
35	7	1	17	14	2	0.3	35	28	83	80	63	54
36	9	1	21	11	4	2	33	25	79	76	68	56
37	5	1	12	20	5	1	37	32	88	86	72	55
38	8	3	19	38	2	1	34	28	81	82	62	38
39	8	1	19	13	4	1	34	26	81	76	49	31
40	14	3	33	21	8	2	28	17	67	61	42	18

contd.

Week no.	F (d)	F (dd)	P (d) %	P (dd) %	2d %	3d %	F (w)	F (ww)	P (w) %	P (ww) %	2w %	3w %
41	13	3	31	23	10	5	29	18	69	62	30	9
42	19	6	45	32	23	16	23	10	55	43	17	6
43	20	18	48	50	35	30	22	13	52	31	17	6
44	30	22	71	73	60	48	12	4	29	33	10	0
45	33	28	79	85	63	58	9	3	21	33	0	0
46	35	28	83	80	76	66	7	0	17	0	0	0
47	39	36	93	92	80	80	3	0	7	0	1	0
48	36	31	86	86	86	77	6	1	14	17	0	0
49	42	42	100	100	90	88	0	0	0	0	0	0
50	40	38	95	90	93	93	2	0	5	0	0	0
51	41	40	98	98	98	--	1	0	2	0	0	--
52	42	42	100	100	--	--	0	0	0	0	--	--

Table C-2 Forward and backward accumulation of rain water

Year	Forward			Backward			Forward			Backward				
	75	200	500	300	100	m	F m	75	200	m	F m	500	300	100
	Week no.			Week no.			Ranked			Ranked				
1950	23	25	35	37	40	1	2.3	1	14	42	97.7	31	34	38
1951	17	22	33	40	42	2	4.7	8	14	41	93.3	31	35	39
1952	17	26	35	39	41	3	6.9	8	17	40	93.0	33	35	39
1953	19	28	38	40	46	4	9.3	8	22	39	90.7	33	35	39
1954	20	24	38	43	44	5	11.3	10	22	38	88.4	33	36	40
1955	21	26	41	43	46	6	13.9	10	22	37	86.0	33	36	40
1956	22	23	38	42	45	7	16.3	10	22	36	83.7	33	36	40
1957	10	24	31	34	39	8	18.6	10	23	35	81.4	33	37	40
1958	8	24	38	40	43	9	20.9	11	23	34	79.1	34	37	40
1959	22	26	36	40	43	10	23.3	11	23	33	76.7	34	37	40
1960	22	26	33	35	40	11	25.6	11	23	32	74.4	34	37	40
1961	32	34	37	37	42	12	27.9	11	23	31	72.1	34	37	41
1962	11	23	37	38	44	13	30.2	12	23	30	69.8	34	37	41
1963	19	23	37	41	44	14	32.6	12	23	29	67.4	34	37	41
1964	18	24	37	41	44	15	34.9	14	23	28	65.1	35	37	41
1965	14	24	34	38	40	16	37.2	16	24	27	62.8	35	37	41
1966	1	26	35	37	43	17	39.5	17	24	26	60.5	35	37	42
1967	12	26	34	38	43	18	41.9	17	24	25	58.1	35	38	42
1968	8	26	34	40	40	19	44.2	17	24	24	55.8	35	38	42
1969	23	25	41	44	44	20	46.5	18	25	23	53.5	35	38	42
1970	10	27	33	37	42	21	48.8	19	25	22	51.2	35	38	42
1971	20	23	35	36	41	22	51.2	19	25	21	48.8	35	38	42
1972	26	25	35	40	43	23	53.5	19	25	20	46.5	35	38	43

contd.

1973	17	27	38	42	44	24	55.8	19	25	19	44.2	36	39	43
1974	22	26	35	40	43	25	58.1	19	25	18	41.9	36	39	43
1975	22	25	36	39	43	26	60.5	20	25	17	39.5	36	39	43
1976	25	26	31	36	43	27	62.8	20	26	16	37.2	36	39	43
1977	19	23	36	38	45	28	65.1	20	26	15	34.9	36	40	43
1978	19	25	35	37	42	29	67.4	20	26	14	32.6	37	40	43
1979	16	22	36	38	41	30	69.8	21	26	13	30.2	37	40	43
1980	11	23	35	37	39	31	72.1	21	26	12	27.9	37	40	44
1981	11	14	33	36	40	32	74.4	22	26	11	25.6	37	40	44
1982	10	23	34	37	40	33	76.7	22	26	10	23.3	37	40	44
1983	8	17	36	38	41	34	79.1	22	26	9	20.9	38	40	44
1984	22	25	34	35	38	35	81.4	22	26	8	18.1	38	41	44
1985	20	26	37	39	42	36	83.7	22	26	7	16.3	38	41	45
1986	12	22	39	41	46	37	86.0	22	27	6	13.9	38	41	45
1987	19	27	34	37	45	38	88.4	23	27	5	11.6	38	42	45
1988	20	24	35	39	41	39	90.7	23	27	4	9.3	39	42	45
1989	21	25	33	35	39	40	93.0	25	28	3	6.9	39	43	46
1990	10	14	39	41	45	41	95.3	26	29	2	4.7	41	43	46
1991	11	23	33	37	42	42	97.7	32	34	1	2.3	41	44	46

## APPENDIX-D

Table D-1 Reference crop evapotranspiration by modified Blaney-Criddle method in mm/day

Year:	1960						
	5.566	6.077	6.174	6.450	7.262	6.484	7.724
	7.791	6.663	6.193	6.184	7.897	8.846	9.497
	9.953	10.112	9.894	10.522	10.587	9.562	6.441
	7.588	7.026	8.248	3.914	4.846	3.916	3.922
	5.424	4.122	4.095	3.598	4.207	4.624	4.667
	5.020	4.683	5.329	4.501	3.860	5.622	5.542
	6.598	4.665	5.368	5.194	3.978	4.117	4.457
	4.851	5.284	5.763				
Year:	1961						
	3.527	6.016	5.749	6.674	6.371	4.755	4.294
	7.028	7.763	7.864	8.721	8.068	7.291	7.809
	8.551	9.500	9.552	9.987	6.986	9.675	10.241
	8.026	6.468	5.972	6.968	7.154	3.489	3.527
	4.172	5.904	4.162	3.823	4.256	4.151	4.406
	3.413	5.004	4.778	3.477	5.157	4.845	4.647
	6.393	4.799	5.416	6.442	6.476	6.562	6.245
	5.871	6.029	5.824				
Year:	1962						
	4.033	5.980	6.190	5.854	5.759	6.436	6.369
	6.892	7.137	7.377	6.510	8.717	9.007	8.419
	8.050	8.259	7.089	7.663	8.482	8.167	10.289
	9.187	6.317	5.512	4.343	4.489	6.305	4.779
	4.698	3.570	4.465	4.409	4.351	4.567	4.860
	6.076	3.942	5.184	5.014	5.302	5.509	4.568
	5.312	4.105	6.777	6.507	6.382	6.565	5.960
	5.718	5.984	6.091				
Year:	1963						
	3.424	5.883	6.372	6.149	6.360	6.947	7.757
	7.720	8.040	8.060	8.238	7.603	8.341	8.199
	7.806	8.124	8.300	8.475	7.998	7.955	9.083
	8.790	7.141	6.523	4.436	7.657	4.292	4.345
	4.081	4.813	4.628	4.880	3.893	5.173	4.656
	3.794	4.712	5.315	5.253	4.700	4.959	6.080
	4.136	4.701	6.309	6.206	6.231	6.234	6.292
	6.116	6.496	5.666				

Year: 1964

2.919	5.512	6.203	5.968	6.530	4.854	6.314
7.740	7.618	7.182	8.740	8.868	8.066	8.668
8.893	9.545	7.776	8.131	8.576	8.686	8.952
8.208	8.903	9.873	6.817	4.453	4.182	3.754
5.066	4.734	5.106	6.028	4.425	4.041	3.688
6.104	4.568	5.250	4.512	4.470	5.124	5.547
4.824	5.964	5.799	5.298	5.487	6.505	6.508
6.505	6.244	5.898				

Year: 1965

5.204	6.255	5.606	5.934	7.110	6.989	6.248
6.446	7.410	9.124	8.800	7.545	6.780	7.230
8.500	8.980	10.109	10.217	8.047	10.208	9.499
8.201	10.941	8.670	5.950	4.572	5.240	4.166
4.922	4.269	5.269	5.545	5.297	4.427	5.056
4.593	5.952	3.708	5.906	6.219	5.833	3.453
6.298	6.563	6.735	6.623	6.141	6.242	5.932
6.022	6.222	6.280				

Year: 1966

3.806	5.032	5.920	6.121	6.121	7.038	6.995
6.715	7.789	7.339	8.086	8.121	8.230	8.189
8.746	8.070	9.188	8.967	10.580	11.393	9.104
8.570	9.152	5.735	4.964	3.991	5.504	6.418
3.755	4.765	4.246	4.094	4.851	5.144	5.799
4.148	4.584	6.506	6.571	6.476	5.039	5.675
6.801	6.864	6.643	6.093	3.926	5.342	5.500
5.429	6.490	6.099				

Year: 1967

4.645	2.442	5.636	6.005	6.944	7.140	7.284
8.629	8.162	8.569	7.029	5.462	6.680	8.962
9.147	8.924	7.541	9.598	9.685	9.437	8.833
10.030	10.899	7.329	5.977	5.692	4.917	6.110
6.074	4.847	3.735	4.235	4.916	3.663	4.438
4.529	4.665	4.590	4.422	5.402	5.706	6.696
7.092	6.690	6.739	6.918	6.414	6.396	5.962
4.663	5.668	6.157				

Year: 1968

4.001	6.453	5.561	6.124	6.355	7.003	7.083
6.033	6.827	6.735	7.888	7.533	9.003	9.238
8.455	8.815	8.748	9.274	10.628	8.709	9.201
9.067	7.703	5.214	5.710	5.830	4.388	4.384
5.788	6.032	4.566	4.945	4.172	4.254	5.066
5.511	4.961	4.499	6.021	4.591	4.704	6.728
6.504	3.922	6.170	4.181	5.352	5.507	6.027
6.151	5.861	5.710				

Year: 1969

2.858	6.014	6.115	6.020	6.948	6.570	6.685
7.517	8.226	7.661	7.669	7.336	7.701	8.727
8.073	9.051	8.310	7.777	7.613	8.159	8.138
9.041	6.112	7.792	6.295	5.961	4.415	5.396
4.824	3.719	4.362	4.715	4.255	4.405	6.537
5.117	3.397	4.798	4.430	5.849	4.858	5.812
6.114	6.190	5.910	4.362	6.424	5.248	5.975
5.542	4.299	5.731				

Year: 1970

2.309	5.762	5.684	5.477	5.888	5.849	5.294
6.360	7.036	5.757	5.772	7.521	7.458	7.222
7.440	8.865	8.173	8.064	9.186	8.713	7.864
8.540	6.130	4.929	5.647	6.073	4.359	5.379
5.137	3.784	4.726	5.328	4.500	5.318	3.706
3.580	4.268	6.029	4.920	4.637	3.680	5.391
5.567	6.313	7.021	4.797	6.987	6.493	5.763
6.303	6.006	6.061	.			

Year: 1971

5.638	5.809	6.397	5.232	4.925	6.104	7.210
6.440	6.262	7.606	8.391	8.475	7.766	7.157
7.549	5.709	7.834	8.811	7.172	7.545	8.197
5.818	4.888	5.303	4.201	5.466	4.585	4.498
3.589	5.054	3.927	4.194	4.451	4.940	3.774
4.826	6.349	4.891	4.833	5.486	5.476	4.471
5.973	4.906	6.461	6.125	6.859	6.487	5.737
5.747	5.464	6.118				

Year: 1972

5.538	6.279	5.923	6.228	6.630	6.767	5.286
6.954	8.017	7.478	7.849	8.556	7.959	8.460
8.166	7.982	9.558	9.460	10.454	10.808	8.754
9.460	9.575	8.351	7.979	5.441	4.082	4.347
4.901	5.233	5.491	4.653	4.692	5.320	3.866
5.551	4.311	5.175	4.722	5.229	5.848	6.688
6.868	4.961	6.211	6.745	5.969	6.474	6.738
6.128	6.094	6.386				

Year: 1973

4.326	6.708	7.170	6.945	7.022	6.745	7.695
8.318	7.708	6.391	7.284	8.098	8.763	9.378
8.737	8.919	9.127	8.555	9.077	8.125	8.739
8.637	8.335	6.595	8.758	6.886	4.575	3.559
4.497	5.017	4.277	5.045	4.590	4.219	4.588
4.066	5.204	4.655	4.490	3.558	5.448	5.254
4.252	5.122	6.088	4.843	5.859	6.382	6.093
5.336	5.753	6.031				

Year: 1974

3.350	5.982	6.374	6.186	6.406	7.215	6.866
7.338	8.725	8.631	8.496	8.035	6.569	7.013
8.539	8.348	8.914	9.869	9.319	8.378	9.163
8.001	7.744	8.194	7.106	5.877	6.328	4.200
5.094	5.349	5.420	6.360	3.707	6.966	5.496
6.282	4.713	4.566	5.881	4.091	4.722	5.352
4.565	5.492	6.483	6.596	4.706	5.854	6.535
6.324	6.080	6.054				

Year: 1975

2.813	5.979	5.849	5.983	6.137	5.484	6.640
6.078	7.251	8.601	7.237	6.807	7.004	8.710
8.255	7.895	7.956	9.312	10.149	9.346	8.955
8.521	8.079	6.111	7.119	6.401	4.539	4.869
4.585	5.282	4.938	5.528	3.504	3.887	5.043
4.131	4.526	5.170	5.557	4.256	5.035	4.376
5.630	5.307	5.716	4.645	6.726	4.976	5.872
6.329	6.398	6.081				

Year: 1976

2.325	6.289	6.066	6.104	6.245	6.243	6.635
7.651	8.425	8.223	7.922	7.510	8.000	7.957
8.513	8.162	8.977	8.362	9.040	7.575	8.333
8.950	10.109	7.504	8.236	7.386	5.368	4.838
4.560	4.576	5.756	4.556	5.228	4.822	5.812
3.784	5.050	5.742	6.662	6.531	6.976	7.586
4.083	7.049	5.904	6.184	6.204	5.473	5.004
6.286	6.051	5.932				

Year: 1977

5.780	6.979	5.698	6.542	6.805	7.065	7.516
7.199	8.473	7.856	8.354	7.577	7.883	8.161
6.991	7.699	7.710	7.612	7.198	8.844	8.382
8.886	7.697	6.856	5.069	4.679	4.038	5.215
5.828	4.699	3.797	4.910	5.730	4.488	3.542
4.371	4.761	6.285	5.253	4.774	6.423	6.559
7.062	5.414	6.742	6.232	3.557	5.776	6.176
6.353	5.974	5.373				

Year: 1978

4.384	5.616	6.349	5.755	6.757	5.904	6.504
6.220	7.389	7.578	6.831	6.228	6.521	6.781
8.040	6.951	7.526	8.762	7.904	7.493	8.163
9.687	8.651	8.423	5.958	4.098	4.974	3.907
5.880	5.464	4.829	4.363	4.229	4.548	5.109
5.756	5.030	4.605	5.156	4.962	5.431	5.333
5.938	4.606	5.527	6.299	6.890	6.099	5.989
6.014	6.286	5.248				

Year: 1979

4.106	6.252	6.025	5.784	6.730	6.132	6.776
7.603	7.128	8.039	8.496	8.108	7.559	9.346
8.810	8.031	8.893	8.252	8.357	9.200	10.300
9.688	9.988	8.812	7.971	5.482	5.640	4.695
5.377	6.947	5.224	3.795	5.927	6.341	6.061
4.874	4.150	6.305	5.652	4.939	6.073	6.758
6.585	6.357	6.056	6.725	7.049	6.338	6.549
6.396	5.995	6.534				

Year: 1980

3.417	5.958	6.235	6.593	7.490	7.006	6.891
6.812	8.228	7.865	7.260	8.327	8.279	7.799
8.948	9.155	9.824	9.098	9.473	9.411	9.810
8.805	7.139	7.171	4.839	3.792	3.695	4.729
4.783	4.785	4.258	4.305	4.561	5.936	4.476
4.618	4.061	4.615	4.792	5.770	6.511	6.980
4.559	6.631	6.830	6.088	6.462	6.751	6.313
3.564	6.444	6.123				

Year: 1981

2.356	6.749	5.146	6.404	5.712	6.055	7.066
7.585	8.065	8.337	7.389	7.093	7.079	6.010
8.110	8.448	7.166	8.441	6.714	8.270	7.866
6.786	8.000	8.439	6.959	4.860	5.071	4.234
4.165	5.054	5.611	4.471	5.158	5.498	5.210
5.008	4.899	5.324	4.898	5.294	6.902	7.028
7.065	5.916	6.802	6.758	7.047	7.075	6.816
4.995	5.355	5.657				

Year: 1982

6.034	6.023	5.365	4.881	6.130	5.926	6.272
6.598	5.970	5.695	6.783	7.916	8.146	7.885
8.321	7.563	8.761	9.277	8.731	9.351	9.980
6.775	7.138	5.776	6.168	6.440	9.171	4.918
6.038	4.823	5.066	4.246	3.941	4.157	5.085
4.582	5.023	6.796	6.331	6.718	6.871	5.069
6.663	6.757	6.750	6.059	5.932	6.336	6.509
5.899	6.459	6.355				

Year: 1983

5.684	6.275	5.356	5.953	6.441	4.195	6.243
6.542	6.196	6.533	8.097	6.635	6.914	8.349
7.433	7.299	7.846	7.902	8.110	7.876	9.324
8.731	8.896	8.341	6.911	5.936	4.886	6.182
5.076	4.772	3.762	4.809	4.500	4.897	4.291
4.354	5.265	5.025	5.270	3.756	4.476	6.139
6.673	6.596	5.941	6.655	5.661	6.803	6.400
5.955	6.196	5.506				

Year: 1984

4.264	6.092	5.529	5.728	6.114	5.545	5.721
6.659	7.665	8.025	8.152	8.681	7.598	8.042
8.515	9.151	8.015	9.297	9.042	8.802	9.268
7.329	6.302	4.852	5.823	4.323	4.183	4.765
4.912	5.241	5.545	4.535	4.555	5.826	4.677
3.710	4.974	6.346	6.638	6.345	5.382	4.485
5.860	6.508	6.672	6.206	6.671	6.311	5.444
6.071	6.654	5.381				

Year: 1985

2.663	5.304	5.199	6.159	6.543	6.838	5.578
6.603	8.131	8.305	8.071	7.179	7.320	8.340
8.874	8.355	8.411	8.164	8.179	8.068	8.263
8.341	6.296	8.230	6.826	6.956	3.913	4.215
4.310	5.596	4.650	4.449	6.234	4.382	3.835
3.334	4.194	4.048	5.296	5.202	4.932	4.707
5.623	6.624	6.262	6.723	6.466	6.972	6.467
6.160	6.056	6.390				

Year: 1986

2.833	5.843	4.826	5.942	6.843	6.552	6.504
5.682	7.393	6.913	8.287	8.631	8.811	8.873
8.138	8.043	8.331	7.396	7.682	7.682	6.555
7.770	9.318	8.872	5.465	3.193	5.150	5.498
4.992	4.805	4.624	5.164	5.394	4.628	5.889
5.627	5.057	5.448	4.964	4.993	3.507	5.851
6.602	6.616	3.898	5.118	6.381	6.224	6.197
5.632	5.329	5.696				

Year: 1987

2.307	5.732	5.179	5.724	6.475	6.778	6.640
6.642	7.912	6.001	6.389	8.841	8.255	7.273
8.404	7.766	7.912	6.712	6.588	7.556	9.492
9.090	7.700	6.654	7.108	7.908	9.268	4.311
4.600	4.238	4.987	4.632	6.799	5.493	4.021
5.460	4.865	5.352	4.839	6.036	5.988	5.740
5.564	6.529	4.255	6.146	3.948	5.702	5.877
5.023	5.605	6.022				

Year: 1988

5.366	5.532	5.677	6.249	6.957	7.226	6.523
6.120	6.660	6.846	7.971	9.176	8.882	8.595
9.151	7.092	7.679	8.103	8.964	7.251	6.432
7.793	6.202	4.334	6.508	5.375	5.380	4.872
5.878	4.666	4.329	4.011	5.038	5.462	5.352
4.446	5.478	3.906	5.722	5.151	6.590	6.529
6.742	5.714	6.406	7.077	7.182	5.511	6.391
5.894	6.452	5.943				

Year: 1989

4.581	5.805	5.873	6.016	6.783	7.627	7.638
7.391	7.666	7.637	6.620	8.426	8.013	8.809
9.105	8.419	8.430	8.546	10.255	8.135	6.358
5.879	6.999	5.884	3.458	5.595	4.383	5.659
5.972	4.410	3.927	4.260	4.856	4.923	4.421
5.331	3.853	5.267	4.502	5.823	5.232	5.396
6.204	6.108	6.724	5.639	6.214	6.279	6.082
5.897	5.799	5.040				

Year: 1990

3.796	5.913	6.277	6.474	6.695	6.523	5.845
4.910	6.277	4.838	5.602	6.847	5.712	6.018
6.651	6.201	7.246	6.633	5.384	4.893	6.689
6.732	6.233	5.609	5.037	4.219	3.908	3.644
4.017	4.691	4.601	5.357	4.921	4.680	4.833
3.906	4.443	5.500	4.773	4.387	3.798	5.700
4.990	5.740	3.732	5.797	5.856	5.596	5.543
5.482	4.332	5.724				

Year: 1991

3.080	5.192	3.715	4.425	6.088	6.143	7.045
6.478	7.879	6.486	6.576	7.370	7.183	8.470
7.780	7.749	7.510	8.000	8.183	8.405	8.640
7.655	6.437	5.531	7.571	5.379	4.303	5.633
4.107	3.943	4.514	3.986	3.132	3.851	3.645
3.565	4.859	4.566	4.319	5.097	3.736	4.320
5.879	3.446	4.055	5.558	4.080	5.772	5.575
5.148	4.561	4.877				

---

Table D-2 Reference crop evapotranspiration by modified Radiation method  
in mm/day

Year: 1960

## Radiation Method

4.235	4.845	4.884	5.029	5.735	5.410	6.202
6.156	5.717	5.374	5.995	6.682	7.092	7.447
7.807	8.055	8.042	8.315	8.851	8.009	5.021
6.313	5.289	6.724	3.258	4.431	3.059	3.287
4.900	3.444	3.369	3.017	3.572	4.038	3.934
4.242	4.094	4.792	3.877	3.003	4.888	4.980
5.780	3.620	4.302	4.537	3.589	3.797	3.144
3.803	4.316	4.293				

Year: 1961

2.980	4.791	4.225	5.214	4.939	3.908	3.652
6.000	6.505	6.352	7.061	6.446	5.644	6.518
6.969	7.617	7.882	7.632	6.190	7.949	8.160
6.216	4.390	4.573	5.718	5.647	2.581	2.744
3.362	5.620	3.550	3.111	3.720	3.512	3.783
2.596	4.376	4.333	2.841	4.373	4.117	4.056
5.705	3.921	4.103	5.163	5.143	5.148	4.761
4.499	4.753	4.658				

Year: 1962

3.216	4.725	4.883	4.671	4.569	5.389	4.959
5.468	5.746	6.321	5.698	7.383	7.332	6.721
6.296	6.684	6.229	6.679	7.157	6.939	8.758
7.199	5.171	4.183	3.046	3.786	5.741	4.117
3.931	2.777	3.671	3.939	3.728	3.978	4.672
5.727	3.473	4.503	4.483	4.325	4.444	3.614
4.436	3.134	5.254	5.147	5.059	5.037	4.241
4.321	4.448	4.651				

Year: 1963

2.708	4.574	4.753	4.886	5.170	5.653	5.999
5.958	6.252	6.615	6.544	5.979	6.606	6.473
6.058	6.755	6.680	6.877	6.615	6.905	7.870
7.476	6.196	5.420	3.510	6.789	3.851	3.565
3.446	4.082	4.192	4.372	3.329	4.944	4.211
3.168	4.070	4.756	4.562	3.855	4.099	5.129
3.477	4.071	5.017	4.895	4.954	4.685	4.765
4.660	4.896	4.479				

Year: 1964

2.207	4.259	4.749	4.611	5.173	3.993	5.248
6.131	5.880	5.782	7.051	6.915	6.415	6.879
7.394	7.789	6.656	7.376	7.553	7.554	7.845

6.900	7.519	7.793	5.419	3.369	3.519	3.113
4.591	4.035	4.629	5.606	3.991	3.420	2.910
5.762	3.886	5.049	4.025	3.649	4.214	4.879
4.038	5.027	4.673	4.282	4.171	5.114	4.960
4.819	4.759	4.485				

Year: 1965

3.893	4.937	4.179	4.446	5.519	5.802	5.249
5.542	6.240	7.327	7.126	6.111	5.793	6.518
7.345	7.321	8.129	7.788	6.631	8.358	8.277
6.655	8.309	6.600	4.427	2.997	4.462	3.600
4.496	3.596	4.491	4.931	4.772	3.956	4.544
4.067	5.489	3.197	5.611	5.264	5.113	2.811
5.460	5.471	5.241	5.118	4.857	4.691	4.306
4.350	4.649	4.763				

Year: 1966

2.990	4.032	4.758	4.892	4.698	5.664	5.586
5.450	6.267	6.160	6.537	6.419	6.623	6.852
7.216	6.513	8.061	7.433	8.690	8.916	8.028
7.476	7.775	4.095	4.081	3.202	4.748	5.831
3.110	4.552	3.662	3.440	4.421	4.724	5.262
3.710	4.053	5.963	6.025	5.632	4.194	4.938
5.829	5.653	5.106	4.736	2.768	4.104	4.225
4.114	4.891	4.628				

Year: 1967

3.771	1.632	4.608	4.908	5.368	5.854	5.722
6.483	6.453	6.946	5.990	4.481	6.005	7.848
7.754	7.724	6.753	7.935	8.325	8.006	7.654
8.281	8.233	5.707	5.165	5.241	4.102	5.223
5.623	4.267	3.061	3.432	4.439	2.855	3.941
3.948	4.068	3.919	3.856	4.642	4.918	5.805
6.182	5.569	5.339	5.180	4.913	4.840	4.396
3.388	4.109	4.577				

Year: 1968

3.150	5.019	4.593	4.866	5.201	5.796	5.755
4.875	5.920	5.945	6.662	6.166	7.183	7.639
7.374	7.332	7.217	7.959	8.480	7.350	8.010
7.691	6.649	4.117	4.471	5.046	3.675	3.350
5.048	5.697	3.813	4.324	3.510	3.663	4.283
4.729	4.411	4.077	5.755	3.875	3.899	5.853
5.595	2.963	4.759	3.207	4.284	4.517	4.670
4.732	4.393	4.385				

Year: 1969

2.162	4.830	4.863	4.784	5.469	5.412	5.246
5.983	6.538	6.480	6.273	5.752	6.559	7.232
7.164	7.441	6.888	6.692	6.939	7.614	7.550

8.105	4.893	6.272	5.040	4.821	3.531	4.428
4.368	3.289	3.992	3.992	3.660	3.922	6.323
4.884	2.878	4.547	3.848	4.999	4.159	5.151
5.206	5.063	4.501	3.358	4.946	3.804	4.567
4.258	3.019	4.363				

Year: 1970

1.653	4.602	4.437	4.198	4.798	4.960	4.570
5.147	5.883	5.201	5.377	6.339	6.448	6.491
6.511	7.733	7.060	7.098	8.057	7.732	7.067
7.838	5.540	4.086	5.184	5.224	3.641	4.725
4.518	2.883	4.223	4.876	4.161	5.193	3.185
2.972	3.753	5.547	4.692	3.969	2.934	4.732
4.753	4.978	5.390	3.561	5.280	5.049	4.432
4.802	4.560	4.568				

Year: 1971

4.511	4.614	4.900	4.066	4.032	5.134	5.976
5.256	5.381	6.668	6.882	6.634	6.403	6.242
6.868	5.205	7.129	7.685	6.400	6.889	7.330
5.526	3.865	4.279	3.572	4.473	3.785	3.863
2.835	4.318	3.364	3.646	3.936	4.566	3.091
4.430	5.620	4.282	4.303	4.880	4.563	3.706
5.283	4.091	5.082	4.817	5.357	5.069	4.340
4.450	4.303	4.615				

Year: 1972

4.408	4.898	4.547	4.804	5.057	5.649	4.552
5.750	6.345	6.214	6.527	6.788	6.590	6.763
7.059	7.033	7.907	7.902	8.538	8.931	7.539
8.211	7.839	6.501	6.426	4.736	3.253	3.602
4.229	4.390	4.556	3.977	4.163	4.916	3.078
4.947	3.678	4.646	4.264	4.338	4.862	5.776
5.880	3.984	4.695	5.062	4.353	4.945	5.029
4.507	4.531	4.588				

Year: 1973

3.360	4.903	5.367	5.237	5.528	5.534	5.950
6.371	6.045	5.610	6.325	6.731	7.098	7.371
7.298	7.386	7.953	7.445	7.909	7.051	8.020
7.507	6.959	5.362	6.651	5.616	3.911	2.691
3.789	4.230	3.557	4.716	4.156	3.588	3.861
3.344	4.839	4.127	4.052	2.824	4.659	4.675
3.626	4.212	4.730	3.744	4.538	5.002	4.630
4.001	4.328	4.625				

Year: 1974

2.662	4.773	5.056	4.784	5.096	5.771	5.837
5.746	6.716	6.891	7.002	6.463	5.719	6.443
6.996	7.290	7.566	8.042	7.918	6.951	7.751
6.571	6.090	6.705	6.172	4.858	5.664	3.255
4.283	4.726	4.778	6.088	2.913	6.423	4.839
5.620	4.041	4.004	5.436	3.129	3.949	4.816
3.798	4.793	5.320	5.200	3.532	4.351	4.958
4.732	4.558	4.808				

Year: 1975

2.147	4.805	4.665	4.689	4.831	4.520	5.263
4.904	6.130	6.848	5.917	5.792	6.110	7.272
6.921	6.549	6.897	7.808	8.256	7.809	7.879
7.420	6.252	4.510	5.885	5.885	3.705	4.084
3.985	4.587	4.308	5.211	2.699	3.288	4.606
3.712	3.929	4.690	4.937	3.556	4.368	3.386
4.996	4.531	4.372	3.481	5.194	3.642	4.503
4.783	4.752	4.648				

Year: 1976

1.657	4.978	4.750	4.811	5.060	4.966	5.553
6.009	6.868	6.887	6.599	6.278	6.470	6.706
7.059	6.908	7.416	7.401	7.903	6.512	7.650
7.814	8.221	5.852	6.707	6.619	4.362	3.964
3.822	3.903	5.244	4.141	4.484	4.226	5.633
3.238	4.660	4.960	5.906	5.581	5.822	6.243
3.152	5.692	4.446	4.703	4.614	3.900	3.652
4.633	4.527	4.341				

Year: 1977

4.544	5.189	4.361	5.106	5.442	5.778	5.887
5.747	6.516	6.651	6.974	6.145	6.324	6.758
6.185	6.951	6.551	6.661	6.728	7.776	7.498
7.740	6.048	5.824	4.043	4.093	3.398	4.218
5.328	3.844	2.981	4.589	5.323	4.149	2.908
3.690	4.300	5.515	4.806	4.042	5.449	5.491
6.089	4.470	5.133	4.711	2.519	4.367	4.687
4.798	4.541	4.026				

Year: 1978

3.695	4.537	4.905	4.624	5.293	4.972	5.389
5.190	6.141	6.437	6.072	5.364	5.721	6.049
6.881	5.959	6.682	7.530	7.241	6.717	7.091
8.215	6.612	7.508	5.217	3.101	4.365	3.364
5.245	4.926	4.145	3.464	3.796	4.227	4.558
4.972	4.570	4.148	4.598	4.102	4.731	4.599
5.243	3.699	4.360	4.775	5.283	4.602	4.498
4.652	4.759	3.864				

Year: 1979

3.243	4.846	4.569	4.395	5.067	5.337	5.592
6.155	5.923	6.786	7.211	6.738	5.957	7.349
7.309	7.078	7.468	7.442	7.278	8.236	8.312
7.890	7.992	7.160	6.616	4.444	4.413	3.845
4.811	6.387	4.960	2.978	5.122	5.607	5.503
4.269	3.525	5.786	5.203	4.177	5.209	5.693
5.696	5.196	4.600	5.101	5.227	4.608	4.793
4.702	4.429	4.842				

Year: 1980

2.624	4.741	4.717	4.793	5.747	5.588	5.587
5.484	6.507	6.428	6.103	6.598	6.566	6.448
7.257	7.353	8.131	7.427	7.751	7.613	7.971
7.613	6.104	6.330	3.983	2.886	2.806	3.685
3.899	4.063	3.683	3.736	3.943	5.563	3.872
4.087	3.582	3.982	4.240	4.893	5.534	5.679
3.627	5.481	5.259	4.625	5.032	4.962	4.708
2.194	4.737	4.447				

Year: 1981

1.695	5.095	4.069	5.021	4.614	4.992	5.668
5.840	6.504	6.892	6.020	6.133	6.209	5.585
6.943	7.201	6.245	7.373	6.052	7.575	7.052
6.046	6.738	6.983	5.431	3.914	4.615	3.257
3.068	4.125	5.067	3.930	4.628	4.638	4.598
4.291	4.457	4.621	4.331	4.394	5.825	5.961
5.670	4.833	5.178	5.097	5.408	5.350	5.123
3.476	4.089	4.204				

Year: 1982

4.585	4.631	4.135	3.966	4.899	4.939	5.008
5.344	5.097	5.253	5.976	6.547	6.780	6.725
7.085	6.752	7.264	7.287	7.234	7.739	8.339
5.662	6.411	4.660	5.029	5.249	7.594	4.221
5.343	4.023	4.262	3.416	3.207	3.504	4.472
3.838	4.413	5.986	5.538	5.358	5.554	4.206
5.569	5.499	5.013	4.569	4.454	4.689	4.796
4.257	4.576	4.668				

Year: 1983

4.493	4.851	4.070	4.456	5.006	3.520	5.166
5.386	5.271	5.750	6.537	5.720	5.960	6.929
6.462	6.498	6.928	6.843	7.123	6.996	8.133
7.460	7.254	6.990	5.732	4.988	4.076	5.719
4.322	4.031	2.964	4.416	3.729	4.529	3.636
3.707	4.588	4.439	4.913	3.006	3.687	5.653
5.801	5.406	4.508	5.120	4.250	5.056	4.836
4.574	4.528	4.098				

Year: 1984

3.464	4.763	4.273	4.482	4.851	4.340	4.685
5.329	6.629	6.590	6.704	6.675	6.258	6.812
7.257	7.719	6.840	7.863	7.832	7.932	8.153
6.272	4.839	4.123	4.737	3.064	3.530	4.191
4.218	4.743	5.234	3.918	3.916	5.524	4.120
3.020	4.674	5.741	6.030	5.340	4.598	3.606
5.063	5.260	5.368	4.549	5.169	5.015	3.953
4.620	4.926	3.875				

Year: 1985

1.895	4.080	3.982	4.842	5.205	5.710	4.606
5.461	6.618	6.604	6.402	6.123	6.368	6.722
7.621	7.162	7.090	7.234	7.280	7.207	7.514
7.230	5.250	6.667	5.409	6.165	2.918	3.432
3.586	4.906	4.134	3.896	5.692	3.762	2.973
2.633	3.577	3.449	4.714	4.493	4.184	3.881
5.423	5.541	4.779	5.131	4.785	5.181	4.824
4.556	4.294	4.667				

Year: 1986

2.112	4.740	3.435	4.688	5.298	5.269	5.171
4.542	6.110	5.936	6.965	6.968	7.040	7.213
7.110	6.929	6.986	6.703	6.815	6.976	5.945
6.853	7.831	7.630	4.632	2.443	4.325	4.568
4.553	4.052	4.040	4.710	5.070	3.829	5.239
4.771	4.169	4.840	4.285	4.418	2.737	5.122
5.665	5.611	2.949	3.908	4.931	4.815	4.613
4.189	3.911	4.300				

Year: 1987

1.649	4.542	3.992	4.577	5.273	5.551	5.424
5.499	6.365	5.365	5.524	7.040	6.639	6.378
6.990	6.513	6.776	6.003	6.138	6.587	7.673
7.588	6.483	5.826	5.759	6.628	7.884	3.418
3.759	3.499	4.206	3.949	6.444	5.020	3.239
4.826	4.224	4.659	4.095	4.944	5.051	4.771
4.852	5.463	3.088	4.724	2.945	4.346	4.637
3.627	4.253	4.602				

Year: 1988

4.294	4.330	4.333	4.584	5.399	5.733	5.098
4.810	5.468	5.611	6.744	7.384	6.978	7.125
7.191	6.129	6.589	7.365	7.672	6.436	5.681
6.751	5.359	3.405	5.724	4.638	4.575	4.157
5.395	3.853	3.744	3.436	4.475	5.147	4.845
3.813	5.075	3.235	5.317	4.448	5.835	5.629
5.739	4.481	4.836	5.422	5.480	3.797	4.670
4.193	4.769	4.477				

Year: 1989

3.704	4.559	4.735	4.683	5.324	5.934	5.760
5.876	6.127	6.265	5.641	6.507	6.534	7.321
7.301	7.059	6.821	6.988	8.286	7.275	5.534
5.277	5.858	4.803	2.552	5.033	3.571	5.159
5.375	3.820	3.090	3.531	4.451	4.648	3.973
4.714	3.283	4.679	3.893	4.879	4.346	4.450
5.378	4.955	5.138	4.103	4.644	4.739	4.577
4.457	4.431	3.780				

Year: 1990

3.012	4.576	4.827	4.928	5.172	5.202	4.593
4.166	5.247	4.394	5.246	6.065	5.044	5.639
6.373	5.602	6.347	6.026	4.793	4.396	6.114
6.081	5.285	4.806	4.446	3.401	3.100	2.800
3.155	4.071	3.717	5.027	4.430	4.228	4.242
3.123	3.812	4.933	4.255	3.671	2.983	4.887
3.963	4.623	2.560	4.549	4.573	4.099	4.006
4.130	3.079	4.377				

Year: 1991

2.377	4.340	2.844	3.453	4.757	5.004	5.592
5.216	6.260	5.568	5.906	6.160	6.161	6.943
6.540	6.742	6.406	6.606	6.745	7.039	7.129
6.468	5.481	4.702	6.219	4.352	3.363	4.967
3.244	3.160	4.104	3.340	2.538	3.148	2.858
2.823	4.308	3.966	3.839	4.238	3.039	3.452
4.946	2.504	2.920	4.381	2.890	4.411	4.078
3.908	3.315	3.771				

---

Table D-3 Reference crop evapotranspiration by modified Penman method in mm/d  
Year: 1960

4.170	4.188	4.327	4.411	4.906	4.863	5.458
5.903	6.078	5.848	6.257	7.266	7.671	8.890
9.754	10.561	9.805	10.624	12.094	10.552	6.653
7.953	6.749	8.365	3.794	5.043	3.663	3.794
5.616	3.947	3.955	3.458	4.169	4.576	4.457
4.710	4.573	5.171	4.326	3.337	5.013	4.959
5.270	3.912	4.097	4.116	3.377	3.410	3.260
3.380	3.551	3.733				

Year: 1961

2.680	4.128	3.863	4.458	4.576	4.069	3.713
5.481	6.257	6.707	7.537	7.013	6.785	7.454
8.120	9.332	10.286	11.021	7.356	9.864	10.221
8.052	6.415	6.085	6.541	6.714	3.159	3.330
4.020	6.133	4.070	3.601	4.151	3.999	4.250
3.039	4.888	4.679	3.176	4.713	4.389	4.171
5.256	3.970	4.177	4.547	4.441	4.390	4.031
3.799	4.106	3.879				

Year: 1962

2.841	4.025	4.206	4.036	4.361	4.985	4.918
5.320	6.060	6.674	5.979	7.319	7.664	8.735
8.297	7.702	7.578	8.114	8.968	8.286	10.876
9.698	6.206	5.278	3.908	4.433	6.456	4.737
4.604	3.274	4.313	4.453	4.325	4.602	5.153
6.228	3.837	5.057	4.920	4.519	4.672	3.778
4.598	3.420	4.634	4.402	4.349	4.426	3.873
3.957	3.841	4.021				

Year: 1963

2.421	4.093	4.312	4.359	4.432	5.016	5.860
5.774	6.479	6.640	7.900	6.562	7.799	7.592
7.699	8.408	8.280	8.314	8.644	8.300	9.790
9.043	7.154	6.519	4.270	7.699	4.354	4.203
3.942	4.690	4.739	4.927	3.728	5.528	4.704
3.543	4.521	5.341	4.884	4.174	4.307	5.142
3.703	4.027	4.561	4.392	4.321	4.270	4.193
3.871	4.120	3.771				

Year: 1964

2.098	3.844	4.401	4.367	5.030	4.134	5.233
5.781	6.808	6.719	7.147	8.213	7.959	8.790
9.774	10.515	8.813	8.996	10.135	9.207	9.522
8.165	9.264	10.323	6.770	4.177	4.062	3.488
5.182	4.660	5.292	6.351	4.514	3.933	3.371
6.356	4.358	5.412	4.392	3.986	4.479	5.064
4.291	4.917	4.634	4.136	4.225	4.678	4.206
4.058	4.150	3.901				

Year: 1965

3.664	4.318	4.031	4.087	4.843	5.890	4.852
5.572	6.280	7.796	7.446	6.971	6.709	7.050
9.149	9.050	10.390	9.702	8.668	10.963	9.238
8.260	10.751	8.499	5.613	4.396	5.272	4.119
5.056	4.222	5.247	5.585	5.388	4.447	5.103
4.522	5.866	3.538	5.818	5.309	5.113	3.006
5.348	4.894	4.573	4.443	4.480	4.250	4.082
4.724	4.164	4.064				

Year: 1966

3.139	3.657	4.163	4.181	4.531	5.245	5.678
5.517	6.714	6.835	6.570	6.806	7.014	8.569
8.714	8.549	9.868	9.308	10.615	10.518	10.420
9.294	10.330	5.823	4.872	3.782	5.642	6.772
3.550	5.070	4.245	3.979	4.992	5.418	5.719
4.085	4.450	6.181	6.155	5.973	4.452	5.004
5.679	5.131	4.599	4.399	3.163	4.023	3.981
4.039	4.294	3.821				

Year: 1967

3.497	2.114	4.106	4.125	5.048	5.259	5.718
6.597	6.403	7.934	6.747	5.153	6.343	8.067
8.391	9.840	7.844	9.823	11.116	9.771	9.878
10.454	10.273	7.926	6.012	5.963	4.884	6.083
6.480	4.863	3.544	4.059	4.991	3.406	4.380
4.376	4.493	4.353	4.302	4.765	5.083	5.442
5.775	5.013	4.579	4.481	4.371	4.270	3.998
3.437	3.754	4.055				

Year: 1968

2.777	4.753	4.227	4.206	4.786	5.447	5.657
5.022	5.787	5.962	6.760	6.981	8.321	8.837
9.005	9.119	8.047	9.366	10.535	9.481	10.568
10.691	7.965	5.013	5.556	5.880	4.236	4.186
5.766	6.440	4.469	4.981	4.054	4.136	4.780
5.000	4.880	4.480	6.113	4.222	4.244	5.614
5.342	3.263	4.452	3.394	3.928	3.855	3.928
3.848	3.872	3.591				

Year: 1969

1.954	4.052	4.350	4.021	4.853	5.290	5.124
5.612	6.679	6.953	7.213	7.113	7.763	8.204
8.504	9.622	9.550	8.015	7.779	8.443	8.464
9.609	5.947	7.810	6.096	5.838	4.102	5.290
4.978	3.661	4.498	4.697	4.219	4.420	6.808
5.269	3.202	4.949	4.243	5.034	4.304	5.096
4.962	4.607	4.249	3.469	4.295	3.488	3.846
3.437	3.082	3.484				

Year: 1970

1.724	3.673	3.893	3.742	4.352	4.662	4.522
5.378	5.912	5.443	5.478	6.978	7.271	7.570
7.800	9.499	7.938	8.334	9.912	9.268	9.113
10.242	6.599	4.883	5.949	6.157	4.259	5.439
5.157	3.480	4.813	5.528	4.681	5.665	3.570
3.306	4.103	6.175	5.130	4.268	3.155	4.874
4.650	5.258	4.928	3.572	5.066	4.037	3.581
3.918	3.795	3.841				

Year: 1971

3.684	4.013	4.309	3.786	4.034	5.260	5.804
5.366	5.441	6.493	6.911	7.399	8.088	7.892
8.558	5.970	8.105	9.548	7.581	7.663	8.464
6.255	4.847	5.011	4.120	5.389	4.362	4.401
3.297	5.025	3.845	4.151	4.488	5.073	3.535
4.866	6.008	4.635	4.758	5.128	4.864	3.966
5.184	4.374	4.557	4.200	4.954	4.459	3.811
3.852	3.605	3.902				

Year: 1972

3.529	4.198	4.025	4.055	4.875	5.839	4.696
5.178	6.361	6.706	7.207	8.147	7.808	8.567
8.311	8.368	9.033	10.175	10.943	11.847	9.637
10.474	9.999	8.503	8.852	5.523	3.826	4.192
4.916	5.065	5.403	4.612	4.718	5.484	3.648
5.339	4.218	5.063	4.735	4.494	5.040	5.394
5.363	4.107	4.536	4.702	4.508	4.730	4.756
4.172	3.919	4.029				

Year: 1973

2.972	4.619	5.032	4.904	5.213	5.364	5.908
6.555	7.031	6.035	6.773	7.085	7.639	9.122
9.175	9.698	10.513	9.872	10.223	8.898	9.805
9.975	8.838	6.400	8.550	6.778	4.485	3.231
4.400	4.994	4.127	5.245	4.674	4.086	4.423
3.799	5.178	4.568	4.448	3.097	4.937	4.868
3.860	4.325	4.641	3.825	4.425	4.384	4.082
3.982	3.856	3.994				

Year: 1974

2.405	3.980	4.397	4.128	4.697	5.606	5.306
5.488	6.569	7.464	7.030	7.239	6.837	7.619
8.279	9.147	9.773	10.338	10.818	9.626	9.643
7.727	7.425	7.376	7.475	5.818	6.314	3.939
5.018	5.365	5.502	6.773	3.487	7.413	5.440
6.026	4.471	4.425	5.802	3.591	4.273	4.891
3.968	4.503	4.417	4.546	3.980	4.507	4.149
4.030	3.854	4.192				

Year: 1970

1.724	3.673	3.893	3.742	4.352	4.662	4.522
5.378	5.912	5.443	5.478	6.978	7.271	7.500
7.800	9.499	7.938	8.334	9.912	9.268	9.113
10.242	6.599	4.883	5.949	6.157	4.259	5.439
5.157	3.480	4.813	5.528	4.681	5.665	3.570
3.306	4.103	6.175	5.130	4.268	3.155	4.874
4.650	5.258	4.928	3.572	5.066	4.037	3.581
3.918	3.795	3.841				

Year: 1971

3.684	4.013	4.309	3.786	4.034	5.260	5.804
5.366	5.441	6.493	6.911	7.399	8.088	7.892
8.558	5.970	8.105	9.548	7.581	7.663	8.464
6.255	4.847	5.011	4.120	5.389	4.362	4.401
3.297	5.025	3.845	4.151	4.488	5.073	3.535
4.866	6.008	4.635	4.758	5.128	4.864	3.966
5.184	4.374	4.557	4.200	4.954	4.459	3.811
3.852	3.605	3.902				

Year: 1972

3.529	4.198	4.025	4.055	4.875	5.839	4.696
5.178	6.361	6.706	7.207	8.147	7.808	8.567
8.311	8.368	9.033	10.175	10.943	11.847	9.637
10.474	9.999	8.503	8.852	5.523	3.826	4.192
4.916	5.065	5.403	4.612	4.718	5.484	3.648
5.339	4.218	5.063	4.735	4.494	5.040	5.394
5.363	4.107	4.536	4.702	4.508	4.730	4.756
4.172	3.919	4.029				

Year: 1973

2.972	4.619	5.032	4.904	5.213	5.364	5.908
6.555	7.031	6.035	6.773	7.085	7.639	9.122
9.175	9.698	10.513	9.872	10.223	8.898	9.805
9.975	8.838	6.400	8.550	6.778	4.485	3.231
4.400	4.994	4.127	5.245	4.674	4.086	4.423
3.799	5.178	4.568	4.448	3.097	4.937	4.868
3.860	4.325	4.641	3.825	4.425	4.384	4.082
3.982	3.856	3.994				

Year: 1974

2.405	3.980	4.397	4.128	4.697	5.606	5.306
5.488	6.569	7.464	7.030	7.239	6.837	7.619
8.279	9.147	9.773	10.338	10.818	9.626	9.643
7.727	7.425	7.376	7.475	5.818	6.314	3.939
5.018	5.365	5.502	6.773	3.487	7.413	5.440
6.026	4.471	4.425	5.802	3.591	4.273	4.891
3.968	4.503	4.417	4.546	3.980	4.507	4.149
4.030	3.854	4.192				

Year: 1975

2.051	4.134	3.927	4.013	4.597	4.521	5.277
5.066	5.669	7.153	6.731	6.347	6.778	7.682
9.052	8.946	8.847	10.374	10.885	10.393	9.785
9.254	8.087	5.757	6.996	6.657	4.443	4.721
4.563	5.353	4.953	5.818	3.198	3.768	5.087
4.053	4.434	5.115	5.344	3.844	4.557	3.723
5.204	4.564	4.560	3.669	4.397	3.713	4.371
3.967	3.934	3.902				

Year: 1976

1.795	4.167	4.000	4.286	4.429	4.814	5.152
5.737	6.431	6.743	7.927	6.808	7.527	7.728
7.677	8.621	9.050	9.016	9.683	8.711	8.894
8.883	10.085	7.720	8.332	7.140	5.287	4.693
4.430	4.500	6.080	4.718	5.182	4.879	6.154
3.597	5.089	5.620	6.289	5.672	5.811	6.078
3.565	5.221	4.358	4.660	4.438	3.854	3.637
4.080	3.955	3.884				

Year: 1977

3.947	4.500	4.237	4.559	4.930	5.672	5.503
6.165	7.013	7.004	8.378	7.284	7.673	9.176
7.558	8.045	8.234	8.364	7.453	9.289	9.089
9.730	8.296	6.905	4.772	4.771	3.912	4.943
5.967	4.553	3.580	5.094	5.935	4.662	3.305
4.127	4.770	5.749	5.116	4.330	5.295	5.285
5.635	4.514	4.783	4.344	2.829	4.173	4.134
3.921	3.688	3.558				

Year: 1978

3.042	3.702	3.991	4.244	4.648	4.804	5.196
5.050	5.700	6.634	6.028	5.568	6.215	6.801
7.544	7.539	7.299	9.037	8.844	7.829	8.584
10.205	8.060	8.572	5.917	3.729	4.824	3.803
5.916	5.520	4.716	4.007	4.261	4.640	5.129
5.444	4.911	4.588	5.076	4.492	4.922	4.726
5.096	3.903	4.354	4.531	4.602	4.162	4.336
4.024	4.249	3.502				

Year: 1979

2.753	4.182	4.113	4.220	5.157	5.256	5.448
5.980	5.946	6.713	7.122	8.271	7.226	8.670
9.052	8.477	8.816	9.431	9.144	9.976	9.501
9.533	9.873	9.680	7.853	5.559	5.468	4.627
5.509	7.171	5.545	3.595	5.967	6.240	6.031
4.771	3.942	6.144	5.561	4.539	5.355	5.665
5.554	5.091	4.539	4.746	5.090	4.534	4.594
4.550	4.094	4.275				

Year: 1980

2.556	4.568	4.396	4.699	5.569	5.820	5.683
5.750	6.678	7.412	6.823	7.155	7.809	7.823
8.575	9.354	10.582	10.349	10.829	10.543	10.251
9.575	7.275	7.509	4.749	3.474	3.387	4.524
4.562	4.704	4.198	4.316	4.495	6.271	4.406
4.519	3.973	4.502	4.730	5.225	5.642	5.691
4.025	5.040	4.824	4.608	4.607	4.430	4.200
2.966	4.113	3.875				

Year: 1981

1.803	4.779	4.171	4.296	4.400	5.269	5.591
5.843	6.326	7.478	6.992	6.426	6.983	6.370
8.078	9.265	7.991	8.865	7.041	8.641	8.774
7.210	8.355	8.481	6.503	4.729	5.267	3.919
3.743	4.744	5.868	4.482	5.424	5.528	5.196
4.817	4.909	5.111	4.751	4.967	5.834	5.744
5.684	4.901	4.858	4.927	5.106	4.758	4.539
4.275	4.072	3.940				

Year: 1982

4.127	4.188	3.972	3.818	4.712	4.694	5.341
5.540	5.335	5.668	6.338	7.389	7.499	8.621
8.757	8.078	9.074	9.181	9.357	9.242	9.539
7.031	7.870	5.642	5.978	6.327	8.836	4.888
6.328	4.741	5.030	4.110	3.730	4.082	5.169
4.333	4.996	6.352	5.862	5.466	5.575	4.445
5.595	5.373	4.826	4.414	4.226	4.313	4.203
3.863	4.150	4.296				

Year: 1983

4.104	4.625	4.131	4.393	5.201	3.976	5.267
5.693	5.589	6.281	7.336	6.613	6.853	7.671
7.915	7.341	8.666	9.169	8.886	8.479	9.735
8.843	8.889	8.518	7.122	6.144	4.778	6.506
5.050	4.724	3.527	5.013	4.369	5.131	4.138
4.201	5.171	4.931	5.356	3.299	3.980	5.491
5.635	5.205	4.641	4.626	4.399	4.873	4.314
3.983	3.888	3.894				

Year: 1984

3.293	4.362	4.051	4.605	4.772	4.532	4.873
5.474	6.092	6.433	7.134	7.352	7.619	8.698
8.393	9.444	8.165	9.641	10.230	10.619	10.941
8.010	6.058	4.836	5.857	4.123	4.063	4.804
4.867	5.310	5.948	4.535	4.548	6.159	4.620
3.436	5.082	6.053	6.001	5.217	4.768	3.962
5.045	4.853	4.822	4.177	4.438	4.376	4.075
4.002	4.244	3.837				

Year: 1985

2.268	3.825	3.831	4.266	4.845	5.644	4.762
5.123	6.281	7.302	7.178	7.170	7.688	8.251
8.983	8.818	9.086	9.131	9.089	8.849	8.837
8.702	6.397	7.913	6.718	7.366	3.714	3.992
4.140	5.613	4.720	4.467	6.366	4.290	3.549
3.019	4.050	3.830	5.258	4.816	4.469	4.275
5.004	4.910	4.366	4.733	4.934	4.468	4.194
3.996	3.752	4.183				

Year: 1986

2.132	4.186	3.794	3.974	4.779	5.238	5.207
4.605	5.960	6.065	7.279	7.854	7.968	8.746
8.702	8.587	9.197	8.029	8.485	8.025	6.946
8.198	9.179	9.453	5.407	2.909	5.041	5.449
5.156	4.828	4.606	5.250	5.764	4.545	5.761
5.148	4.607	5.362	4.710	4.660	3.013	5.334
5.544	5.261	3.083	3.970	4.401	4.219	4.086
3.643	3.795	4.033				

Year: 1987

1.830	3.949	3.818	4.163	4.500	5.184	4.855
5.143	6.002	5.572	5.904	7.497	7.272	7.525
8.414	8.204	8.460	7.382	7.083	7.714	9.694
9.362	7.839	6.582	7.017	8.171	9.562	4.058
4.396	4.100	4.786	4.576	7.197	5.606	3.755
5.330	4.597	5.172	4.560	5.318	5.143	4.982
5.027	5.077	3.299	4.829	3.114	3.901	3.947
3.581	3.951	4.182				

Year: 1988

3.599	3.764	3.937	4.349	4.681	5.239	5.125
5.222	5.952	6.076	7.563	8.155	8.039	9.007
9.034	7.394	7.674	8.038	10.159	7.621	6.925
8.856	6.092	4.169	6.471	5.322	5.477	4.784
6.129	4.527	4.318	3.943	5.068	5.834	5.430
4.231	5.475	3.647	5.621	4.841	5.403	5.205
5.551	4.293	4.316	4.968	4.928	4.402	3.983
4.106	4.153	3.752				

Year: 1989

2.949	3.917	3.941	3.827	4.244	5.565	5.993
6.047	5.808	6.282	5.777	6.972	6.611	8.491
8.101	9.184	8.396	9.174	9.997	9.463	6.261
6.325	7.037	5.779	3.094	5.629	4.176	5.827
5.947	4.283	3.466	3.946	4.800	5.157	4.381
5.093	3.591	4.914	4.150	4.888	4.389	4.281
5.086	4.454	4.222	3.582	3.978	3.896	3.625
3.397	3.477	3.211				

Year: 1990

2.426	3.624	3.742	4.002	4.315	4.914	4.416
4.097	5.108	4.587	5.204	6.045	5.592	5.958
6.809	6.457	7.493	6.878	5.244	4.953	6.509
6.782	5.875	5.324	4.930	3.814	3.586	3.243
3.547	4.394	4.061	5.399	4.904	4.790	4.682
3.488	4.136	5.164	4.604	3.935	3.258	4.762
3.847	4.161	2.841	4.136	4.047	3.699	3.471
3.438	2.948	3.463				

Year: 1991

2.184	3.487	2.767	3.043	4.063	4.679	4.985
4.876	6.136	5.767	6.259	6.593	6.553	8.399
7.287	7.291	6.981	7.530	9.148	9.346	9.257
8.075	6.208	5.518	7.085	4.872	3.858	5.461
3.803	3.654	4.668	3.745	2.892	3.532	3.230
3.121	4.529	4.193	4.115	4.205	3.248	3.522
4.626	2.620	2.851	3.657	2.810	3.545	3.270
3.072	2.760	3.091				

---

Table D-4 Weekly average reference crop evapotranspiration obtained  
by Penman method ( 32 years average )

Week no.	ET o	Week no.	ET o
1	2.83	27	4.84
2	4.05	28	4.61
3	4.08	29	4.82
4	4.18	30	4.80
5	4.70	31	4.63
6	5.08	32	4.67
7	5.22	33	4.71
8	5.50	34	4.92
9	6.15	35	4.67
10	6.54	36	4.47
11	6.84	37	4.60
12	7.05	38	5.01
13	7.30	39	5.09
14	8.08	40	4.57
15	8.42	41	4.66
16	8.64	42	4.83
17	8.74	43	4.97
18	9.10	44	4.54
19	9.28	45	4.35
20	9.14	46	4.29
21	9.12	47	4.26
22	8.76	48	4.20
23	7.82	49	4.02
24	6.94	50	3.38
25	6.04	51	3.85
26	5.45	52	3.85

Table D-5 Consumptive use of arhar (ET ) during different time intervals  
crop

Duration	ET, mm/day	K	Consumptive use in mm for the period
	o	c	
July 25th - 31st	4.700	0.230	7.570
Aug 1st - 7th	4.650	0.230	7.490
8th - 14th	4.690	0.230	7.550
14th - 20th	4.800	0.255	8.570
21st - 27th	4.810	0.375	12.630
28th - Sep 3rd	4.580	0.580	18.600
Sep 4th - 10th	4.530	0.750	23.780
11th - 17th	4.780	0.940	31.450
18th - 24th	5.000	1.095	38.330
25th - 30th	4.820	1.150	38.800
Oct 1st - 7th	4.600	1.150	37.030
8th - 14th	4.730	1.150	38.080
15th - 21st	4.800	1.150	38.640
22nd - 28th	4.790	1.150	38.560
29th - 4th Nov	4.460	1.150	35.900
Nov 5th - 11th	4.320	1.150	34.780
12th - 18th	4.280	1.150	34.450
19th - 25th	4.230	1.100	32.570
26th - 2nd Dec	4.120	0.965	27.830
Dec 3rd - 9th	3.950	0.790	21.840
10th - 16th	3.860	0.625	16.890
17th - 23rd	3.850	0.470	12.660
24th - 30th	3.850	0.315	8.500
<b>Total</b>			<b>572.500</b>

Table D-6 Consumptive use of groundnut ( $ET_{crop}$ ) during different time intervals

Duration	ET , mm/day o	K c	Consumptive use in mm for the period
Jul 10th - 16th	4.730	0.220	7.280
17th - 23rd	4.840	0.220	7.450
24th - 30th	4.770	0.220	7.350
31st - 6th Aug	4.650	0.250	8.140
Aug 7th - 13th	4.680	0.380	12.450
14th - 20th	4.800	0.545	18.310
21st - 27th	4.810	0.725	24.410
28th - 3rd Sep	4.590	0.885	28.440
Sep 4th - 10th	4.530	0.950	30.120
11th - 17th	4.780	0.950	31.790
18th - 24th	5.000	0.950	33.250
25th - 1st Oct	4.820	0.950	32.050
Oct 2nd - 8th	4.610	0.870	28.070
9th - 15th	4.730	0.680	22.510
16th - 17th	4.830	0.550	5.310
Total			296.930

Table D-7 Consumptive use of maize ( $ET_{crop}$ ) during different time intervals

Duration	ET , mm/day o	K c	Consumptive use in mm for the period
Jul 10th - 16th	4.720	0.220	7.280
17th - 23rd	4.840	0.220	7.450
24th - 30th	4.770	0.230	7.680
31st - 6th Aug	4.650	0.350	11.390
Aug 7th - 13th	4.680	0.530	17.360
14th - 20th	4.800	0.720	24.190
21st - 27th	4.810	0.935	31.480
28th - 3rd Sep	4.590	1.050	33.740
Sep 4th - 10th	4.530	1.050	33.300
11th - 17th	4.780	1.050	35.130
18th - 24th	5.000	1.050	36.750
25th - 1st Oct	4.820	1.050	35.430
Oct 2nd - 8th	4.610	0.970	31.300
9th - 15th	4.730	0.783	25.930
16th - 22nd	4.890	0.675	23.110
23rd - 27th	4.970	0.575	11.430
Total			372.950

## APPENDIX - E

Table E - 1 Yearwise yield of arhar and growing degree days at different growth phase

Year	Yeild q/ha	Growing degree days in degree cent. in different growth phase			
		Initial stage	crop dev. stage	Mid season	Late season
1976	8.20	479.55	641.55	1195.60	468.80
1977	9.05	477.70	648.20	1181.75	479.90
1978	9.38	471.25	653.80	1161.80	490.05
1979	12.11	464.65	672.35	1092.00	525.75
1980	9.77	470.20	658.70	1158.35	497.85
1981	9.93	467.85	663.25	1131.75	503.55
1982	9.44	472.15	653.45	1167.70	488.25
1983	10.00	467.25	665.35	1111.80	509.95
1984	7.11	488.55	641.20	1252.60	433.60
1985	7.22	487.85	641.20	1241.30	460.45
1986	11.89	463.45	673.75	1074.10	541.25
1987	13.56	461.95	682.15	1007.00	550.25
1988	10.22	466.25	666.75	1102.30	515.70
1989	9.93	467.85	663.25	1131.75	503.55
1990	11.22	465.85	668.15	1101.00	519.20
1991	9.38	474.35	649.70	1179.25	483.45

Table E - 2 Yearwise yield of groundnut and growing degree days at different growth phase

Year	Yeild q/ha	Growing degree days in degree cent. in different growth phase			
		Initial stage	crop dev. stage	Mid season	Late season
1976	10.28	467.70	558.45	569.80	268.50
1977	10.97	474.10	564.15	563.30	276.90
1978	11.11	475.90	565.45	563.00	278.90
1979	13.84	485.05	583.05	553.80	292.30
1980	12.19	479.30	568.40	560.30	280.85
1981	13.94	485.20	586.65	543.10	298.20
1982	13.80	482.45	577.45	556.70	287.60
1983	13.47	481.60	569.95	558.90	285.55
1984	9.78	465.80	553.90	574.90	263.25
1985	9.72	463.80	553.25	585.10	261.55
1986	10.00	466.70	554.25	573.80	263.75
1987	13.47	479.95	568.55	559.80	281.15
1988	11.94	477.15	566.50	561.50	280.20
1989	10.78	473.60	561.70	564.50	272.30
1990	10.44	471.85	559.15	566.60	271.05
1991	10.92	472.90	559.15	564.50	271.30

Table E - 3 Yearwise yield of maize and growing degree days at different growth phase

Year	Yeild q/ha	Growing degree days in degree cent. in different growth phase			
		Initial stage	crop dev. stage	Mid season	Late season
1976	22.93	369.45	584.10	649.25	433.55
1977	9.14	389.10	553.70	681.80	474.80
1978	19.14	381.05	565.80	652.05	440.50
1979	11.11	389.05	556.70	666.05	464.60
1980	9.59	389.05	554.30	668.50	471.95
1981	16.05	385.95	560.70	661.85	455.05
1982	17.51	384.95	561.60	660.45	453.90
1983	12.39	387.55	557.40	662.55	463.55
1984	19.60	371.55	571.00	650.65	437.60
1985	23.01	368.55	589.10	635.95	423.80
1986	19.44	373.95	568.40	651.00	438.80
1987	18.46	378.95	567.20	652.05	439.50
1988	15.28	387.15	560.20	662.20	459.40
1989	17.38	383.35	564.70	659.75	452.40
1990	22.90	371.35	576.40	650.20	434.50
1991	17.76	382.40	565.80	656.95	450.15

Table E - 4 Yearwise yield of upland paddy and growing degree days at different growth phase

Year	Yeild q/ha	Growing degree days in degree cent. in different growth phase			
		Initial stage	crop dev. stage	Mid season	Late season
1976	11.58	412.65	573.55	551.80	369.30
1977	13.66	395.15	562.85	544.20	377.20
1978	14.77	384.30	557.10	527.10	389.55
1979	11.03	413.00	579.45	553.60	368.10
1980	12.63	394.45	562.05	542.90	379.95
1981	12.46	397.60	567.80	544.80	376.30
1982	10.21	444.35	584.45	564.70	364.15
1983	14.10	410.90	571.50	551.25	371.60
1984	14.16	392.35	560.65	541.50	380.90
1985	14.44	389.55	560.15	530.10	384.75
1986	14.72	388.50	558.95	527.90	387.80
1987	14.72	439.95	584.25	562.00	367.65
1987	10.30	406.70	569.55	550.80	372.00
1988	11.72	403.55	568.35	545.00	375.20
1989	12.00	383.25	556.95	525.90	393.35
1990	17.72	419.30	581.70	555.20	368.10
1991	10.89				