PATTERN OF OCCURRENCE OF RAINFALL AND ESTIMATION OF RAINFALL PROBABILITIES IN NORTHERN DISTRICTS OF KERALA

By
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THESIS
submitted in partial fulfilment of the requirement
for the degree
MASTER OF SCIENCE IN AGRICULTURAL STATISTICS
Faculty of Agriculture
Kerala Agricultural University

Department of Statistics
COLLEGE OF VETERINARY AND ANIMAL SCIENCES
Mannuthy, Trichur

1987

Dedicated to

My Beloved Parents

DECLARATION

I hereby declare that this thesis entitled "Pattern of occurrence of rainfall and estimation of rainfall probabilities in northern districts of Kerala" is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that this thesis entitled "Pattern of occurrence of rainfall and estimation of rainfall probabilities in northern districts of Kerala" is a record of research work done independently by Sri. Santhosh, K. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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ACKNOWLEDGEMENT

I express my profound sense of gratitude and indebtedness to Sri. P.V. Prabhakaran, Professor of Statistics, College of Agriculture, Vellayani, for his expert guidance, critical suggestions and unfailing inspiration throughout the course of the investigation and the preparation of the thesis.

My sincere thanks are due to Sri. V.K. Gopinathan Unnithan, Associate Professor of Statistics, College of Horticulture, Vellanikkara, Sri. N. Raveendranathan, Associate Professor of Statistics, College of Co-operation and Banking, Mannuthy and Dr. V.K. Sasidhar, Professor of Agronomy, College of Agriculture, Vellayani, for their valuable suggestions and critical scrutiny of the manuscript.

I am grateful to Dr. E.J. James, Head, Surface Water Division and Sri. K.E. Sreedharan, Scientist B, of the Centre for Water Resources Development and Management, Calicut, for making available the data for the study and the ever-willing help and co-operation rendered by them.

I extend my sincere gratitude to Dr. K.C.George, Professor and Head, Department of Statistics, College of Veterinary and Animal Sciences, Mannuthy, Sri. A.V.R. Kesava Rao, Assistant Professor, Department of Agrometeorology, College of Horticulture, Vellanikkara and Sri. C.N. Chandrasekharan Nair, Librarian, Vikram Sarabhai Space Centre, Trivendrum for their invaluable assistance and timely advice. Indeed I owe a great deal to them, more than what could be expressed here.

The assistance of Sri. Mathew Sebastian, Junior Assistant Professor, Department of Statistics, College of Veterinary and Animal Sciences, Mannuthy and Sri. C.E. Ajithkumar, Junior Programmer, Department of Agricultural Statistics, College of Agriculture, Vellayani, is sincerely acknowledged

I owe immense gratitude to all others who helped me in the successful completion of this thesis.

I also thank the Kerala Agricultural University for the award of Junior Fellowship during the period of my post graduate programme.

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INTRODUCTION

INTRODUCTION

The repetitive behaviour of seasonal weather has been a fascination for meteorologists and statisticians of all time. The meteorologists are interested in the physical explanation for such phenomena whereas the statisticians' interest centres around exploring the possibilities of model building for explaining the observed phenomena. Such models may provide informations on the physical understanding of the complex phenomena by way of utilising the deductive power of mathematics to reach conclusions that could not have been reached otherwise.

Agrarian economy of any underdeveloped or developing region would predominantly be a weather controlled one. The distinctive characteristics of the tropical environment have major influence on the distribution of natural endowments: soils, rainfall and climate. In tropical countries, water is the limiting factor for crop growth and development; the main source of water being precipitation. In low rainfall areas especially in tropics, the importance of rainfall over rides that of all other climatic factors which influence crop growth and yield. Because of the high evaporative demand during most of the growing season, variation in timing and amount of precipitation are generally the key factors influencing the agricultural production potential of a given region.

Rainfall which is one of the most important of the weather parameters is highly variable in nature. In a particular region, the commencement of rain may be much earlier or considerably delayed than the normal dates. The rain may terminate considerably earlier or persist longer than usual. Rainfall may be unevenly distributed in space and time being excessive in one part of the region and deficit in another part. In order to avoid the risk of cultivation due to the unpredictable nature of rainfall, suitable techniques have to be developed which characterises the rainfall pattern in a given region. The model building technique will be of immense importance in such situations. The analysis of rainfall data over large number of years would reveal the suitable statistical model to be adopted for representing the rainfall pattern. Once such a model is found out, the rainfall pattern could be predicted in advance by utilising the properties of such models.

The food production in India is limited primarily by the erratic nature of weather. Indian farmer knows through long and often bitter experience that there are no certainties in agriculture because nature itself is so unpredictable and that their systems of farming is a hazardous way of life. Water is precious, and extended dry periods often mean empty stomachs for farmers and their families, for they have no means to irrigate their crops. They anxiously look forward to timely commencement and proper distribution of rainfall during the season.

In India, about 27% of the cultivated land enjoys irrigation facilities. In the remaining area, farming is done under unirrigated conditions and as such it depends mostly on the occurrence of rainfall. The inadequacy of rainfall and its uneven distribution significantly affect the total agricultural production of the country. It is often said that the Indian agriculture is a gamble in monsoons. Many studies have been made from time to time to know the pattern of occurrence of abnormal seasonal conditions during which either too much rainfall occurs or no rainfall, when it is most needed, occurs at all. Both these situations affect our agriculture programmes adversely. The quantity of rainfall received over a period of time at a particular place provides a general picture regarding its sufficiency to meet crop needs.

Because of the vagaries of monsoons, scientific approach to study rain water availability for use in dry land agriculture is all the more a necessity. Informations on water availability periods, probability of assured rainfall and the expected amount of precipitation during varying periods of crop growth etc. are of great importance in rainfed farming. In Kerala, year round cultivation mainly depends on south-west and north-east monsoons. But the distribution of rainfall in long and short spells over the past several years has been marginal and erratic. Consequently, there is a growing need for utilising the available monsoon rainfall in the most effective manner. The northern districts of Kerala constitute one of the problem regions of Kerala with regard to the pattern of occurrence of rainfall. Rice is the most important crop in this region. Untimely and irregular premonsoon showers and delay of the onset of monsoon forces the cultivators of these areas to delay sowing and some times the seeds fail to germinate at all. Flood damages during the later stages of the Virippu (Autumn) crop and earlier stages of Mundakan (Winter) crop also occur. Further in these districts, the north-east monsoon is not at all strong and exerts no significant impact on water availability. About 80% of the annual rainfall is received during the period from May to August.

Hence a detailed study of rainfall data for a sufficiently long period will help in understanding the rainfall patterns of the region and suggesting methods of efficient crop planning. The results of the study may reveal useful informations on optimum sowing time, suitable cropping season, periods of moisture deficiency and surplus and the crops to be grown. Such informations are very helpful in lessening the risk of farming due to the adverse weather conditions and inturn enhanced productivity.

In one of his earliest attempts, Fisher (1924) opined to consider the effect of distribution of rainfall rather than its quantum, on crop output. Since the distribution of rainfall depends on the sequence of wet and dry spells over a period of time, the investigation of the pattern of occurrence of such spells during the crop growing period will be very important. If the number of wet days in a given period is more, the rainfall distribution will be good, even if the total seasonal rainfall is less. Thus the expected number of wet days can decide the crop potential of an area. Probability of sequences of wet days can tell us the adequacy of water and probability of sequences of dry days can tell us the recurrence of the risk of crop failure. A two state Markov chain model can give the basic probable representation of the distribution of spells and goes further in making it possible to derive several other properties of rainfall occurrence patterns. The sequence of wet and dry spells can be an aid to better agricultural planning and for finding climatic crop potential.

It is observed in general that the average rainfall at a centre does not give the true picture of the situation. Not enough work has been done with respect to rainfall probabilities, consumptive use of moisture and water requirement of a crop during different crop phases under different agro-climatic zones. This kind of information if collected and studied over large areas of rain grown crops, would go a long way in successfully growing that crop in those regions. This would also help us to locate the areas where a particular crop cannot be grown successfully and would enable us to eliminate that particular crop from that region and other crop with less moisture requirements could be grown successfully.

The study of rainfall probabilities is an approach to sound planning against the hardship caused by large variation in rainfall. In particular, a study of this nature would be useful in deciding upon whether a particular agricultural area needs major, medium or minor irrigation as well as the type of irrigation (well, canal etc.). Moreover, once these irrigation projects are completed, these very statistics would be useful in regulating the water supply in each month or any other time unit. The probability of a fixed amount of rainfall to be expected can be computed by fitting appropriate probability distribution of rainfall.

Rainfall probabilities together with the expected minimum and maximum amounts of rainfall would be much more important and useful from Indian agricultural point of view. These minimum and maximum amounts of rainfall to be expected are otherwise referred to as confidence limits of assured rainfall.

One of the most important uses of the study of confidence limits would be to manipulate sowing dates at a given place. The sowing dates will have to be decided in a manner so that the water logging conditions are avoided. Moreover, one should ensure that this period falls preferably during the months of higher rainfall or in the alternative, when the soil moisture reserves are quite adequate to meet the increasing demands of the crop. In a nutshell, the study of confidence limits helps to determine the possibility or not of any cultural practice/s during a fixed period in general and sowing operation in particular.

From the aforesaid it is clear that it would be appropriate in demonstrating the use of methodologies for quantifying rainfall in agronomically relevant terms. It is with the view in mind, the present study was undertaken for a proper understanding of the pattern of rainfall in the northern districts of Kerala so that necessary orientation could be given to the breeding and agronomic works on crops of that region. The present study was taken up with the following objectives.

1. To determine the pattern of occurrence of moist days during the whole year in terms of the expected length of wet and dry spells, and equillibrium probabilities of occurrence of wet and dry days

in various fortnights.

2. To predict the expected amount of fortnightly rainfall at different reporting stations with a given degree of confidence.

3. To make a comparison of the different districts on the occurrence of rainfall.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Many works have been done earlier in India and abroad with a view to characterize the rainfall occurrences. The repetitive behaviour of seasonal rainfall has been studied by many using a variety of mathematical and probability models. Models based on stochastic process were also being applied in such studies. Some of the important works based on stochastic and probability models are outlined hereunder.

1. Stochastic model

1.1 Markov chain model

One of the pioneer works in this field is that of Besson (1924). He reached the conclusion through a statistical analysis that at Montsouris, France, past weather exerts an influence on future weather.

Gabriel and Newmann (1962) fitted a two state Markov chain model to daily rainfall occurrence at Tel Aviv. The various properties of Markov chain model applicable to rainfall were also discussed.

A two state Markov chain model has been fitted by Hopkins and Robillard (1964) to the daily rainfall observations at Edmonton, Swift Current and Winnipeg. This model provided very serviceable approximation to the April-September frequency statistics.

Bhargava et al. (1972) found that a first order Markov chain model fitted well to the daily rainfall data recorded at 21 raingauge stations located at different parts in Raipur.

The occurrence and persistence of deficient rainfall periods during the main rainy season were analysed by Krishnan and Kushwaha (1973) for Jodhpur and Jaipur by random-model and simple Markov chain model. Simple Markov chain model fitted the observed frequencies better than the random model.

Medhi (1976) used a first order Markov chain model for explaining the occurrence of dry and wet days in Gauhati.

A Markov chain model was fitted for daily rainfall data by Robertson (1976) to establish drought frequencies during 10 day periods.

The use of Markov chain model for crop planning in the Jalagaon area (Maharashtra) was of interest to Narain et al. (1979). The application of the Markov chain model to daily rainfall for efficient crop planning in the area during the crop season of major crops was also discussed.

Victor and Sastry (1979) fitted a first order Markov chain model to daily rainfall data of the monsoon months in the Delhi region.

Mahajan and Rao (1981) studied the behaviour of the occurrence of wet and dry spells during the crop season of rice at Hyderabad using a first order Markov chain model.

2. Probability models

Whitcomb (1940) found that gamma distribution gave an adequate representation of monthly precipitation amounts.

The incomplete gamma curves have been fitted by Barger and Thom (1949) to frequency distribution of n-week rainfall totals. The probabilities of getting a fixed amount or less rainfall have been worked out.

Jeeves *et al.* (1952) employed the incomplete gamma distribution for fitting rainfall data.

It was found by Chow (1954) that lognormal probability law could be applied to model monthly and daily rainfall amounts.

Friedman and Janes (1957) have applied the gamma distribution for obtaining the probability of receiving a given amount of precipitation at different stations in U.S.A.

Gamma distribution has been fitted by Barger *et al.* (1959, a) for obtaining probabilities of weekly precipitation at different stations in U.S.A. They have also fitted gamma distribution for 2 and 3 week precipitation totals (1959, b).

Markovic (1965) discussed the application of gamma distribution function to model annual precipitation.

Neyman and Scott (1967) used gamma distribution to fit the amounts of daily precipitation.

Avtar Singh and Pavate (1968) observed that monthly precipitation amounts at Amravati and Coimbatore followed the normal probability law, when the data are transformed to the squareroot scale. The monthly and annual rainfall probabilities together with the confidence limits were also worked out.

Gamma distribution was adjudged by Mooley and Crutcher (1968) to be the best for representing rainfall data of longer durations such as weeks and months when compared to other continuous distributions.

Thom (1968) recommended the fitting of incomplete gamma functions to skew distributions such as those of rainfall having zero lower bound.

Strommen and Horsfield (1969) used gamma distribution for representing rainfall amounts.

Gamma distribution function has been fitted by Mooley and Appa Rao (1970) to pentad rainfall of two stations in Rajastan during the south-west and north-east monsoon seasons.

Krishnan and Kushwaha (1972) fitted incomplete gamma distribution to pentad rainfall totals of two stations in Rajastan.

Mooley (1973) found that gamma distribution was the most suitable probability model to characterize monthly rainfall pattern.

It was observed by Thomas (1977) that the distributions of the annual amount of rainfall and annual number of rainy days at Pattambi obeyed the normal probability law.

New methods for estimating the weekly rainfall of a place has been developed by Surendran et al. (1977). Weekly amounts of precipitation at Trichur were predicted together with the confidence limits at various probability levels.

Biswas and Khambete (1979) computed the lowest amount of rainfall at different probability levels by fitting gamma distribution probability model to week by week rainfall totals.

MATERIALS AND METHODS

MATERIALS AND METHODS

The data for the present study pertaining to daily rainfall were collected from the meteorological records maintained at the Centre for Water Resources Development and Management (CWRDM), Calicut for the period of 30 years from 1942 onwards. Although informations were available from a large number of meteorological reporting stations of the northern region, six centres alone were selected specifically for the study. Two rain gauge stations were selected at random from Cannanore and Calicut districts and one each from the other two districts viz. Kasaragod and Wynad. The raingauge stations that come within the purview of the study were Kasaragod, Irikkur, Cannanore, Kozhikode, Quilandy and Mananthody.

Methods

3.1 Markov chain modeling of rainfall

3.1.1 Markov Process

The systems which develop in time or space and which conforms with probabilistic laws are discussed in the theory of Stochastic processes. The theory can be applied to explain a variety of phenomena in the field of science and technology.

A stochastic process can be considered to be a set of random variables $X(t)$ depending on a real parameter 't' which varies in a certain set I of natural numbers. It is denoted by $\{X(t),\ t \in I\}$. A real number x is said to be a possible value or a state of a stochastic process $\{X(t),\ t \in I\}$ if there exists a time 't' in I such that the probability $P\ (x-h < X(t) < x+h)$ is positive for every $h > 0$. The set of possible values of a stochastic process is called its state space.

Imagine a finite stochastic process with n states with state space 0,1,2 . . . n and assume that at time t, the process is at state 0. Then at time (t+1), let the probabilities of the process being in states 0,1,2 . . . n be denoted by p_{00}, p_{01} . . . p_{0n} respectively with $p_{00}+p_{01}+ \ldots +p_{0n} = 1$. Similarly if the process is in state 1 at time t, let the probabilities of the process being in states 0,1,2 . . . n at time (t+1) be 0, p_{11}, p_{12} . . . p_{1n} with $p_{11} + p_{12} + \ldots + p_{1n} = 1$. This is true for every state of the stochastic process. If p_{ij} denote the probability of moving from state i to state j in one step, we can note that $\sum_j p_{ij} = 1$. The probabilities p_{ij} are called transition probabilities and $P = (p_{ij})$ is the transition probability matrix.

A stochastic process is said to be Markovian if given the value of X(t) for a given t, the probability distribution of X(s) for $s > t$ does not depend upon the value of X(u), $u < t$. Loosely speaking, the future behaviour of the process depends only on the present state but not on the past. Thus the fundamental principle underlying Markov process is the independence of the future from the past if the present is known. In other words, a finite Markov chain is a stochastic process with a finite number of steps in which the probability of the process being in a particular state at the $(n+1)^{th}$ step depends only on the state occupied at the n^{th} step and this dependence is assumed to be same in all steps.

A stochastic process $\{X(t)\}$ is said to be a Markov process if for any set of n time points $t > t-1 > t-2 \ldots > t-n+1$ in the index set of the process, the conditional distribution of X(t) for given values of X(t-1), X(t-2) . . . X(t-n+1) depends only on X(t-1), the most recent known value. More precisely, for any set of real numbers $x_1, x_2 \ldots x_n$,

$$P\left[X(t) \quad x_n / X(t-n+1) = x_1 \ldots X(t-1) = x_{n-1}\right]$$
$$= P\left[X(t) \quad x_n / X(t-1) = x_{n-1}\right] \qquad (1)$$

3.1.2 Markov chain

A class of Markov processes in discrete time whose state space is discrete is called a Markov chain. It is also evident that equation (1) holds good in the case of Markov chains and the conditional probability is independent of the states occupied at times prior to (t-1).

In general, higher order Markov chains can be defined to represent stochastic processes such that the value of the process at time t is independent on its value in several immediately preceding time periods. Thus an n^{th} order Markov chain is one in which

$$P\left[(X(t) = x_j / X(t-1) = x_i, X(t-2) = x_k \ldots X(0) = x_q\right]$$
$$= P\left[X(t) = x_j / X(t-1) = x_i, X(t-2) = x_k \ldots X(t-n) = x_p\right] (2)$$

If a process is divided into n states, then n^2 transition probabilities must be defined. However at each step, the process must either remain in state i or proceed to one of the other (n-1) states.

Thus $\sum_{j=1}^{n} p_{ij} = 1$ (3)

With this restriction, an n state Markov chain requires that n(n-1) transition probabilities or parameters be estimated. The remaining n p_{ij}'s can be determined from equation (3). The n^2 transition probabilities can be represented by the n x n matrix P given by

$$P = (p_{ij}) = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} & \cdots & p_{2n} \\ \cdot & \cdot & \cdots & \cdot \\ \cdot & \cdot & \cdots & \cdot \\ p_{n1} & p_{n2} & \cdots & p_{nn} \end{bmatrix}$$

Once P is known, all that is required to determine the probabilistic behaviour of the Markov chain is the initial state of the chain. In the following, the notation $p_j^{(n)}$ means the probability that the chain is in state j at step or time n. The $1 \times m$ vector $\underline{p}^{(n)}$ has elements $p_j^{(n)}$

Thus $\underline{p}^{(n)} = \left(p_1^{(n)} \ p_2^{(n)} \ . \ . \ . \ p_m^{(n)}\right)$

It can be easily verified that

$$\underline{p}^{(n)} = p_1^{(n-1)} p_{1j} + p_2^{(n-1)} p_{2j} + \ . \ . \ . + p_r^{(n-1)} p_{rj}$$

$$+ \ . \ . \ . + p_m^{(n-1)} p_{mj}$$

$$= \sum_{k=1}^{m} p_k^{(n-1)} p_{kj} \qquad (4)$$

or it is the product of the row vector $p^{(n-1)}$ and the j^{th} column of the transition matrix $\underset{\sim}{P}$. ie. the components of $p^{(n)}$ are obtained by multiplying $p^{(n-1)}$ by the appropriate column of $\underset{\sim}{P}$

$$\text{Thus } \underline{p}^{(n)} = p^{(n-1)} \underset{\sim}{P} \qquad (5)$$

and in particular

$$\underline{p}^{(1)} = \underline{p}^{(0)} \underset{\sim}{P}$$

$$\underline{p}^{(2)} = \underline{p}^{(1)} \underset{\sim}{P}$$

$$= \underline{p}^{(0)} \underset{\sim}{P}^2$$

$$\underline{p}^{(n)} = \underline{p}^{(0)} \underset{\sim}{P}^n \qquad (6)$$

Furthermore, it can be shown that

$$p^{(n+m)} = \underline{p}^{(m)} \underset{\sim}{P}^n \qquad (7)$$

As the Markov chain advances in time, $p_j(n)$ becomes less and less dependent on $\underline{p}^{(0)}$. That is to say the probability of being in state j after a large number of steps becomes independent of the initial state of the chain. A point is reached where $\underline{p}^{(n)} = \underline{p}^{(n+m)}$ for a sufficiently large n. From equation (6) we then get for a sufficiently large n that $\underset{\sim}{P}^{n} = \underset{\sim}{P}^{n+m}$

when this occurs, the chain is said to have reached a steady state. Under steady state conditions $\underline{p}^{(n)} = \underline{p}^{(n+m)}$ and can thus be denoted simply as $\underline{p}$.

One can therefore calculate the steady state probabilities simply by computing $\underset{\sim}{P}^{n}$ for a large enough n. In practice, one would compute $\underset{\sim}{P}^{n}$ and $\underset{\sim}{P}^{2n}$. If the two differed by an acceptably small amount, $\underline{p}$ would be taken as one of the rows of $\underset{\sim}{P}^{2n}$.

The transition probability matrix $\underset{\sim}{P}$ can be estimated from observed data by tabulating the number of times the observed data went from state i to state j, ie. n_{ij}.

Then an estimate of p_{ij} would be

$$p_{ij} = n_{ij} / \sum_{j=1}^{m} n_{ij} \qquad (9)$$

3.1.3 Two state Markov chain

The theory of two state Markov chain described by Cox and Miller (1965) is presented below.

Consider a Markov chain with two states. Let the two states be "success" and "failure" denoted by 1 and 0 respectively. This is the case of a dependent Bernoulli trial in which the probability of success or failure at each trial depends on the outcome of the previous trial.

Suppose that if the n^{th} trial results in failure, then the probability of success at the $(n+1)^{th}$ trial is α and the probability of failure at the $(n+1)^{th}$ trial is $1 - \alpha$. Similarly if the n^{th} trial results in success, then there are probabilities $1 - \beta$ and β of success and failure respectively at the $(n+1)^{th}$ trial. In other words, if the systems is in state 0 at time n then there is a probability $(1 - \alpha)$ of being in state 0 at time $(n+1)$ and a probability α of being in state 1 at time $(n+1)$. Similarly if the system is in state 1 at time n, then the probabilities of being in state 1 at time (n+1) is $(1-\beta)$ and in state 0 is β. These are the transition probabilities and the transition probability matrix

$$P = \begin{array}{c} \\ 0 \\ 1 \end{array}\begin{array}{c} \begin{array}{cc} 0 & 1 \end{array} \\ \begin{bmatrix} 1-\alpha & \alpha \\ \beta & 1-\beta \end{bmatrix} \end{array}$$

The matrix element in position (i,j) denotes the conditional probability of a transition to the state j at time (n+1) given that the system is in state i at time n. The assumption here is that the transition probabilities are independent of time. Also we exclude the somewhat trivial cases

(1) $\alpha + \beta = 0$ ie. $\alpha = 0$, $\beta = 0$; in this case the system remains for ever in its initial state.

(2) $\alpha + \beta = 2$ ie. $\alpha = 1$, $\beta = 1$; in this case the system alternates deterministically between the two states, and if the initial state is given, the behaviour of the systems is non random.

Let the row vector $\underline{p}^{(n)} = \left(p_0^{(n)}\ p_1^{(n)}\right)$ denote the probabilities of finding the systems in states 0 or 1 at time n when the initial probabilities of the two states are given by $p^{(0)} = \left(p_0^{(0)}\ p_1^{(0)}\right)$. Consider the event of being in state 0 at time n. This event can occur in two mutually exclusive ways; either state 0 was occupied at time (n-1) and no transition out of state 0 occurred at time n; this has probability $p_0^{(n-1)}(1-\alpha)$. Alternatively state 1 was occupied at time (n-1) and a transition from state 1 to state 0 occurred at time n; this has probability $p_1^{(n-1)}\beta$. These considerations may lead to the following recurrence relations.

$$p_0^{(n)} = p_0^{(n-1)}(1-\alpha) + p_1^{(n-1)}\beta \qquad (10)$$
$$p_1^{(n)} = p_0^{(n-1)}\alpha + p_1^{(n-1)}(1-\beta)$$

which in matrix notation may be compactly written

$$\underline{p}^{(n)} = \underline{p}^{(n-1)}\ \underset{\sim}{P} \qquad (11)$$
$$\underline{p}^{(n)} = \underline{p}^{(n-2)}\ \underset{\sim}{P}^2 = \ldots \underline{p}^{(0)}\ \underset{\sim}{P}^n \qquad (12)$$

Thus given the initial probabilities $\underline{p}^{(0)}$ and the matrix of transition probabilities $\underset{\sim}{P}$, the state occupation probabilities at any time n can be found out using the relation (12).

Let $p_{ij}^{(n)}$ denote the $(i,j)^{th}$ element of $\underset{\sim}{P}^n$. If the system is initially in state 0, then $\underline{p}^{(0)} = (1\ ,\ 0)$

and $\underline{p}^{(n)} = \left(p_{00}^{(n)} \; p_{01}^{(n)}\right)$. If the system is initially in state 1 then $\underline{p}^{(0)} = (0 \, , \, 1)$ and $\underline{p}^{(n)} = \left(p_{10}^{(n)} \; p_{11}^{(n)}\right)$.

Thus $p_{ij}^{(n)} = P$ (state j at time n/state i at time 0)

$p_{ij}^{(n)}$ are the n step transition probabilities.

A matter of interest at this stage would be to see whether after a sufficiently long period of time, the system settles down to a condition of statistical equillibrium at which the state occupation probabilities become independent of the initial conditions. If this is so, then there is an equillibrium probability distribution $\Pi = (\Pi_0, \Pi_1)$ and on letting $n \to \infty$ in (11), Π will clearly satisfy

$$\Pi = \Pi P$$

$$\text{or } \Pi(I-P) = 0 \qquad (13)$$

thus $\Pi_0 \alpha - \Pi_1 \beta = 0, \; - \Pi_0 \alpha + \Pi_1 \beta = 0$

This is a homogeneous system of equations and have a non zero solution if and only if the determinant $|I-\underset{\sim}{P}|$ vanishes. Clearly $|I-\underset{\sim}{P}|$ does vanish and we can make the solution unique by noting that we need the condition, $\Pi_0 + \Pi_1 = 1$

for a probability distribution.

Thus $\pi_0 = \beta / (\alpha + \beta)$, $\pi_1 = \alpha / (\alpha + \beta)$ (14)

It may be noted that if the initial probability distribution is π, then $\underline{p}^{(1)} = \pi \underset{\sim}{P} = \pi$,

$\underline{p}^{(2)} = \underline{p}^{(1)} \underset{\sim}{P} = \pi \underset{\sim}{P} = \pi$

and $\underline{p}^{(n)} = \pi$ $(n = 1, 2, \ldots)$

Thus the distribution $\underline{p}^{(n)}$ is stationary if $\underline{p}^{(0)} = \pi$ ie. it does not change with time.

3.1.4 Analytical procedure

Each month in an year is divided into two fortnights of 15 or 16 days duration. However, February is divided into 2 fortnights each with 14 days duration. The various fortnights in an year are defined as follows.

Month	Dates	Fortnight number
January	1-15	1
	16-31	2
February	1-14	3
	15-28*	4

Month	Dates	Fortnight number
March	1-15	5
	16-31	6
April	1-15	7
	16-30	8
May	1-15	9
	16-31	10
June	1-15	11
	16-30	12
July	1-15	13
	16-31	14
August	1-15	15
	16-31	16
September	1-15	17
	16-30	18
October	1-15	19
	16-31	20
November	1-15	21
	16-30	22
December	1-15	23
	16-31	24

*In leap year, the fortnight no.4 will have 15 days.

Similarly the three crop seasons for rice (*Oryza sativa*) viz. *Virippu*, *Mundakan* and *Punja* can be defined as follows.

Season number	Season	Dates	Duration in days
1	Virippu (Autumn)	May 1 - September 15	138
2	Mundakan (Winter)	September 16 - January 15	122
3	Punja (Summer)	January 16 - April 30	105

Based on daily rainfall data during the whole year, a classification of days are made based on the amount of rainfall received on each day. A wet day can be defined as a day on which the amount of rainfall received is greater than or equal to 2.5 mm (Gabriel and Neumann, 1962). Similarly, a dry day is defined as a day which receives an amount of rainfall which is less than 2.5 mm. By this classification, a sequence of wet and dry days are obtained. One of the following four possibilities may occur while classifying each day of such a sequence.

1. A dry day preceded by a dry day
2. A wet day preceded by a dry day

3. A dry day preceded by a wet day
4. A wet day preceded by a wet day

The number of days for the above four possibilities are counted for each fortnight. The process is repeated each year and the total number of days are obtained for all the fortnights separately. Let these frequencies be denoted by n_{11}, n_{12}, n_{21} and n_{22} respectively with $n_{11} + n_{12} = n_1$ and $n_{21} + n_{22} = n_2$. Given that the previous day is dry, let the probabilities of a day being dry and wet be respectively p_{11} and p_{12} with $p_{11} + p_{12} = 1$ where $p_{11} = n_{11}/n_1$ and $p_{12} = n_{12}/n_1$ which are the maximum likelihood estimates. Similarly, given that the previous day is wet, let the probabilities of a day being dry and wet be respectively p_{21} and p_{22} with $p_{21}+p_{22} = 1$, where $p_{21} = n_{21}/n_2$ and $p_{22} = n_{22}/n_2$. It is assumed that the probability of rainfall on any day depends only on whether the previous day was wet or dry. Given the event on the previous day, then, the probability of rainfall is assumed independent of events of further preceding days. Such a probability model is the Markov chain whose parameters are the two conditional probabilities.

p_{12} = P (wet day preceded by dry day)

p_{22} = P (wet day preceded by a wet day)

This model is formulated entirely in terms of occurrence and non occurrence of rainfall on any day; no account being taken of amounts of precipitation.

After having obtained the parameters of the model, the next step would be to explore the possibilities of how these parameters could be utilised in determining whether the Markov chain is of first order. The method can be explained as follows.

Consider the sequence of wet and dry days. Given the previous day was dry, let the occurrence of a wet day be termed as 'success' and a dry day be denoted as 'failure'. Hence the occurrence of wet or dry day subject to the above condition can be considered as a Bernoulli trial with two possible outcomes for each trial (success or failure). Let p_{12} be the probability of success and $(1-p_{12})$, the probability of failure. Then for a sequence of

n_1 days, the probability of getting exactly x successes is $\binom{n_1}{x} p_{12}^{x} (1-p_{12})^{n_1-x}$, given by the binomial probability law. The proportion of successes is given by $p_{12} = x/n_1$ and making use of the properties of binomial distribution we get $V(p_{12}) = p_{12}(1-p_{12})/n_1$. In a similar manner, we can show that $V(p_{22}) = p_{22}(1-p_{22})/n_2$.

In order to test whether the occurrence of day and wet days assumes a first order Markov chain model, the usual normal deviate test can be applied. We compute $Z = \left|p_{12} - p_{22}\right| / SE\,(p_{12} - p_{22}) \quad N(0,1)$

$SE\,(p_{12} - p_{22})$ is estimated by $pq\,(1/n_1 + 1/n_2)$ where $p = (n_1\, p_{12} + n_2\, p_{22}) / (n_1 + n_2)$; $q = 1-p$

A significant value of Z reveals that the occurrence of rainfall on a particular day depends on the immediately preceding day's rainfall which is evidently the property of the first order Markov chain. In such cases, the sequence of wet and dry days over a given period strictly follows a two state Markov chain with 4 transition probabilities having parameters p_{12} and p_{22} as explained earlier.

The transition probability matrix

$$P = \begin{bmatrix} p_{11} & p_{12} \\ p_{21} & p_{22} \end{bmatrix}$$

The equillibrium probabilities π_0 and π_1, which are independent of the initial conditions, given as per equation (14) can be written as

$$\pi_0 = \beta / (\alpha + \beta) = (1-p_{22}) / (1-p_{22} + p_{12})$$

$$\pi_1 = \alpha / (\alpha + \beta) = p_{12} / (1-p_{22} + p_{12})$$

The number of days after which the equillibrium is achieved is equal to the number of times the P matrix is powered till the elements of a column of the powered matrix become equal correct to 4 decimal places.

3.1.5 Expected length of dry and wet spells and that of weather cycle

The various other properties of the Markov chain model can be further demonstrated by utilising the properties of the geometric distribution.

Under the assumption that the weather of any day depends only on the previous day's weather, the probability that a wet day will be followed by wet or dry day and vice versa can be determined. Further, the probability of an X-day long wet or dry spell can be determined. A wet spell of length W is defined as W successive wet days followed by a dry day.

Hence the probability of a wet spell of length k is given by $P(W = k) = p_{22}^{k-1}(1-p_{22})$,

where W is a random variable following geometric distribution and its expectation is given by

$$E(W) = \sum_{k=1}^{\infty} k\, p_{22}^{k-1}(1-p_{22})$$

$$= 1 / (1-p_{22})$$

Similarly if D is the length of a dry spell, that is D successive dry days followed by a wet day, the probability of an m day long dry spell is given by

$$P(D = m) = (1-p_{12})^{m-1}\, p_{12}$$

D is a random variable following geometric distribution with its expectation given by $E(D) = \sum_{n=1}^{\infty} m(1-p_{12})^{m-1} p_{12}$

$$= 1/p_{12}$$

Now a weather cycle is defined as a wet spell followed by a dry spell or vice versa. That is if C denotes the length of a weather cycle, then $C = D + W$. The lengths of successive spells are readily seen to be independent and the probability of a weather cycle of n days is

$$p_{12} (1-p_{22}) \left[(1-p_{12})^{n-1} - p_{22}^{n-1}\right] / (1-p_{12} - p_{22})$$

The expected length of a weather cycle is given by

$$E(C) = E(W) + E(D)$$
$$= 1/(1-p_{22}) + 1/p_{12}$$

3.1.6 Comparison of different districts on the occurrence of rainfall.

Having obtained the estimates of the two parameters p_{12} and p_{22} of the Markov chain for each centre separately, the common estimates of these parameters pooled over all centres can be obtained. Such of the centres, the parameters of which, do not differ significantly from their common value is regarded as belonging to the same homogeneous group. Let's consider the procedure of grouping of the centres.

Suppose the cell frequencies for i^{th} centre be denoted by n_{11i}, n_{12i}, n_{21i} and n_{22i} respectively with $n_{11i} + n_{12i} = n_{1i}$ and $n_{21i} + n_{22i} = n_{2i}$

The estimates of p_{12} and p_{22} pooled over all the centres are then $\bar{p}_{12} = \sum n_{12i} / \sum n_{1i}$

$$\bar{p}_{22} = \sum n_{22i} / \sum n_{2i}$$

Taking these estimates as the expected probabilities at each of the centre, we can compute two chi-squares for each centre, testing for the discrepancies between observation and expectation. Hence with usual notation, the observed frequencies for the i^{th} centre for assessing the discrepancy between p_{12} and $\bar{p}_{12}$ can be put as n_{11i} and n_{12i} with $n_{11i} + n_{12i} = n_{1i}$. Let the corresponding expected frequencies be $n_{1i}\ (1-\bar{p}_{12})$ and $n_{1i}\ \bar{p}_{12}$. Similarly, for finding out whether there is any significant deviation between the observed and theoretical proportions p_{22} and $\bar{p}_{22}$ respectively of the i^{th} centre, the usual chisquare test can be applied taking n_{21i} and n_{22i} as the observed and $n_{2i}\ (1-\bar{p}_{22})$ and $n_{2i}\ \bar{p}_{22}$ as expected frequencies with $n_{21i}+n_{22i}=n_{2i}$. Let's denote by $\chi^2_{p_{12}}$, the chi-square for assessing the significant deviation between p_{12} and $\bar{p}_{12}$.

Now $$\chi^2_{p_{12}} = \frac{\left[n_{11i} - n_{1i}\,(1-\bar{p}_{12})\right]^2}{n_{1i}\,(1-\bar{p}_{12})} + \frac{(n_{12i} - n_{1i}\,\bar{p}_{12})^2}{n_{1i}\,\bar{p}_{12}}$$

$$= \frac{n^2_{11i}}{n_{1i}\,(1-\bar{p}_{12})} + \frac{n^2_{12i}}{n_{1i}\,\bar{p}_{12}} - n_{1i} \sim \chi^2 -$$

distribution with 1 degree of freedom.

In a similar manner, the chi-square statistic for testing the significance of the deviation of p_{22} from its expected value is given by

$$\chi^2_{p_{22}} = \frac{n^2_{21i}}{n_{2i}\,(1-\bar{p}_{22})} + \frac{n^2_{22i}}{n_{2i}\,\bar{p}_{22}} - n_{2i} \sim \chi^2 -$$

distribution with 1 degree of freedom.

These two chi-squares are worked out for the 3 seasons. Those centres which show non-significant chi-square values for both the parameters are regarded as similar in the pattern of occurrence of rainfall. They can then be grouped together for obtaining common estimates of the two parameters.

3.2 Fitting of a probability distribution to fortnightly rainfall and estimation of rainfall probabilities

3.2.1 Characteristics of the distributions fitted

Theoretical distributions are also fitted to characterize the rainfall pattern in the tract within the purview of the study. Normal distribution, its two modified versions viz. the root normal and lognormal and the gamma distributions are the four theoretical distributions to be tried for fitting fortnightly rainfall amounts. Characteristics of these distributions are discussed below.

1. Normal distribution

The most widely used and most important continuous probability distribution is the Gaussian or normal distribution, named after Gauss who first discussed the properties of the distribution in 1809. A random variable X is said to follow a normal distribution if its probability density function is

$$f(x) = (1/\sqrt{2\pi}\,\sigma)\cdot\exp\ (-1/2)\ (x-\mu)^2/\sigma^2 \qquad (15)$$

$$-\infty < x < \infty$$

μ = mean and σ^2 = variance are the parameters of the distribution.

It is well known that $\hat{\mu} = \bar{x}$, the sample mean and $\hat{\sigma}^2 = s^2$, the sample variance.

Let $Z = (X - \mu) / \sigma$

Then the probability density function of Z is given by

$$f(Z) = (1/\sqrt{2\pi}) \exp (-1/2)(Z^2) \quad -\infty < Z < \infty \quad (16)$$

This distribution, known as the standard normal distribution does not depend upon the parameters μ and σ

2. Root normal distribution

Let $Y = \sqrt{X}$ be normally distributed. Then X is said to follow root normal distribution.

Since Y is normally distributed, we have

$$f_Y(y) = (1/\sqrt{2\pi}\,\sigma_y) \exp (-1/2)(y-\mu_y)^2/\sigma_y^2$$

$$-\infty < y < \infty$$

The distribution of X can be found from

$$f_X(x) = f_Y(y) \left|\frac{dy}{dx}\right|$$

$$Y = \sqrt{X}$$

$$\left|\frac{dy}{dx}\right| = \frac{1}{2\sqrt{x}} \qquad x > 0$$

$$f_X(x) = (1/2\sqrt{x}\sqrt{2\pi}\,\sigma_y) \exp \left[(-1/2)(x-\mu_y)^2/\sigma_y^2\right] \quad (17)$$

$$x > 0$$

This gives the distribution of X as the root normal

distribution with parameters μ_y and σ^2_y.
$Y = \sqrt{X}$ is normally distributed while X is root normally distributed.

The parameters μ_y and σ^2_y can be estimated by $\bar{y}$ and s_y^2 in the usual manner by first transforming all of the X_i's to Y_i's by $y_i = \sqrt{x_i}$
Then $\bar{y} = \sum x_i/n$ and $s_y^2 = (1/n)\sum y_i^2 - \bar{y}^2$
with all summations from 1 to n.
The r^{th} raw moment

$$\mu'_r = \int_0^\infty x^r \; f(x)\, dx$$
$$= \int_{-\infty}^{\infty} y^{2r} \; f(y)\, dy$$

On simplication, we get

$$\mu'_1 = \mu_x = \mu^2_y + \sigma^2_y$$

3. <u>Lognormal distribution</u>

In 1879, Galton pointed out that if $X_1, X_2, \ldots X_n$ are independent positive random variables and $T_n = \prod_{i=1}^{n} X_i$, then $\log_e T_n = \sum \log_e X_i$ would tend to normal distribution as $n \rightarrow \infty$.

If there is a number θ such that $Y = \log_e (X-\theta)$ is normally distributed, the distribution of X is said to be lognormal. It is clear that X can take any value exceeding θ but has zero probability of taking a value less than θ. In many cases, θ can be taken to be equal to zero or X is a positive random variable. This important case is called the two parameter lognormal distribution.

Mc Alister (1879) appears to be the first person to set down explicitly and in some detail the theory of the lognormal distribution.

If $Y = \log_e X$ is normally distributed, then the distribution of X is given by

$$f_X(x) = f_Y(y) \left| \frac{dy}{dx} \right|$$

$$= (1/x \sqrt{2\pi}\, \sigma_y) \exp\ (-1/2)\ (\log_e x - \mu_y)^2/\sigma_y^2 \qquad (18)$$

$$x > 0$$

This is the distribution of X as the lognormal distribution with parameters μ_y and σ_y^2.

$Y = \log_e X$ is normally distributed whereas X is lognormally distributed.

The estimates of the parameters μ_y and σ_y^2 are $\bar{y} = (1/n)\sum y_i$ and $s_y^2 = (1/n)\sum y_i^2 - \bar{y}^2$ respectively which can be obtained by transforming all X_i's to Y_i's by the transformation $y_i = \log_e x_i$

The r^{th} raw moment of the distribution is given by

$$\mu_r' = \int_0^\infty x^r f(x)\,dx$$

$$= \int_{-\infty}^{\infty} e^{yr} f(y)\,dy, \text{ since } Y = \log_e X$$

$$= \exp\left[r\mu_y + (1/2) r^2 \sigma_y^2\right]$$

$$\text{Mean} = \mu_x = \exp\left[\mu_y + (1/2)\sigma_y^2\right]$$

$$\text{Variance} = \sigma_x^2 = \exp(2\mu_y + 2\sigma_y^2) - \exp(2\mu_y + \sigma_y^2)$$

$$= \exp(2\mu_y + \sigma_y^2)\left[\exp(\sigma_y^2) - 1\right]$$

$$= \mu_x^2\left[\exp(\sigma_y^2) - 1\right]$$

From the above two relations, it is evident that

$$\mu_y = (1/2)\log_e\left[\mu_x^2/(CV_x^2 + 1)\right]$$

and $\sigma_y^2 = \log_e(CV_x^2 + 1)$ where CV_x is the coefficient of variation of the original data given by $CV_x = \sigma_x/\mu_x$

From equation (18) we have $f_X(x) = f_Y(y)/x$

Expressing $f_Y(y)$ in terms of standard normal density $f_Z(z)$, we have $f_Y(y) = f_Z(z) \left|\frac{dz}{dx}\right| = f_Z(z)/\sigma_y$

or $f_X(x) = f_Z(z)/x\,\sigma_y$.

The prob $(X \leq x)$ is equal to the prob $(Y \leq y)$ since $Y = \log_e X$ is a monotonic single valued function.

Since Y is normally distributed, prob $(Y \leq y)$=prob $(Z \leq z)$ where $Z = (Y - \mu_y)/\sigma_y$

Therefore the standard normal tables can be used to evaluate $f_X(x)$ and $F_X(x)$.

4. Gamma distribution

A random variable X is said to follow gamma distribution if its probability density function is of the form

$$f(x) = (x - \alpha)^{\eta-1} \exp\left[-(x - \alpha)/\beta\right] / \beta^{\eta}\Gamma\eta$$

$$\alpha > 0,\ \beta > 0,\quad x > \alpha$$

This distribution is included in type III Pearsonian system and depends on three parameters α, β, η

Putting $x = 0$ and $1/\beta = \lambda$ the distribution turns to be

$$f(x) = x^{\eta-1} \exp(-\lambda x)\lambda^{\eta}/\Gamma\eta \qquad x, \lambda, \eta > 0$$

where $\Gamma(\eta) = \int_0^\infty t^{\eta-1} \exp(-t)\, dt \quad$ for $\eta > 0$

$$\Gamma(\eta + 1) = \eta\Gamma(\eta) \qquad \text{for} \quad \eta > 0$$

$$\Gamma(1) = \Gamma(2) = 1 \;;\; \Gamma(1/2) = \sqrt{\pi}$$

η is the shape parameter and λ is the scale parameter.

Moment generating function of the distribution is given by $M_X(t) = \int_0^\infty \exp(tx)\,\lambda^{\eta} x^{\eta-1} \exp(-\lambda x)/\Gamma\eta$

$$= \left[1 - (t/\lambda)\right]^{-\eta}$$

Kumulant generating function $K_X(t) = \log_e M_X(t)$

$$= \log_e (1 - (t/\lambda))^{-\eta}$$

$$= -\eta \left[(t/\lambda) + (t^2/2\lambda^2) + (t^3/3\lambda^3) + \ldots \right]$$

K_1 = mean = coefficient of $t/1! = \eta/\lambda$

K_2 = variance = coefficient of $t^2/2! = \eta/\lambda^2$

4.1 Estimation of parameters

Maximum likelihood estimates of η and λ which are consistent and efficient are obtained as per method given by Thom (1958).

The likelihood function is given by

$$M = \prod_{i=1}^{n} x^{\eta-1} \exp(-\lambda x)\lambda^{\eta}/\Gamma(\eta)$$

$$\log_e M = \sum_{i=1}^{n} \log_e \; x^{\eta-1} \exp(-\lambda x) \quad / \Gamma(\eta)$$

$$= \sum_{i=1}^{n} (\eta - 1) \log_e x_i + \sum_{i=1}^{n} (-\lambda) x_i + \sum_{i=1}^{n} \eta \log_e \lambda$$

$$- \sum_{i=1}^{n} \log_e \Gamma(\eta)$$

$$\frac{\partial}{\partial \hat{\eta}} \log_e M = \sum_{i=1}^{n} \log_e x_i + \sum_{i=1}^{n} \log_e \hat{\lambda} - \sum_{i=1}^{n} \psi(\hat{\eta})$$

$$= \sum_{i=1}^{n} \log_e x_i + n \log_e \hat{\lambda} - n \psi(\hat{\eta}) = 0 \qquad (19)$$

where $\psi(\hat{\eta}) = \dfrac{\partial}{\partial \hat{\eta}} \log_e \Gamma(\hat{\eta})$

$$\frac{\partial}{\partial \hat{\lambda}} \log_e M = - \sum_{i=1}^{n} x_i + \sum_{i=1}^{n} \hat{\eta} / \hat{\lambda}$$

$$= - \sum_{i=1}^{n} x_i + n \hat{\eta}/\hat{\lambda} = 0 \qquad (20)$$

ie. $\bar{X} = \hat{\eta}/\hat{\lambda}$ where $\bar{X}$ is the arithmetic mean

From equation (19)

$$(1/n) \sum_{i=1}^{n} \log_e x_i = - \log_e \hat{\lambda} + \psi(\hat{\eta})$$

$$\log_e G + \log_e \hat{\lambda} - \psi(\hat{\eta}) = 0$$

$$\log_e G + \log_e (\hat{\eta}/\bar{X}) - \psi(\hat{\eta}) = 0$$

$$\log_e \hat{\eta} - \psi(\hat{\eta}) + \log_e (G/\bar{X}) = 0 \qquad (21)$$

where $\log_e G = (1/n) \sum_{i=1}^{n} \log_e x_i = \log_e (x_1 x_2 \ldots x_n)^{1/n}$

Thus G is the geometric mean of the n quantities

$x_1, x_2 \ldots x_n$.

Now $G/A \leq 1$, hence $\log_e (G/A) \leq 0$. The sign of equality holds when $x_1 = x_2 = \ldots x_n = A$, which is a trivial case. Thom (1958) has approximated $(\log_e \hat{\eta} - \psi(\hat{\eta}))$ to $1/2\hat{\eta} + 1/12\hat{\eta}^2$

Substituting this in equation (21) we get

$$(1/12\hat{\eta}^2) + (1/2\eta) + \log_e (G/\bar{X}) = 0$$

$$12 \log_e (G/\bar{X})\ \hat{\eta}^2 + 6\hat{\eta} + 1 = 0$$

Hence $\hat{\eta} = \left[-1-\sqrt{1-(4/3) \log_e (G/\bar{X})}\right] / 4 \log_e (G/\bar{X})$

the other root being negative is in admissible.

3.2.2 Analytical procedure

1. Normal distribution

The fortnightly totals can be used to obtain a frequency table. The moments and the parameters of the distribution are then computed. Measure of skewness given by $\beta_1 = \mu_3^2 / \mu_2^3$ and measure of kurtosis $\beta_2 = \mu_4 / \mu_2^2$ are also calculated where μ_2, μ_3 and μ_4 are respectively the second, third and fourth moments about the mean μ.

As a test of normality, the significane of β_1 and β_2 are tested by the normal deviate test. In large samples ($n > 24$), Pearson and Hartley (Buck, 1975) have shown that $Z_1 = \sqrt{\frac{\beta_1 (n+1)(n+3)}{6(n-2)}}$ is approximately normally distributed with mean zero and SD = 1

Similarly $Z_2 = \left[(\beta_2 - 3) + \frac{6}{n+1}\right]\sqrt{\frac{(n+1)^2 (n+3)(n+5)}{24\, n (n-2)(n-3)}}$

is approximately normally distributed with mean zero and SD = 1.

In such fortnights where β_1 and β_2 are found non significant, the distribution can be assumed to be normal.

2. Root normal and Lognormal distribution

The fortnightly totals are transformed to the square root and logarithic scales. In fortnights where there are zero values, $\sqrt{X+1}$ and log (X+1) transformations are used. The moments are computed and the testing of normality can be done as explained above.

3. Gamma distribution

In fortnights where the distribution was found to be highly skewed, the gamma distribution can be tried to fit rainfall amounts.

In order to establish the relation between gamma and chi-square random variables let's consider the probability density function of a chi-square random variable given by

$$f(\chi^2) = 1/2^{n/2}\Gamma(n/2) \; \exp(-\chi^2/2) \; (\chi^2)^{n/2-1}$$

$$0 \leq \chi^2 < \infty \quad \text{with n degrees of freedom.}$$

Comparing this with the probability density function of the gamma variate, we get $\eta = n/2$; $n = 2\eta$

$$(1/2)\,\chi^2 = \lambda x; \; \chi^2 = 2\lambda x$$

Hence the tables of χ^2 can be used to evaluate the cumulative density function of gamma variates. For this purpose, "Biometrika tables for statisticians" vol. 1, edited by Pearson and Hartley (1954) can be used.

In order to find out the expected frequencies, the parameters η and λ are first estimated from the observed data. The table contains $1 - P_X(x)$ and is entered with $\chi^2 = 2\lambda x$ and $\nu = 2\eta$; ν being degrees of freedom. These are the two parameters required in using the tables. The expected probabilities can be found out from the table and hence the expected frequencies computed. The goodness of fit can be tested by employing the usual chi-square test.

3.3 Estimation of rainfall probabilities and confidence limits

The probabilities of receiving a minimum assured amount of rainfall can be computed by utilising the properties of the corresponding distribution in various fortnights. For normal, root normal and lognormal distributions the table of standard normal distribution can be used for obtaining the rainfall probabilities as

$P(X \leq x) = P(Z \leq z)$ where $Z = (X - \hat{\mu}) / \hat{\sigma}$

For the gamma distribution, these probabilities can be computed using "Biometrika tables for statisticians".

80% and 90% confidence limits for the mean total rainfall for such fortnights which follow normal, rootnormal or lognormal distributions can be computed as

$$\bar{X} \pm t_{n-1,\alpha} \, SE\,(\bar{X})$$

where t_{n-1} is the value of t for (n-1) degrees of freedom at the desired probability level.

RESULTS

RESULTS

The data were analysed according to the procedure described in the preceding section and the results are outlined hereunder.

1. Markov chain model

The conditional probabilities p_{12} and p_{22} were estimated for every fortnight and for each centre and the difference in these estimates were tested for significance by the usual normal deviate test. A significant value of Z would show that the weather of a particular day was influenced by the weather of the previous day and hence the occurrence of wet and dry days could be described by a two state Markov chain model. Such a model was then fitted to rainfall data in such fortnights which showed significant Z values.

The transition probabilities p_{12} and p_{22} along with the values of the normal deviate for each centre in different fortnights are presented in columns 2, 3 and 10 of table 1.1 to 1.6. Expected length of dry and wet spells and that of weather cycle in different centres are given in columns 4, 5 and 6 of table 1.1 to 1.6. The state occupation probabilities at equillibrium and the number of days required for the system to achieve the state of equillibrium were worked out and are presented in columns 7, 8 and 9 of the tables.

The estimates of parameters and the various properties of Markov chain model fitted to wet and dry days in various fortnights of the Kasaragod reporting station are presented in table 1.1. It was found that the Markov chain model was not suitable to describe the pattern of rainfall occurrence in the 1st till the 5th fortnight of the year since the corresponding values of the normal deviate (Z) were non significant. A maximum value of the parameter p_{12} which amounted to 0.6779661 was noticed in the 14th fortnight while the minimum value of 0.0106610 was noticed in the 6th fortnight. p_{22} was maximum in the 13th fortnight and minimum in the 7th fortnight; the maximum and minimum values being 0.9515739 and 0.1904762 respectively. Maximum equillibrium probability for wet day was found to be 0.9246 in the

Table 1.1

Characteristics and estimates of parameters of Markovchain model - Kasaragod.

Fort-night	Transition probabilities		Expected length of			Equilibrium state probabilities		No. of days to equilli-brium	Values of Z
	p_{12}	p_{22}	dry spell	wet spell	weather cycle	π_0	π_1		
1	0.0022271	0							0.04
2	0.0083857	0							0.15
3	0.0023866	0							0.04
4	0	0.5							14.57
5	0.0089285	0							0.13
6	0.0106610	0.3636364	93.79	1.57	95.37	0.9836	0.0164	13	8.59
7	0.0466201	0.1904762	21.44	1.23	22.68	0.9456	0.0544	6	2.86
8	0.1030151	0.2307692	9.70	1.30	11.00	0.8818	0.1182	6	2.68
9	0.1478494	0.3333333	6.76	1.50	8.26	0.8184	0.1816	6	3.87
10	0.2330097	0.6140351	4.29	2.59	6.88	0.6236	0.3764	10	8.28
11	0.4537815	0.8700906	2.20	7.69	9.90	0.2226	0.7774	12	9.11
12	0.5	0.9304124	2.00	14.37	16.37	0.1222	0.8778	13	9.39
13	0.5945946	0.9515739	1.68	20.65	22.33	0.0754	0.9246	9	7.76
14	0.6779661	0.9002376	1.47	10.02	11.49	0.1283	0.8717	7	4.80
15	0.4776120	0.9086162	2.09	10.94	13.03	0.1606	0.8394	13	8.98
16	0.4112150	0.8552279	2.43	6.90	9.33	0.2604	0.7396	14	9.43
17	0.3141362	0.7451738	3.18	3.92	7.10	0.4479	0.5521	13	9.10
18	0.2352941	0.7179488	4.25	3.54	7.79	0.5452	0.4548	15	10.21
19	0.2233677	0.5471698	4.47	2.20	6.68	0.6697	0.3303	10	6.94
20	0.2389937	0.5123457	4.18	2.05	6.23	0.6711	0.3289	11	6.01
21	0.1120000	0.4666667	8.92	1.87	10.80	0.8264	0.1736	11	7.44
22	0.0716049	0.3111111	14.00	1.45	15.45	0.9058	0.0942	7	5.18
23	0.0309524	0.4666667	32.30	1.87	34.17	0.9451	0.0549	13	10.18
24	0.0149253	0.2727273	67.00	1.37	68.37	0.9799	0.0201	8	5.91

13th fortnight while the minimum was 0.0164 in the 6th fortnight. Number of days to attain the steady state varied between 6 to 15 in various fortnights.

Expected length of wet and dry spells for the 6th, 7th, 12th, 13th, 23rd and 24th fortnights were not reliable as the expected length of the weather cycle based on these values exceeded the actual length of the corresponding fortnights. The variation in the expected length of dry spell was between 1 to 14 days, that of wet spell was in the range from 1 to 11 (10.94) days and that of weather cycle ranged from 6 (6.23) to 15 (15.45) days. Expected length of wet spell was maximum in the 15th fortnight, the length of the spell being 11 (10.94) days. The expected length of dry spell had a maximum value of 14 days in the 22nd fortnight. Thus during the 15th fortnight, one can expect 11 continuous rainy days in a time span of 13 days. The minimum and maximum expected length of weather cycle were 6 (6.23) and 15 (15.45) days during the 20th and 22nd fortnights respectively.

From table 1.2, it could be seen that at

Table 1.2

Characteristics and estimates of parameters of Markov chain model - Irikkur.

Fortnight	Transition probabilities		Expected length of			Equilibrium state probabilities		No. of days to equilibrium	Values of Z
	p_{12}	p_{22}	dry spell	wet spell	weather cycle	π_0	π_1		
1	0.0089887	0.2	111.25	1.25	112.50	0.9889	0.0111	7	4.05
2	0.0062893	0.3333333	159.00	1.50	160.50	0.9907	0.0093	12	6.21
3	0.00238663	0							0.04
4	0.0070754	0							0.16
5	0.0044642	0							0.09
6	0.0170213	0.2	58.74	1.25	59.99	0.9792	0.0208	7	4.01
7	0.0778588	0.2820513	12.84	1.39	14.23	0.9022	0.0978	7	4.15
8	0.1440443	0.4382023	6.94	1.78	8.72	0.7959	0.2041	9	6.18
9	0.1794872	0.3939394	5.57	1.65	7.22	0.7715	0.2285	8	4.50
10	0.2150171	0.6951871	4.65	3.28	7.93	0.5863	0.4136	14	10.46
11	0.3629630	0.8698412	2.75	8.00	10.75	0.2639	0.7361	15	10.94
12	0.4307692	0.9402598	2.32	16.73	19.05	0.1218	0.8782	15	7.64
13	0.5945946	0.9467312	1.68	18.77	20.45	0.0822	0.9178	10	7.46
14	0.5789474	0.9457014	1.72	18.41	20.13	0.0857	0.9143	13	7.84
15	0.5056180	0.8698061	2.00	7.68	9.68	0.2048	0.7952	11	7.66
16	0.2957747	0.8461539	3.38	6.50	9.88	0.3422	0.6578	16	11.83
17	0.2666666	0.7625000	3.75	4.21	7.96	0.4711	0.5289	15	10.51
18	0.2727273	0.6923077	3.66	3.25	6.91	0.5301	0.4699	12	8.89
19	0.2375479	0.6455027	4.20	2.82	7.02	0.5988	0.4012	12	8.68
20	0.2723881	0.6509434	3.67	2.86	6.53	0.5617	0.4383	11	8.29
21	0.1517857	0.5175439	6.58	2.07	8.65	0.7607	0.2393	11	7.85
22	0.0805195	0.5230769	12.41	2.09	14.50	0.8556	0.1444	15	9.38
23	0.0216346	0.5882353	46.22	2.42	48.64	0.9501	0.0499	15	12.93
24	0.0105932	0.5	94.39	2.00	96.39	0.9793	0.0207	15	10.11

Irikkur, the values of the normal deviate failed to show statistical significance in the fortnights numbered 3, 4 and 5 and as such the Markov chain model was not constructed for those fortnights. It was found that the maximum and minimum p_{12} of 0.5945946 and 0.0062893 were observed in the 13th and 2nd fortnights respectively. The maximum p_{22} was noticed during 13th fortnight and the minimum p_{22} was observed during 6th and 1st fortnights. The maximum and minimum values of p_{22} were 0.9467312 and 0.2 respectively. The state occupation probabilities at equillibrium was found to vary between 0.0822 to 0.9907 for dry days and between 0.0093 to 0.9178 for wet days. The variation in the number of days to attain the steady state was from 7 to 16 days. The maximum and minimum equillibrium probabilities were noticed in the 2nd and 13th fortnights respectively for the dry days and during 13th and 2nd fortnights for the wet days.

The expected length of weather cycle for the fortnights numbered 1, 2, 6, 12, 13, 14, 23 and 24 were found to exceed the length of the corresponding fortnights and hence those estimates were not taken into consideration for further discussion. It was noticed that the expected length of dry spell was maximum during the 7th fortnight which amounted to 13 (12.84) days and it was minimum during 13th, 14th and 15th fortnights; the minimum expected length being 2 days. The maximum expected length of wet spell of 8 days was noted during 11th and 15th fortnights. The expected length of the weather cycle ranged from 7 to 15 days.

At Cannanore, the Z - test failed to show statistical significance in the 2nd and 4th fortnights whereas in all other fortnights, the basic assumption of the Markov chain model was justified. From table 1.3, the maximum p_{12} of 0.5810811 was observed during the 12th fortnight and a minimum of 0.0022321 in the 1st fortnight. The maximum and minimum values of p_{22} observed in the 13th and 5th fortnights were respectively 0.9136126 and 0.1. During the 3rd fortnight, there was not even a single record of wet day and hence no attempt was made to fit the Markov chain model to the rainfall sequence of that fortnight. The equillibrium probability for a dry day was found to be maximum (0.9956) during the

Table 1.3

Characteristics and estimates of parameters of Markov chain model - Cannanore.

Fort-night	Transition probabilities		Expected length of			Equilibrium state probabilities		No. of days to equilibrium	Values of Z
	P_{12}	P_{22}	dry spell	wet spell	weather cycle	π_0	π_1		
1	0.0022321	0.5	448.00	2.00	450.00	0.9956	0.0044	15	10.55
2	0.0041841	0							0.09
4	0.0142517	0							0.29
5	0.0112108	0.2500000	89.19	1.33	90.52	0.9853	0.0147	8	4.14
6	0.0148936	0.1	67.14	1.11	68.25	0.9837	0.0163	6	2.08
7	0.0728155	0.2894737	13.73	1.40	15.13	0.9070	0.0930	7	4.44
8	0.1007557	0.2452830	9.92	1.32	11.24	0.8822	0.1178	6	3.06
9	0.1280000	0.4266667	7.81	1.74	9.55	0.8175	0.1825	9	6.17
10	0.1949686	0.6296296	5.12	2.70	7.82	0.6551	0.3449	13	9.49
11	0.3701299	0.8581081	2.70	7.04	9.74	0.2771	0.7229	15	10.62
12	0.5810811	0.8882979	1.72	8.95	10.67	0.1612	0.8388	10	6.55
13	0.4705882	0.9136126	2.12	11.57	13.69	0.1551	0.8449	15	9.34
14	0.4204546	0.9030612	2.37	10.31	12.68	0.1874	0.8126	14	10.52
15	0.4504405	0.8407079	2.22	6.27	8.49	0.2612	0.7388	13	8.18
16	0.2937853	0.8019802	3.40	5.05	8.45	0.4026	0.5974	16	11.03
17	0.2196970	0.6720430	4.55	3.04	7.59	0.5988	0.4012	14	9.61
18	0.1702128	0.7261905	5.87	3.65	9.52	*	*		11.76
19	0.1640857	0.5354331	6.09	2.15	8.24	0.7390	0.2610	11	7.99
20	0.2023460	0.5179856	4.94	2.07	7.01	0.7043	0.2956	9	6.88
21	0.0981432	0.4794521	10.18	1.92	12.10	0.8414	0.1586	12	8.13
22	0.0555555	0.2500000	17.99	1.33	19.32	0.9310	0.0690	7	4.35
23	0.0330188	0.4230769	30.28	1.73	32.01	0.9459	0.0541	12	8.42
24	0.0084388	0.3333333	118.49	1.50	119.99	0.9875	0.0125	13	7.11

* Equilibrium could not be attained in 15 days.

P_{12} could not be found out as no wet day was observed during 3rd fortnight.

1st fortnight and minimum (0.1551) during the 13th fortnight. Similarly for the occurrence of wet days, the equillibrium probability was maximum during 13th fortnight with a value of 0.8449 and was minimum during the 1st fortnight with a value of 0.0044. The number of days to attain the steady state varied between 6 to 15 days. However for the 18th fortnight, the equillibrium could not be attained within a time span of 15 days.

The expected length of dry and wet spells was found to vary between 2 (1.73) to 14 (13.73) days and 1 to 12 (11.57) days respectively. In the case of the weather cycle, the maximum expected length of 15 (15.13) days was noted during the 7th fortnight whereas the minimum of 7 (7.01) days was observed during the 20th fortnight. Maximum number of rainy days were expected in the 13th fortnight. Fortnights numbered 12 and 14 were also expected to have a majority of wet days in the weather cycle compared to other periods of the year.

Characteristics and estimates of parameters of the Markov chain model fitted to rainfall data at Kozhikode are presented in table 1.4. The normal deviate test revealed that the Markov chain model could not be fitted to the distribution of wet and dry days of the fortnights numbered 1, 3, 5, 8 and 24. The conditional probabilities p_{12} and p_{22} were found to be maximum during the 12th and 13th fortnights respectively while the minimum values were noticed during the 2nd and 4th fortnights respectively. The maximum values of p_{12} and p_{22} were respectively 0.556962 and 0.8989638 whereas the minimum observed values of these probabilities were 0.008438 and 0.25 respectively. The maximum number of wet days could be expected during the 13th fortnight. Equillibrium state probability for a dry day was found to vary between 0.1559 to 0.9834 while that for a wet day varied between 0.0166 to 0.8441. The number of days after which the system would settle down to a condition of statistical equillibrium varied between 5 to 16 days.

For the 2nd, 4th, 6th, 22nd and 23rd fortnights, the expected length of the weather cycle

Table 1.4

Characteristics and estimates of parameters of Markov chain model - Kozhikode.

Fortnight	Transition probabilities		Expected length of			Equilibrium state probabilities		No. of days to equilibrium	Values of Z
	p_{12}	p_{22}	dry spell	wet spell	weather cycle	π_0	π_1		
1	0.0135135	0							0.28
2	0.0084388	0.5	118.49	2.00	120.49	0.9834	0.0166	16	9.98
3	0.0047847	0							0.09
4	0.0192771	0.2500000	51.87	1.33	53.20	0.9749	0.0251	7	4.97
5	0.0157657	0							0.30
6	0.0394737	0.3750000	25.33	1.60	26.93	0.9406	0.0594	10	6.95
7	0.1357703	0.2537314	7.36	1.34	8.70	0.8461	0.1539	5	2.47
8	0.1785715	0.2325581							1.15
9	0.2123894	0.4144144	4.70	1.70	6.40	0.7338	0.2662	7	4.20
10	0.2659176	0.6619718	3.76	2.95	6.71	0.5597	0.4403	16	8.68
11	0.4475525	0.8338763	2.23	6.01	8.24	0.2707	0.7293	13	8.41
12	0.556962	0.8894879	1.79	9.04	10.83	0.1656	0.8344	10	7.16
13	0.5468750	0.8989638	1.82	9.89	11.71	0.1559	0.8441	12	7.28
14	0.5056180	0.8849104	1.97	8.68	10.65	0.1854	0.8146	11	8.30
15	0.6245630	0.7617755	2.12	5.58	7.70	0.2761	0.7239	10	7.33
16	0.2659575	0.8082192	3.76	5.21	8.97	0.4190	0.5810	15	11.81
17	0.2490119	0.6802031	4.01	3.12	7.13	0.5622	0.4378	13	9.14
18	0.2030075	0.7010870	4.92	3.34	8.26	0.5955	0.4045	15	10.57
19	0.2640264	0.4761905	3.78	1.90	5.68	0.6649	0.3351	7	4.47
20	0.2307692	0.5357143	4.33	2.15	6.48	0.6680	0.3320	9	6.73
21	0.1734104	0.4326923	5.76	1.76	7.52	0.7658	0.2351	8	5.48
22	0.0705289	0.3396226	14.17	1.51	15.68	0.9035	0.0965	10	6.07
23	0.0668317	0.4565218	14.96	1.84	16.80	0.8905	0.1095	11	8.11
24	0.1705760	0							0.43

exceeded the number of days in the corresponding fortnights and hence were unreliable. In other fortnights, the expected length of wet and dry spell was maximum during the 13th and 7th fortnights with their lengths being 10 (9.89) and 7 (7.36) days respectively. The expected length of weather cycle varied between 6 (5.68) to 12 (11.71) days with the maximum expected length in the 13th fortnight.

At Guilandy, (Table 1.5) the conditional probability p_{12} was found to vary between 0.0041928 to 0.5384616 and p_{22} was found to vary between 0.125 to 0.9037433. The maximum number of wet days could be expected in the 13th and 14th fortnights. The maximum value of the equillibrium probability was 0.8343; the minimum was 0.0111 during the first fortnight. It was also noticed that between 6 to 16 days, the system settles down to a state of statistical equillibrium in which the state occupation probabilities become independent of the initial conditions. The expected length of dry and wet spells and that of weather cycle during fortnights numbered 1 till

Table 1.5

Characteristics and estimates of parameters of Markov chain model - Quilandy.

Fort-night	Transition probabilities		Expected length of			Equilibrium state probabilities		No. of days to equilibrium	Values of Z
	p_{12}	p_{22}	dry spell	wet spell	weather cycle	π_0	π_1		
1	0.0067415	0.4	148.33	1.66	149.99	0.9889	0.0111	11	8.34
2	0.0041928	0.3333333	238.49	1.50	239.99	0.9937	0.0063	12	7.21
3	0.0023866	0							0.04
4	0.0167064	0.1250000	59.85	1.14	60.99	0.9813	0.0187	6	2.23
5	0.0111857	0.3333333	89.39	1.50	90.89	0.9835	0.0165	9	4.84
6	0.0303687	0.2631597	32.92	1.35	34.27	0.9604	0.0396	8	5.10
7	0.0950002	0.3600000	10.52	1.56	12.08	0.8707	0.1293	9	5.35
8	0.1394102	0.2857143	7.17	1.40	8.57	0.8367	0.1633	6	3.15
9	0.1581921	0.4166667	6.32	1.71	8.03	0.7867	0.2133	8	5.48
10	0.2791519	0.6548224	3.58	2.89	6.47	0.5529	0.4471	11	8.17
11	0.2513514	0.8543047	2.84	6.86	9.70	0.2931	0.7069	15	10.82
12	0.4631579	0.8845071	2.15	8.65	10.80	0.1996	0.8004	14	9.04
13	0.4342106	0.9037433	2.30	10.38	12.69	0.1815	0.8185	14	9.80
14	0.5384616	0.8930348	1.85	9.34	11.19	0.1657	0.8343	11	7.72
15	0.4351145	0.8087775	2.29	5.22	7.51	0.3053	0.6947	12	7.85
16	0.3152174	0.777027	3.17	4.48	7.65	0.4143	0.5857	16	10.04
17	0.2218045	0.6684783	4.50	3.01	7.51	0.5991	0.4009	14	9.49
18	0.1805054	0.7167630	5.54	3.53	9.07	0.6108	0.3892	15	11.36
19	0.2535212	0.5662651	3.94	2.30	6.24	0.6311	0.3689	10	6.63
20	0.2370130	0.5465116	4.21	2.20	6.41	0.6568	0.3432	11	6.82
21	0.1432507	0.3793104	6.98	1.61	8.59	0.8125	0.1875	7	5.05
22	0.0755667	0.4339623	13.23	1.76	14.99	0.8822	0.1178	12	7.60
23	0.0539215	0.4523810	18.54	1.82	20.36	0.9104	0.0896	13	8.54
24	0.0149893	0.2307692	66.71	1.30	68.01	0.9809	0.0191	7	5.37

the 6th, 23 & 24 were unreliable as the expected length of weather cycle exceeded the number of days in the fortnight.

It was also found that the largest weather cycle of 15 days could be expected during the 22nd fortnight while the smallest one of length 6 days would be realised in the 19th fortnight. The maximum expected length of wet spell was in the 13th fortnight while the minimum was in the 8th fortnight.

The value of the normal deviate failed to reveal statistical significance in the 3rd fortnight at Mananthody and hence the Markov chain model could not be fitted to the data of that fortnight. The parameters and the characteristics of the Markov chain model fitted to the other fortnights are presented in table 1.6. Due to the reasons indicated already, estimates on the expected length of dry and wet spells that that of weather cycle of fortnights numbered 1 to 6, 23 and 24 had to be rejected.

The conditional probability p_{12} was found

Table 1.6

Characteristics and estimates of parameters of Markov chain model - Mananthody.

Fort-night	Transition probabilities		Expected length of			Equilibrium state probabilities		No. of days to equilibrium	Values of Z
	p_{12}	p_{22}	dry spell	wet spell	weather cycle	π_0	π_1		
1	0.0022271	0	448.99	1.00	449.99	0.9978	0.0022	2	4.72
2	0.0126582	0.1666667	78.99	1.20	80.19	0.9850	0.0150	6	3.12
3	0.0096385	0							0.22
4	0.0266344	0.2666667	37.54	1.36	38.90	0.9650	0.0350	9	4.96
5	0.0205011	0.3636364	48.77	1.57	50.34	0.9688	0.0312	10	6.71
6	0.0514541	0.3030303	19.43	1.43	20.86	0.9313	0.0687	12	5.51
7	0.1675978	0.3913044	5.96	1.64	7.60	0.7841	0.2159	8	4.67
8	0.2059702	0.4086957	4.85	1.69	6.54	0.7417	0.2583	8	4.28
9	0.1842901	0.4705882	5.42	1.88	7.30	0.7418	0.2582	9	6.10
10	0.2215569	0.5273973	4.51	2.11	6.62	0.6808	0.3192	9	6.63
11	0.3286385	0.7637131	3.04	4.23	7.27	0.4183	0.5817	13	9.27
12	0.4693878	0.8778409	2.13	8.18	10.31	0.2065	0.7935	12	8.76
13	0.5373135	0.9060052	1.86	10.63	12.49	0.1489	0.8511	12	7.82
14	0.5671642	0.9031477	1.76	10.32	12.08	0.1459	0.8541	10	7.27
15	0.4880952	0.8797814	2.04	8.31	10.35	0.1976	0.8024	12	8.19
16	0.3507463	0.8410405	2.85	6.29	9.14	0.3119	0.6881	14	10.55
17	0.2435898	0.7175926	4.10	3.54	7.64	0.5369	0.4631	14	10.06
18	0.2150538	0.6549708	4.65	2.89	7.54	0.6160	0.3840	13	9.32
19	0.2310231	0.5102041	4.32	2.04	6.36	0.6795	0.3205	11	5.94
20	0.2113565	0.5644172	4.73	2.29	7.02	0.6733	0.3267	12	7.78
21	0.1685714	0.4	5.93	1.66	7.59	0.7807	0.2193	8	4.92
22	0.0776942	0.3137255	12.87	1.45	14.32	0.8983	0.1017	10	5.18
23	0.0525059	0.3870968	19.04	1.63	20.67	0.9211	0.0789	10	6.80
24	0.0064102	0.5	156.00	2.00	158.00	0.9873	0.0127	15	12.44

to be maximum during the 14th fortnight and minimum during the 1st fortnight. Similarly p_{22} was found maximum during the 13th fortnight and minimum during 1st fortnight. The maximum equillibrium probability for a wet day was 0.8541 and for a dry day was 0.0022; the maximum and minimum probabilities were observed during the 14th and 1st fortnights of the year respectively. Similarly, state occupation probability at equillibrium for a dry day was found to be maximum in the 1st fortnight while it was minimum in the 14th fortnight. The number of days to attain equillibrium varied between 2 to 15 days.

The expected length of wet and dry spells varied between 1.0 to 11 (10.63) days and 2 (1.76) to 13 (12.87) days respectively. The expected length of wet spell was found maximum during 13th fortnight while it was minimum during the 1st fortnight. The maximum expected length of a weather cycle was 14 (14.32) days in the 22nd fortnight.

The two state Markov chain model was also fitted to the distribution of dry and wet days of the <u>Virippu</u>, (Autumn), <u>Mundakan</u> (winter) and <u>Punja</u> (summer) crop seasons for all the six centres. The parameters of the model were estimated and the various properties of it were discussed and presented in table 2. It can be seen from this table that for the first season the expected length of dry spell varied between 3 (3.07) and 4 (3.69) days, that of wet spell varied between 5 (5.29) and 7 (7.26) days and that of weather cycle varied between 8 (8.36) and 11 (10.66) days. Similarly for the 2nd season, the variations in the expected length of dry spell, wet spell and that of weather cycle were 9 (8.65) to 12 (12.42) days, 2 (2.01) to 3 (2.62) days and 10 (10.71) to 15 (14.65) days respectively. In the case of the 3rd season, the expected length of dry spell ranged from 16 (15.57) to 41 (41.08) days, the expected length of wet spell ranged from 1 (1.29) to 2 (1.57) days and that of a weather cycle ranged from 17 (17.15) to 42 (42.37) days. The state occupation probabilities at equillibrium are given in columns 10 & 11 of the table. The number of days to

Table 2

Characteristics and estimates of parameters of Markov chain model for the 3 seasons.

Centre	Season	Transition probabilities		Expected length of			Equilibrium state probabilities		No. of days to equilibrium	Values of Z
		p_{12}	p_{22}	dry spell	wet spell	weather cycle	π_0	π_1		
Kasaragod	1	0.3084113	0.8565121	3.24	6.96	10.21	0.3175	0.6825	17	34.71
	2	0.0967853	0.5519380	10.33	2.23	12.56	0.8224	0.1776	15	27.22
	3	0.0243407	0.2258065	41.08	1.29	42.37	0.9695	0.0305	8	11.12
Irikkur	1	0.2943455	0.8624124	3.39	7.26	10.66	0.3185	0.6815	20	35.90
	2	0.1076529	0.6195788	9.28	2.62	11.91	0.7794	0.2206	16	30.62
	3	0.0341144	0.3466667	29.31	1.53	30.84	0.9504	0.0496	10	17.21
Cannanore	1	0.2705283	0.8276430	3.69	5.80	9.49	0.3892	0.6108	18	35.26
	2	0.0804559	0.5513514	12.42	2.22	14.65	0.8479	0.1521	14	28.19
	3	0.0288919	0.2272728	34.61	1.29	35.90	0.9640	0.0360	8	10.95
Kozhikode	1	0.3252362	0.8111111	3.07	5.29	8.36	0.3674	0.6326	19	30.76
	2	0.1155337	0.5150215	8.65	2.06	10.71	0.8076	0.1924	13	23.90
	3	0.0529824	0.2524753	18.87	1.33	20.20	0.9338	0.0662	7	11.02
Quilandy	1	0.2965117	0.8145885	3.37	5.39	8.76	0.3847	0.6153	16	32.79
	2	0.1057455	0.5577746	9.45	2.26	11.71	0.8070	0.1930	14	27.03
	3	0.0394463	0.2962963	25.35	1.42	26.77	0.9469	0.0531	8	14.18
Mananthody	1	0.3021249	0.8189103	3.30	5.52	8.83	0.3748	0.6252	16	32.70
	2	0.1069314	0.5247376	9.35	2.01	11.46	0.8163	0.1837	12	24.99
	3	0.0641903	0.3642857	15.57	1.57	17.14	0.9083	0.0917	9	16.58

attain the steady state are presented in column 12. It was seen that the number of days to attain equillibrium varied for the first season from 16 to 20, that for the second season from 12 to 16 and that for the third season from 7 to 10.

In order to test for homogenity among centres with respect to precipitation pattern, chi-square tests were used in accordance with the procedure outlined in the preceding section. The values of χ^2 for the three seasons are given in table 3. It could be seen from the table that for the first season at Mananthody centre, both the chi-square values ie. $\chi^2_{p_{12}}$ and $\chi^2_{p_{22}}$ were non significant. For the second season, both chi-square values were non significant at Kasaragod, Quilandy and Mananthody centres. Similarly in the third season, the chi-square values were non significant at Irikkur and Quilandy centres.

2. <u>Intensity of rainfall and its variability</u>

The fortnightly average rainfall together with the coefficient of variation are presented in

Table 3

Chi-square test for the grouping of centres.

Season	$\bar{p}_{12}$	$\bar{p}_{22}$		χ^2- values for the centres each with 1 df					
				Kasaragod	Irikkur	Cannanore	Kozhikode	Quilandy	Mananthody
1	0.1991246	0.8326810	$\chi^2_{p_{12}}$	0.5282	0.1406	6.1278*	4.8196*	0.0505	0.0648
			$\chi^2_{p_{22}}$	11.0794*	17.2002*	0.4429	8.4153*	5.7656*	3.3972
2	0.1019587	0.5554738	$\chi^2_{p_{12}}$	0.8457	0.9673	15.0637*	5.7139*	0.4443	0.7754
			$\chi^2_{p_{22}}$	0.0326	13.4306*	0.0382	4.6323*	0.0150	2.5519
3	0.0403696	0.2998997	$\chi^2_{p_{12}}$	19.6177*	2.9312	10.0046*	11.7034*	0.0637	40.6167*
			$\chi^2_{p_{22}}$	2.4317	1.5625	2.7635	2.1638	0.0100	5.5285*

* Significant at 5% level

table 4. It is seen from the table that at Kasaragod centre, a maximum fortnightly average rainfall of 564 mm was received in the 14th fortnight while the minimum being 0.1016 mm in the 3rd fortnight. The minimum coefficient of variation of rainfall of 27.3% was noted in the 13th fortnight whereas the maximum variability (538.5%) was noticed in the 3rd fortnight.

At Irikkur, a maximum of 661.2833 mm of rainfall with a minimum coefficient of variation of 50.7% was recorded in the 13th fortnight whereas a minimum precipitation of 0.7451 mm with the highest coefficient of variation of 538.5% was recorded in the 3rd fortnight.

At Cannanore, a maximum average rainfall of 525.8750 mm was received during the 13th fortnight whereas the minimum rainfall (0 mm) was received during the 3rd fortnight. The coefficient of variation of rainfall at this centre ranged from 44.2% in the 12th fortnight to 525.9% in the 1st fortnight.

Table 4

Mean and coefficient of variation of rainfall.

Fort-night	Kasaragod		Irikkur		Cannanore		Kozhikode		Quilandy		Mananthody	
	Mean (mm)	C.V. (%)	Mean (mm)	C.V. (%)	Mean (mm)	C.V. (%)	Mean (mm)	C.V. (%)	Mean (mm)	C.V. (%)	Mean (mm)	C.V. (%)
1	0.2717	194.0	3.0567	164.4	1.1154	525.9	2.4750	180.0	1.9812	499.5	0.1954	468.9
2	1.1633	278.0	1.7695	471.7	2.1661	427.1	4.1993	371.0	3.2225	429.5	3.7333	180.7
3	0.1016	538.5	0.7451	538.5	0		0.6334	327.2	0.1101	538.5	1.3122	308.4
4	0.3733	453.8	1.3729	458.0	2.6333	174.2	8.5277	326.1	11.1857	284.6	6.4000	158.7
5	2.1617	182.0	1.9925	367.3	4.0667	148.1	5.7000	160.0	3.9167	178.1	7.3917	161.5
6	4.7500	209.6	9.7833	252.4	4.0120	318.6	4.7535	126.3	18.9667	155.8	11.9205	111.6
7	13.9233	172.6	37.1333	115.6	26.3500	111.4	51.0000	87.8	33.8704	96.0	38.2710	78.7
8	36.4000	98.1	66.1833	156.6	23.6044	92.1	36.6147	82.7	36.7220	90.3	43.0115	74.1
9	35.5973	97.5	57.4986	77.8	59.4750	112.1	65.8972	84.3	57.4650	83.1	36.1860	105.9
10	148.5797	89.7	146.9016	83.9	123.9176	102.9	228.6333	76.7	164.3235	183.3	82.8793	87.6
11	413.0000	41.7	265.4067	68.1	359.6333	64.6	376.0000	51.2	363.7794	98.4	169.3083	61.8
12	553.0000	43.7	473.1334	52.7	444.9442	44.2	445.2000	45.6	516.2083	49.6	292.2233	68.1
13	547.5000	27.3	661.2833	50.7	525.8750	45.2	472.7084	45.4	488.5500	49.1	562.1333	60.4
14	564.0000	38.6	555.6769	56.2	477.2819	48.7	420.0333	52.2	475.2779	47.7	421.0000	53.3
15	366.8792	46.0	307.6088	57.0	264.8379	55.8	261.8750	48.8	272.3708	75.2	269.8864	59.9
16	265.2784	50.2	238.2840	64.6	182.0931	68.0	182.1000	50.9	213.6833	55.7	194.6474	74.4
17	151.2843	69.7	132.7405	73.4	87.7833	99.7	108.5750	83.7	67.2753	109.3	76.6148	67.2
18	121.2891	87.5	116.3000	69.1	92.2328	88.6	107.6737	92.6	158.3250	120.7	76.1583	77.1
19	85.8577	79.3	141.9158	79.0	85.0167	87.8	87.7978	70.9	96.8277	93.0	61.2813	64.3
20	85.8184	67.7	142.4443	63.6	114.4602	87.0	107.4875	79.7	139.1224	83.7	86.3500	69.1
21	28.4015	102.1	70.9167	76.6	62.0000	102.4	65.1615	92.4	59.9848	105.9	21.4573	99.4
22	17.6754	102.2	8.9416	134.0	6.0332	125.8	17.9521	109.4	71.5917	254.7	7.0499	114.1
23	18.4167	154.7	21.6250	147.9	4.3277	142.3	25.4082	116.0	7.5689	118.3	5.3102	146.2
24	9.0000	105.7	7.7000	165.3	7.1583	184.0	5.2033	120.8	5.3939	354.8	3.7000	160.7

At Kozhikode, a maximum mean fortnightly rainfall of 472.7084 mm with a minimum coefficient of variation of 45.4% was received in the 13th fortnight and a minimum precipitation of 0.6334 mm with a maximum coefficient of variation of 327.2% was received in the 3rd fortnight.

The maximum and minimum rainfall amounts at Quilandy were 516.2083 mm and 0.1101 mm respectively. The maximum average rainfall was received during the 12th fortnight and the minimum amount was during the 3rd fortnight. The lowest coefficient of variation of 47.7% was observed during the 13th fortnight while the highest estimate (538.5%) was in the 3rd fortnight.

At Mananthody, the maximum mean rainfall which amounted to 562.1333 mm was received during the 13th fortnight whereas a minimum amount of 0.1954 mm was received during the 1st fortnight. The maximum coefficient of variation of 468.9% was observed during the 1st fortnight while the minimum coefficient of variation of 53.3% was observed during the 14th fortnight.

3. <u>Rainfall probabilities and confidence limits</u>

Normal, root normal and log normal distributions were tried to characterize the fortnightly rainfall pattern. Measure of skewness and kurtosis, β_1 and β_2 were computed and their significance tested by the normal deviate test given in the previous section. Appropriate distributions were fitted in accordance with the values of β_1 and β_2. These values together with the test statistic for testing their significance are presented in columns 3 to 6 of tables 5.1 to 5.6. If lack of normality was evidenced in the original data by the statistical significance of Z_1 and Z_2, the root normal distribution was first tried. In case normality could be established by this transformation, no further transformation was attempted. In the reverse case the logarithmic transformation was tried to restore normality. Gamma distribution was also tried to characterize the pattern of fortnightly precipitation in such of the fortnights in which all the three above mentioned distributions were not found to fit well. After fitting the appropriate probability distributions, the probabilities of receiving fixed amounts or less of rainfall and the 80% and 90% confidence limits of the mean fortnightly rainfall were worked out. The amounts of expected rainfall which are 20% & 40% above and below the average observed rainfall together with the relevant probabilities are given in columns 8 & 9 of tables 5.1 to 5.6. The mean rainfall in various fortnights are presented in column 7 and the 80% and 90% confidence limits are given in columns 10-14 of tables 5.1 to 5.6. However for fortnights in which gamma distribution was fitted, only the rainfall probabilities were estimated. No probability distribution was found to fit the rainfall amounts in the fortnights numbered 1-7, 23 and 24 for the Kasaragod and Irikkur centres, fortnights 1-6, 9 and 24 for the Cannanore station, fortnights 1-5 and 24 for Kozhikode, fortnights 1-6, 18 and 24 for Quilandy and fortnights 1, 3, 4, 5 and 24 for Mananthody centres since most of the data were zeros.

The rainfall probabilities and confidence limits for Kasaragod are presented in table 5.1. It was found that during the earlier fortnights, the probability of receiving rainfall amounts which were less than 20% and 40% of the mean rainfall was more, but it gradually decreased towards the period of intensive monsoon rainfall and thereafter gradually increased towards the later fortnights. In the 8th fortnight, the probability of receiving 21.84 mm or more rainfall was 0.5363 while during the 13th fortnight, the probability of receiving more than 328.5 mm of rainfall was 0.9286. But during the 22nd fortnight, the probability of receiving more than 10.6052 mm of rainfall is 0.7230. That is towards middle fortnights, the probability of receiving high rainfall was more as compared to that in the first and last few fortnights. The 80% lower confidence limits were found to vary between 26.3374 mm in the 9th fortnight to 511.1088 mm in the 14th fortnight and then decreased to 11.9832 mm in the 22nd fortnight. The upper 80% confidence limits ranged from 46.2055 mm during earlier fortnights

Table 5.1

Rainfall probabilities and confidence limits - Kasaragod.

Fort-night	Distribution fitted	β_1	β_2	Z_1	Z_2	Mean rainfall (mm)	Rainfall amounts (x mm)	Probability of receiving x mm or less rainfall	Confidence limits			
									80% limits		90% limits	
									Lower limit	Upper limit	Lower limit	Upper limit
1	2	3	4	5	6	7	8	9	10	11	12	13
							21.8400	0.4637				
8	Gamma					36.4000	29.1200	0.5643				
							43.6800	0.7122				
							50.9600	0.7662				
							21.3584	0.2365				
9	Rootnormal	0.1499	2.4507	0.9553	0.5080	35.5973	28.4778	0.3598	26.3374	46.2055	23.8554	49.6037
							42.7168	0.6401				
							49.8362	0.7634				
							89.1478	0.2266				
10	Rootnormal	0.1527	2.1612	0.9642	0.9214	148.5797	118.8638	0.3557	112.1139	190.1321	102.2967	203.4042
							178.2956	0.6443				
							208.0116	0.7734				
							247.8000	0.1690				
11	Normal	0.1189	2.9210	0.8509	0.1637	413.0000	330.4000	0.3159	371.0216	454.9784	358.5979	467.4022
							495.6000	0.6840				
							578.2000	0.8309				
							331.8000	0.1804				
12	Normal	0.0119	1.9285	0.2695	1.2538	553.0000	442.4000	0.3239	494.0553	611.9448	476.6101	629.3899
							663.6000	0.6760				
							774.2000	0.8195				
							328.5000	0.0714				
13	Normal	0.5303	2.5532	1.7969	0.3617	547.5000	438.0000	0.2319	511.1088	583.8912	500.3386	594.6615
							657.0000	0.7681				
							766.5000	0.9286				
							338.4000	0.1505				
14	Normal	0.3892	2.7531	1.5395	0.0761	564.0000	451.2000	0.3025	510.9048	617.0952	495.1909	632.8091
							676.8000	0.6975				
							789.6000	0.8495				
							220.1275	0.0476				
15	Rootnormal	0.4628	3.2161	1.6788	0.5850	366.8792	293.5034	0.2021	325.3101	410.9469	313.4866	424.4682
							440.2550	0.7979				
							513.6309	0.9524				

Table 5.1 contd.

Rainfall probabilities and confidence limits - Kasaragod.

Fort-night	Distribution fitted	β_1	β_2	Z_1	Z_2	Mean rainfall (mm)	Rainfall amounts (x mm)	Probability of receiving x mm or less rainfall	Confidence limits: 80% limits, Lower limit	Confidence limits: 80% limits, Upper limit	Confidence limits: 90% limits, Lower limit	Confidence limits: 90% limits, Upper limit
1	2	3	4	5	6	7	8	9	10	11	12	13
							159.1670	0.0714				
16	Rootnormal	0.0597	2.6585	0.6030	0.2113	265.2784	212.2227	0.2319	231.1929	301.7068	221.5544	312.9373
							318.3341	0.7681				
							371.3898	0.9286				
							90.7706	0.1499				
17	Rootnormal	0.2586	2.2799	1.2548	0.7518	151.2843	121.0274	0.3021	124.1994	181.0386	116.6954	190.3565
							181.5412	0.6979				
							211.7980	0.8501				
							72.7735	0.2191				
18	Rootnormal	0.0095	1.9007	0.2405	1.2934	121.2891	97.0313	0.3492	92.4926	153.9458	84.7103	164.3511
							145.5469	0.6508				
							169.6047	0.7809				
							51.5146	0.1995				
19	Rootnormal	0.0713	2.1380	0.6590	0.9545	85.8577	68.6862	0.3365	66.9636	107.0664	61.8156	113.7871
							103.0292	0.6635				
							120.2008	0.8005				
							51.4910	0.1675				
20	Rootnormal	0.0119	2.5495	0.2689	0.3669	85.8184	68.6547	0.3149	69.1676	104.2403	64.5794	110.0321
							102.9821	0.6851				
							120.1458	0.8325				
							17.0409	0.2646				
21	Rootnormal	0.5695	2.8226	1.8623	0.0230	28.4015	22.7212	0.3766	20.0028	38.2096	17.7874	41.3826
							34.0818	0.6234				
							39.7621	0.7354				
							10.6052	0.2790				
22	Rootnormal	0.5589	2.3852	1.8449	0.6015	17.6754	14.1403	0.3848	11.9832	24.3996	10.4963	26.5876
							21.2105	0.6152				
							24.7456	0.7210				

to 617.0952 mm towards the middle fortnights and then decreased to 24.3996 mm towards the later fortnights. Similarly at 90% confidence level 9th fortnight had assured rainfall of 23.8554 mm, it reached a maximum of 500.3386 during 13th fortnight and then decreased to 10.4963 mm in the 22nd fortnight. The upper limit varied between 49.6037 mm in the 9th fortnight to a maximum of 632.8091 mm in the 4th fortnight and then decreased to 26.5876 mm in the 22nd fortnight.

At Irikkur, the probability of receiving an amount of rainfall which are above and below 20% and 40% of the average are presented in column 9 of table 5.2. It was noticed that the probability of high rainfall was more during the 14th and 15th fortnights when compared to other fortnights. During the 14th fortnight, the probability of receiving an amount of rainfall which would exceed 333.4061 mm was 0.9354. This probability was found to decrease towards the beginning and at the end of the fortnights of the year. The variation in the 80% and 90%

Table 5.2

Rainfall probabilities and confidence limits - Irikkur.

Fort-night	Distribution fitted	β_1	β_2	Z_1	Z_2	Mean rainfall (mm)	Rainfall amounts (x mm)	Probability of receiving x mm or less rainfall	Confidence limits			
									80% limits		90% limits	
									Lower limit	Upper limit	Lower limit	Upper limits
1	2	3	4	5	6	7	8	9	10	11	12	13
8	Gamma					66.1833	39.7099	0.3955				
							52.9467	0.4888				
							79.4199	0.6345				
							92.6567	0.6908				
9	Rootnormal	0.0247	2.9103	0.3878	0.1483	57.4986	34.4992	0.1841	45.5249	70.9418	42.2439	75.0535
							45.9989	0.3264				
							68.9983	0.6736				
							80.4980	0.8159				
10	Rootnormal	0.0526	2.1195	0.5659	0.9810	146.9016	88.1410	0.2090	113.4793	184.5987	104.4075	196.5752
							117.5213	0.3427				
							176.2819	0.6573				
							205.6622	0.7910				
11	Rootnormal	0.0968	2.7109	0.7679	0.1364	265.4067	159.2440	0.1611	215.5780	320.3900	201.8193	337.6512
							212.3254	0.3103				
							318.4880	0.6897				
							371.5694	0.8389				
12	Normal	0.0542	2.0003	0.5742	1.1512	473.1334	283.8800	0.2242	412.3495	533.9173	394.3601	551.9068
							378.5067	0.3524				
							567.7601	0.6476				
							662.3868	0.7758				
13	Normal	0.4322	2.9286	1.6222	0.1744	661.2833	396.7700	0.2155	579.5360	743.0306	555.3423	767.2243
							529.0266	0.3469				
							793.5400	0.6531				
							925.7966	0.7845				
14	Rootnormal	0.1894	3.6812	1.0738	1.2492	555.6769	333.4061	0.0646	486.6607	629.2679	467.1122	651.9250
							444.5415	0.2239				
							666.8123	0.7761				
							777.9477	0.9354				
15	Rootnormal	0.0012	2.8386	0.0856	0.0459	307.6088	184.5653	0.0893	264.6745	353.7688	252.5863	368.0488
							246.0870	0.2506				
							369.1306	0.7494				
							430.6523	0.9107				

Table 5.2 contd.

Rainfall probabilities and confidence limits - Irikkur.

Fort-night	Distribution fitted	β_1	β_2	Z_1	Z_2	Mean rainfall (mm)	Rainfall amounts (x mm)	Probability of receiving x mm or less rainfall	Confidence limits			
									80% limits		90% limits	
									Lower limit	Upper limit	Lower limit	Upper limit
1	2	3	4	5	6	7	8	9	10	11	12	13
							142.9704	0.2681				
16	Normal	0.4663	2.3510	1.6851	0.6504	238.2840	190.6272	0.3786	200.7637	275.8043	189.6593	286.9087
							285.9408	0.6214				
							333.5976	0.7319				
							79.6443	0.2930				
17	Normal	0.4508	2.1928	1.6568	0.8763	132.7405	106.1924	0.3927	109.0099	156.4711	101.9867	163.4943
							159.2886	0.6073				
							185.8367	0.7070				
							69.7800	0.2816				
18	Normal	0.1614	2.2751	0.9944	0.7588	116.3000	93.0400	0.3862	96.7137	135.8863	90.9170	141.6831
							139.5600	0.6138				
							162.8200	0.7184				
							85.1495	0.2021				
19	Rootnormal	0.2679	1.7738	1.2772	1.4747	141.9158	113.5326	0.3383	110.4943	177.2331	101.9419	188.4326
							170.2990	0.6617				
							198.6821	0.7979				
							85.4666	0.2647				
20	Normal	0.2951	2.5303	1.3406	0.3943	142.4443	113.9554	0.3767	120.3796	164.5090	113.8494	171.0392
							170.9332	0.6233				
							177.4220	0.7353				
							42.5500	0.3009				
21	Normal	0.2509	2.1769	1.2360	0.8990	70.9167	56.7333	0.3970	57.6843	84.1490	53.7681	88.0652
							85.0999	0.6030				
							99.2833	0.6991				
							5.3650	0.2972				
22	Lognormal	0.0973	1.6467	0.7697	1.6562	8.9416	7.1533	0.3950	5.5320	14.1309	4.7685	16.1337
							10.7299	0.6050				
							12.5182	0.7028				

assured rainfall was from 5.5320 mm in the 22nd fortnight to 579.5360 mm and from 4.7685 mm to 555.3423 mm respectively in the 13th fortnight.

At Cannanore, the probability of receiving an amount of rainfall which would be less than 40% of the mean rainfall in the corresponding fortnights was found to be more during the earlier and later fortnights of the year. In the 7th fortnight, the probability of receiving an amount of rainfall less than 36.89 mm was as high as 0.8167 while in the 15th fortnight, probability of receiving a rainfall less than 158.9027 mm was still higher. Thus a considerable increase in the probability of precipitation was noticed towards the fortnights of the active monsoon season and thereafter it gradually declined. In the 23rd fortnight, there was a very small probability of 0.3473 for getting 6.0588 mm rainfall or more. A minimum assured rainfall of 2.5189 mm at 80% confidence was noted during the 23rd fortnight while the maximum of 467.9832 mm was observed during the 13th fortnight. The upper 80%

Table 5.3

Rainfall probabilities and confidence limits - Cannanore.

Fort-night	Distribution fitted	β_1	β_2	Z_1	Z_2	Mean rainfall (mm)	Rainfall amounts (x mm)	Probability of receiving x mm or less rainfall	Confidence limits			
									80% limits		90% limits	
									Lower limit	Upper limit	Lower limit	Upper limit
1	2	3	4	5	6	7	8	9	10	11	12	13
							15.8100	0.6160				
7	Gamma					26.3500	21.0800	0.6855				
							31.6200	0.7821				
							36.8900	0.8167				
							14.1626	0.2349				
8	Rootnormal	0.1584	2.2649	0.9821	0.7732	23.6044	18.8835	0.3588	17.4234	30.6779	15.7652	32.9425
							28.3253	0.6412				
							33.0462	0.7651				
							74.3506	0.2471				
10	Rootnormal	0.5209	2.6203	1.7810	0.2659	123.9176	99.1341	0.3662	91.1390	161.7217	82.4017	173.8738
							148.7011	0.6338				
							173.4846	0.7529				
							215.7800	0.2680				
11	Normal	0.1459	2.4720	0.9424	0.4776	359.6333	287.7066	0.3785	303.0412	416.2254	286.2924	432.9742
							431.5600	0.6215				
							503.4867	0.7320				
							266.9665	0.0416				
12	Rootnormal	0.1574	3.1040	0.9789	0.4250	444.9442	355.9553	0.1932	396.3370	496.3621	382.4904	512.1187
							533.9330	0.8068				
							622.9219	0.9584				
							315.5250	0.1882				
13	Normal	0.4279	2.8199	1.6141	0.0192	525.8750	420.7000	0.3292	467.9832	583.7668	450.8498	600.9003
							631.0500	0.6708				
							736.2250	0.8118				
							286.3692	0.2060				
14	Normal	0.1519	1.8283	0.9616	1.3968	477.2819	381.8255	0.3408	420.6293	533.9345	403.8625	550.7013
							572.7383	0.6592				
							668.1946	0.7940				
							158.9027	0.0956				
15	Rootnormal	0.1611	2.2369	0.9904	0.8133	264.8379	211.8703	0.2566	226.8526	305.7621	216.1742	318.4375
							317.8055	0.7434				
							370.7731	0.9044				

Table 5.3 contd.

Rainfall probabilities and confidence limits - Cannanore.

Fort-night	Distribution fitted	β_1	β_2	Z_1	Z_2	Mean rainfall (mm)	Rainfall amounts (x mm)	Probability of receiving x mm or less rainfall	Confidence limits: 80% limits: Lower limit	Confidence limits: 80% limits: Upper limit	Confidence limits: 90% limits: Lower limit	Confidence limits: 90% limits: Upper limit
1	2	3	4	5	6	7	8	9	10	11	12	13
							109.2559	0.1332				
16	Rootnormal	0.0009	2.0809	0.0759	1.0361	182.0931	145.6745	0.2892	151.5886	215.3923	143.0964	225.7833
							218.5117	0.7108				
							254.9303	0.8668				
							52.6700	0.2260				
17	Rootnormal	0.5311	2.8151	1.7984	0.0123	87.7833	70.2266	0.3535	66.5173	111.9944	60.7882	119.7246
							105.3400	0.6465				
							122.8966	0.7740				
							55.3397	0.2287				
18	Rootnormal	0.1067	2.5411	0.8062	0.3790	92.2328	73.7862	0.3551	69.3994	118.2680	63.2557	126.5874
							110.6794	0.6449				
							129.1259	0.7713				
							51.0100	0.3244				
19	Normal	0.3275	1.8126	1.4121	1.4192	85.0167	68.0133	0.4099	66.8425	103.1908	61.4637	108.5696
							102.0200	0.5901				
							119.0233	0.6756				
							68.6761	0.2127				
20	Rootnormal	0.0137	1.8423	0.2889	1.3768	114.4602	91.5682	0.3451	87.9727	144.3940	80.7945	153.9141
							137.3522	0.6549				
							160.2443	0.7873				
							37.2000	0.5349				
21	Gamma					62.0000	49.6000	0.6016				
							74.4000	0.6990				
							86.8000	0.7360				
							3.6199	0.3076				
22	Lognormal	0.2411	1.7608	1.2118	1.4932	6.0332	4.8266	0.4008	3.8198	9.2632	3.3098	10.4778
							7.2398	0.5992				
							8.4465	0.6924				
							2.5966	0.3473				
23	Lognormal	0.6140	1.8789	1.9336	1.3246	4.3277	3.4622	0.4222	2.5189	7.0665	2.1123	8.1201
							5.1932	0.5778				
							6.0588	0.6527				

confidence limits ranged from 7.0665 mm to 583.7668 mm. The 90% lower confidence limit had a value 15.7652 mm during the 8th fortnight, it reached a maximum value of 450.8498 mm in the 13th fortnight and then declined to 2.1123 mm during the 23rd fortnight. The upper limits at 90% confidence ranged from 8.1201 mm to 600.9003 mm during the above period.

Rainfall amounts which are above and below 20% and 40% of the average quantity together with their probability and the confidence limits of estimated mean for Kozhikode centre are given in table 5.4. It was seen that at Kozhikode, there would be a non negligible chance (0.3214) of getting low rainfall during the 6th fortnight, the expected precipitation being less than 2.8521 mm whereas in the 12th, 13th and 14th fortnights, there were more chances of getting very high rainfall say over 450 mm. The probability of high rainfall increased from 0.6716 in the 6th fortnight to 0.8105 in the 13th fortnight and then reduced to 0.7079 during 23rd fortnight. The 80% lower confidence limits of rainfall ranged from

Table 5.4

Rainfall probabilities and confidence limits - Kozhikode.

Fortnight	Distribution fitted	β_1	β_2	Z_1	Z_2	Mean rainfall (mm)	Rainfall amounts (x mm)	Probability of receiving x mm or less rainfall	Confidence limits: 80% limits Lower limit	80% limits Upper limit	90% limits Lower limit	90% limits Upper limit
1	2	3	4	5	6	7	8	9	10	11	12	13
							2.8521	0.3284				
6	Lognormal	0.3551	1.7547	1.4704	1.5019	4.7535	3.8028	0.4121	2.9209	7.4429	2.5002	8.4577
							5.7043	0.5879				
							6.6550	0.6716				
							30.6000	0.4998				
7	Gamma					51.0000	40.8000	0.5819				
							61.2000	0.7297				
							71.4000	0.7825				
							21.9688	0.1735				
8	Rootnormal	0.1806	2.4943	1.0486	0.4458	36.6147	29.2918	0.3192	29.2264	44.8101	27.1945	47.3903
							43.9376	0.6808				
							51.2606	0.8264				
							39.5383	0.1955				
9	Rootnormal	0.1925	3.0808	1.0827	0.3917	65.8972	52.7178	0.3340	51.7849	81.7080	47.9339	86.7131
							79.0766	0.6660				
							92.2561	0.8045				
							137.1800	0.3011				
10	Normal	0.2563	1.9265	1.2492	1.2656	228.6333	182.9067	0.3972	185.9148	271.3518	173.2719	283.9947
							274.3600	0.6028				
							320.0866	0.6989				
							225.6000	0.2177				
11	Normal	0.2566	3.0722	1.2501	0.3795	376.0000	300.8000	0.3483	329.0533	422.9467	315.1590	436.8410
							451.2000	0.6517				
							526.4000	0.7823				
							267.1200	0.1902				
12	Normal	0.1422	2.1916	0.9304	0.8780	445.2000	356.1600	0.3305	395.7753	494.6247	381.1477	509.2523
							534.2400	0.6695				
							623.2800	0.8098				
							283.6250	0.1895				
13	Normal	0.3787	2.7471	1.5185	0.0848	472.7084	378.1667	0.3301	420.3874	525.0294	404.9027	540.5141
							567.2501	0.6700				
							661.7918	0.8105				
							252.0200	0.2218				
14	Normal	0.2743	2.3939	1.2925	0.5891	420.0333	336.0267	0.3509	366.6282	473.4384	350.8226	489.2441
							504.0400	0.6491				
							588.0466	0.7782				

Table 5.4 contd.

Rainfall probabilities and confidence limits - Kozhikode.

Fort-night	Distribution fitted	β_1	β_2	Z_1	Z_2	Mean rainfall (mm)	Rainfall amounts (x mm)	Probability of receiving x mm or less rainfall	Confidence limits: 80% limits, Lower limit	80% limits, Upper limit	90% limits, Lower limit	90% limits, Upper limit
1	2	3	4	5	6	7	8	9	10	11	12	13
							157.1250	0.2064				
15	Normal	0.1603	1.9473	0.9879	1.2269	261.8750	209.5000	0.3411	230.7416	293.0084	221.5274	302.2226
							314.2500	0.6589				
							366.6250	0.7936				
							109.2600	0.2162				
16	Normal	0.1185	2.5610	0.8495	0.3505	182.1000	145.6800	0.3474	159.5107	204.6893	152.8252	211.3748
							218.5200	0.6526				
							254.9400	0.7838				
							65.1450	0.3164				
17	Normal	0.5567	2.4922	1.8411	0.4487	108.5750	86.8600	0.4056	86.4452	130.7048	79.8957	137.2543
							130.2900	0.5944				
							152.0050	0.6836				
							64.6042	0.2445				
18	Rootnormal	0.1829	2.5913	1.0554	0.3072	107.6737	86.1390	0.3647	79.2324	140.4217	71.6409	150.9396
							129.2084	0.6353				
							150.7432	0.7555				
							52.6787	0.1571				
19	Rootnormal	0.0001	2.4814	0.0232	0.4642	87.7978	70.2382	0.3074	71.4434	105.8152	66.9222	111.4666
							105.3574	0.6926				
							122.9169	0.8429				
							64.4925	0.1779				
20	Rootnormal	0.0001	2.3628	0.0167	0.6336	107.4875	85.9900	0.3222	86.0101	131.3562	80.1124	138.8789
							128.9850	0.6778				
							150.4825	0.8221				
							39.0969	0.2447				
21	Rootnormal	0.0229	2.2349	0.3735	0.8161	65.1615	52.1292	0.3648	48.0943	84.8155	43.5392	91.1284
							78.1938	0.6352				
							91.2261	0.7553				
							10.7713	0.2778				
22	Rootnormal	0.4186	1.8760	1.5966	1.3287	17.9521	14.3617	0.3840	12.2081	24.7303	10.7065	26.9347
							21.5425	0.6159				
							25.1329	0.7222				
							15.2449	0.2921				
23	Rootnormal	0.3764	1.9194	1.5140	1.2668	25.4082	20.3266	0.3922	16.8481	35.6397	14.6352	38.9883
							30.4898	0.6078				
							35.5715	0.7079				

2.9209 mm to 420.3874 mm while the upper limits ranged from 7.4429 mm to 525.0294 mm. The lower limits at 90% confidence ranged from 2.5002 mm to 404.9027 mm while the upper limits ranged from 8.4577 mm to 540.5141 mm. The maximum assured rainfall would be expected in the 13th fortnight followed by 12th and 14th fortnights of the year.

At Quilandy, the largest amount of rainfall was received during 12th, 13th and 14th fortnights. During 12th fortnight, the expected probability of receiving 722.6915 mm of rainfall or more would be 0.2101 while during the 13th fortnight, the probability of receiving a minimum rainfall of 683.97 mm amount to 0.2078. But in the next fortnight, the probability reduced to 0.0497 for a minimum amount of 665.3891 mm rainfall. It indicated that relatively high rainfall would be expected during the 12th fortnight when compared to the other two fortnights. The 80% confidence limits had lower and upper limits of 24.2711 and 45.0118 mm during 1st fortnight, 453.8586 mm and 578.5580 mm during 12th

Table 5.5

Rainfall probabilities and confidence limits - Quilandy.

Fort-night	Distribution fitted	β_1	β_2	Z_1	Z_2	Mean rainfall (mm)	Rainfall amounts (x mm)	Probability of receiving x mm or less rainfall	Confidence limits: 80% limits, Lower limit	Confidence limits: 80% limits, Upper limit	Confidence limits: 90% limits, Lower limit	Confidence limits: 90% limits, Upper limit
1	2	3	4	5	6	7	8	9	10	11	12	13
							20.3222	0.2562				
7	Rootnormal	0.0763	1.7996	0.6816	1.4378	33.8704	27.0963	0.3717	24.2711	45.0118	21.7258	48.6049
							40.6445	0.6283				
							47.4186	0.7438				
							22.0332	0.2228				
8	Rootnormal	0.1559	2.3047	0.9746	0.7165	36.7220	29.3776	0.3315	27.7031	46.9712	25.2698	50.2404
							44.0664	0.6485				
							51.4108	0.7772				
							34.4790	0.1936				
9	Rootnormal	0.0757	2.9717	0.6788	0.2360	57.4650	45.9720	0.3327	45.0404	71.3720	41.6475	75.7721
							68.9580	0.6673				
							80.4510	0.8064				
							98.5941	0.0376				
10	Lognormal	0.0516	2.6032	0.5606	0.2903	164.3235	131.4588	0.1868	124.2887	217.2540	114.4304	235.9706
							197.1882	0.8132				
							230.0529	0.9624				
							218.2674	0.1768				
11	Rootnormal	0.1983	4.0008	1.0989	1.7055	363.7794	291.0235	0.3214	291.2263	444.3692	271.2949	469.7615
							436.5353	0.6786				
							509.2912	0.8232				
							309.7250	0.2101				
12	Normal	0.4504	2.6109	1.6560	0.2792	516.2083	412.9666	0.3434	453.8585	578.5580	435.4057	597.0108
							619.4499	0.6566				
							722.6915	0.7899				
							293.1300	0.2078				
13	Normal	0.6196	2.9307	1.9425	0.1774	488.5500	390.8400	0.3420	430.1194	546.9806	412.8264	564.2736
							586.2600	0.6580				
							683.9700	0.7922				
							285.1667	0.0497				
14	Rootnormal	0.0815	2.9921	0.7045	0.2651	475.2779	380.2200	0.2050	420.7555	533.1209	405.2561	550.8768
							570.3335	0.7950				
							665.3891	0.9503				

Table 5.5 contd.

Rainfall probabilities and confidence limits - Quilandy.

Fort-night	Distribution fitted	β_1	β_2	Z_1	Z_2	Mean rainfall (mm)	Rainfall amounts (x mm)	Probability of receiving x mm or less rainfall	Confidence limits: 80% limits, Lower limit	80% limits, Upper limit	90% limits, Lower limit	90% limits, Upper limit
1	2	3	4	5	6	7	8	9	10	11	12	13
15	Rootnormal	0.2367	2.2254	1.2004	0.8298	272.3708	163.4225	0.1571	222.2050	327.6382	208.3364	344.9733
							217.8966	0.3074				
							326.8450	0.6926				
							381.3191	0.8429				
16	Normal	0.5426	2.7750	1.8177	0.0449	213.6833	128.2100	0.2364	184.7074	242.6592	176.1318	251.2348
							170.9466	0.3598				
							256.4200	0.6402				
							299.1566	0.7636				
17	Lognormal	0.0439	2.2479	0.5168	0.7977	66.2753	39.7652	0.0885	48.9772	89.6830	44.7834	98.0814
							53.0202	0.2498				
							79.5304	0.7502				
							92.7854	0.9115				
19	Rootnormal	0.4214	2.5845	1.6019	0.3169	96.8277	58.0966	0.2049	75.0749	121.3121	69.1609	129.0824
							77.4622	0.3401				
							116.1932	0.6599				
							135.5588	0.7951				
20	Rootnormal	0.0101	1.9164	0.2477	1.2710	139.1224	83.4734	0.1966	108.9808	172.9098	100.7594	183.6086
							111.2979	0.3347				
							166.9469	0.6653				
							194.7714	0.8034				
21	Rootnormal	0.5702	2.8084	1.8634	0.0028	59.9848	35.9909	0.2646	42.5685	80.3228	37.9742	86.9022
							47.9878	0.3766				
							71.9818	0.6234				
							83.9787	0.7354				
22	Gamma					71.5917	57.2734	0.6392				
							71.5917	0.6931				
							85.9100	0.7371				
							100.2284	0.7735				
23	Lognormal	0.1697	1.5635	1.0164	1.7749	7.5689	4.5413	0.3215	4.4565	12.4568	3.7742	14.3799
							6.0551	0.4083				
							9.0827	0.5917				
							10.5965	0.6784				

fortnight and 4.4565 mm and 12.4568 mm in the 23rd fortnight. The assured rainfall at 90% confidence ranged from 3.7742 mm in the 23rd fortnight to 435.4057 mm in the 12th fortnight.

At Mananthody, the maximum rainfall was received during 13th and 14th fortnights. During 14th fortnight, the probability of high rainfall which would be more than 589.4 mm was 0.2265 whereas in the 13th fortnight, the probability of rainfall which would be greater than 786.9866 mm was 0.2542. Hence a high rainfall would be expected during the 13th fortnight than during 14th fortnight. The 80% and 90% assured rainfall ranged from 3.3487 to 479.3668 mm and 2.8950 to 454.8714 mm respectively.

Table 5.6

Rainfall probabilities and confidence limits - Mananthody.

Fort-night	Distribution fitted	β_1	β_2	Z_1	Z_2	Mean rainfall (mm)	Rainfall amounts (x mm)	Probability of receiving x mm or less rainfall	Confidence limits: 80% limits Lower limit	80% limits Upper limit	90% limits Lower limit	90% limits Upper limit
1	2	3	4	5	6	7	8	9	10	11	12	13
							2.2399	0.4092				
2	Gamma					3.7333	2.9867	0.5334				
							4.4799	0.7189				
							5.2267	0.7841				
							7.1523	0.2788				
6	Rootnormal	0.6032	2.1273	1.9167	0.9698	11.9205	9.5364	0.3847	7.9866	16.5667	6.9589	18.0783
							14.3046	0.6153				
							16.6887	0.7212				
							22.9626	0.1902				
7	Rootnormal	0.0014	2.0700	0.0926	1.0516	38.2710	30.6168	0.3305	30.0343	47.4761	27.7822	50.3861
							45.9252	0.6695				
							53.5794	0.8098				
							25.8069	0.1950				
8	Rootnormal	0.0026	2.2173	0.1252	0.8413	43.0115	34.4092	0.3337	33.6055	53.5470	31.0383	56.8816
							51.6138	0.6663				
							60.2161	0.8050				
							21.7116	0.1287				
9	Lognormal	0.5077	3.4768	1.7583	0.9573	36.1860	28.9488	0.2856	26.2490	49.7469	23.8535	54.6381
							43.4232	0.7144				
							50.6604	0.8713				
							49.7276	0.1859				
10	Rootnormal	0.1319	2.4067	0.8962	0.5708	82.8793	66.3034	0.3276	65.5873	102.1651	60.8520	108.2552
							99.4552	0.6724				
							116.0310	0.8141				
							101.5850	0.2590				
11	Normal	0.3424	2.9260	1.4439	0.1707	169.3083	135.4466	0.3733	143.7983	194.8183	136.2484	202.3682
							203.1700	0.6267				
							237.0316	0.7410				
							175.3339	0.1395				
12	Rootnormal	0.0560	2.3384	0.5839	0.6684	292.2233	233.7786	0.2941	242.0301	347.1427	228.0813	364.3028
							350.6680	0.7059				
							409.1126	0.8605				
							337.2800	0.2542				
13	Normal	0.6117	2.8914	1.9300	0.1214	562.1333	449.7067	0.3704	479.3668	644.8998	454.8714	669.3951
							674.5600	0.6296				
							786.9866	0.7458				
							252.6000	0.2265				
14	Normal	0.1848	2.6420	1.0608	0.2348	421.0000	336.8000	0.3538	366.3711	475.6290	350.2033	491.7968
							505.2000	0.6462				
							589.4000	0.7735				

Table 5.6 contd.

Rainfall probabilities and confidence limits - Mananthody.

Fort-night	Distribution fitted	β_1	β_2	Z_1	Z_2	Mean rainfall (mm)	Rainfall amounts (x mm)	Probability of receiving x mm or less rainfall	Confidence limits			
									80% limits		90% limits	
									Lower limit	Upper limit	Lower limit	Upper limit
1	2	3	4	5	6	7	8	9	10	11	12	13
							161.9318	0.0934				
15	Rootnormal	0.2723	3.1629	1.2876	0.5091	269.8864	215.9091	0.2546	231.5342	311.1763	220.7470	323.9597
							323.8637	0.7454				
							377.8410	0.9066				
							116.7884	0.0031				
16	Lognormal	0.0447	2.5233	0.5215	0.4044	194.6474	155.7179	0.0855	161.3691	234.7884	152.6586	248.1853
							233.5769	0.9145				
							272.5064	0.9969				
							45.9689	0.1506				
17	Rootnormal	0.2346	3.0059	1.1951	0.2848	76.6148	61.2918	0.3026	62.8622	91.7268	59.0527	96.4599
							91.9378	0.6974				
							107.2607	0.8494				
							45.6950	0.3020				
18	Normal	0.5359	2.6185	1.2064	0.2684	76.1583	60.9267	0.3977	61.8532	90.4635	57.6195	94.6972
							91.3899	0.6023				
							106.6217	0.6980				
							36.7688	0.1393				
19	Rootnormal	0.0266	2.6019	0.4028	0.2921	61.2813	49.0250	0.2940	50.5886	72.9803	47.6170	76.6356
							73.5376	0.7060				
							85.7938	0.8607				
							51.8100	0.2814				
20	Normal	0.6077	3.0431	1.9237	0.3379	86.3500	69.0800	0.3861	71.8201	100.8799	67.5199	105.1801
							103.6200	0.6139				
							120.8900	0.7186				
							12.8744	0.1770				
21	Lognormal	0.3481	2.5902	1.4560	0.3087	21.4573	17.1658	0.3215	15.1958	30.1396	13.7025	33.3025
							25.7488	0.6785				
							30.0402	0.8230				
							4.2299	0.3073				
22	Lognormal	0.1838	1.5529	1.0578	1.7901	7.0499	5.6399	0.4007	4.3770	11.0516	3.7717	12.5803
							8.4599	0.5993				
							9.8699	0.6927				
							3.1861	0.3149				
23	Lognormal	0.3478	1.8843	1.4552	1.3168	5.3102	4.2482	0.4048	3.3487	8.1563	2.8950	9.2228
							6.3722	0.5952				
							7.4343	0.6851				

DISCUSSION

DISCUSSION

The amount and distribution of rainfall determine the choice of the crop and cultivation practices of a location. Though Kerala is blessed with south-west and north-east monsoon rains, the State has experienced severe drought conditions several times in the past, especially in recent years. In Kerala, the percentage of net area irrigated to net area sown is negligibly small. Though the State with its numerous rivers and rivulets coupled with moderate rainfall provide enormous irrigation potentialities, the present level of exploitation is very low. Agriculture in Kerala has now become more or less a gamble in the face of south-west and north-east monsoons. During the <u>kharif</u> season, all the major crops of Kerala are grown mostly under rainfed condition and so any amount of deficit or excess rainfall at critical phases of crop growth would affect the crop and depress the yield. Estimates of probable amount of rainfall that would be expected at particular periods are very helpful in working out the regional strategy for agricultural development and in advising farmers in operation management. The occurrence of rainfall at a particular period in a locality is beset with uncertainty. Stochastic models of varying types are therefore used for the study of the behaviour of the occurrence of rainfall in short intervals of time. In this study, an attempt was made to characterize the behaviour of fortnightly rainfall in six selected reporting stations of north Kerala by the use of a simple Markov chain model and by fitting suitable theoretical distributions. The results obtained in the investigation are discussed below.

The study revealed that a first order Markov chain model could represent the behaviour of the fortnightly occurrence of wet and dry days in the selected centres throughout the crop growing period except in certain earlier fortnights. In all the centres, p_{22} was higher than p_{12} for all the fortnights indicating that there would be greater chance for a wet day to be preceded by a wet day than by a dry day. The equillibrium probability of occurrence of wet day (π_1) showed increasing trend at all the centres upto the 12th, 13th or 14th fortnights and thereafter recorded a steady decline. The distribution of wet days in relation to the order of the fortnights could be described by a quadratic polynomial curve with an optimum lying some where in the neighbourhood of the 13th fortnight. This time actually coincides with the period when the south-west monsoon becomes most active. The expected heavy rainfall during the period usually has a depressing effect on crop growth and yield; low lying lands get submerged under water, rivers overflow and crops are damaged. South-west monsoon commences in the month of June and continues till September. The commencement of south-west monsoon is usually accompanied by heavy showers. A significant difference between any two earliest consecutive values of p_{22} (or p_{12}) in the anticipated time scale indicates the probable start of monsoon rains. It could be seen that at all the centres, the likely commencement of south-west monsoon was in the 11th fortnight (1st week of June). The intensity of south-west monsoon was found to decline gradually after the 14th fortnight and was completely weakened by the 19th fortnight. North-east monsoon was active in the months of October and November. But in northern Kerala, the contribution of north-east monsoon towards total rainfall was negligibly small.

Realistic estimates on the expected lengths of wet and dry spells were not available for the first six fortnights and the last two fortnights of the year owing to extremely larger proportion of dry days in comparison with wet days. In particular, practically no precipitation was recorded in the 3rd fortnight of the year all over the reporting stations during the entire sequence of years indicating that the 3rd fortnight of the year could be regarded as the most dry fortnight of the year. The probability of rain in the first six fortnights was found to be extremely small. The values of p_{12} and p_{22} were found to be negligibly small in the summer months indicating the need for strengthening the irrigation facilities. The expected length of dry runs in the other fortnights varied between 1 to 14 days whereas that for the wet runs varied between 1 to 11 days. Thus it could be seen that after every 1 to 11 consecutive wet days, a dry day is expected to occur whereas after every 1 to 14 consecutive dry days, a wet day is expected to occur. If we designate a fortnight with greater expected length of wet spell than that of dry spell as 'wet', then all the fortnights in the range between sl. no. 11 to sl. no. 16 could be considered to be wet at all the centres. But at Kasaragod and at Irikkur, the wet fortnights extends further to fortnight no. 17 also. Thus the timespan from 11th fortnight to 17th fortnight could be considered to be the wettest period of the year in northern Kerala.

The number of days to attain equillibrium in various fortnights at different centres varied from 5 to 15 days. This indicated that after 5 to 15 days from the beginning of the fortnight, the probability of a day being dry or wet would be independent of the initial condition of the weather. The equillibrium probability for a wet day was maximum in the 13th fortnight in most of the centres except at Quilandy and Mananthody where the 14th fortnight recorded the highest equillibrium probability. Thus the month of July which include these two fortnights could be considered to be the wettest month of the year. Anon (1976) has reported that 46% of the total rainfall received in Kerala was contributed by the rainfall received during the months of June and July. In northern Kerala, the estimates were found to be still higher.

The results on expected number of wet and dry days in different fortnights at different centres exhibit certain distinct characteristics. At Mananthody, a sufficiently higher number of rainy days (about 4 per fortnight) could be expected in the 7th and 8th fortnights of the year while at Kasaragod, a maximum of 1 or 2 rainy days alone could be expected during the entire month of April. In the 9th fortnight also, there had been better expectation for rainy days at Mananthody, Calicut and Irikkur when compared to that at Kasaragod and Cannanore. But by the 10th fortnight, the distribution of rainfall becomes more or less even in all the centres. Expected rainfall during the 11th fortnight at Mananthody was significantly lower than that at the other centres. Kasaragod and Irikkur experienced a longer wet spell, during the peak period of monsoon than the other centres. At Kasaragod centre, the expectation of dry days in the 14th fortnight is only 1 while 3-4 dry days could be expected at the other centres except at Irikkur. Kasaragod and Irikkur experience slightly higher number of rainy days during the 16th and 17th fortnights also. But towards the end of the north-east monsoon, Kasaragod centre also experience drought condition along with other centres. The distribution of north-east monsoon was found to be almost uniform in all the centres. The equillibrium probability of wet day during the 11th fortnight at Mananthody was only 0.5817 which was significantly lower than that in the other centres. At the 21st fortnight Kasaragod and Cannanore recorded very low probability of rainfall when compared to that in other centres.

The seasonwise analysis of rainfall data for the comparison of centres in respect of the pattern of occurrence of rainfall revealed that the rainfall pattern at different centres for the first season were different. During the second season, rainfall pattern at Kasaragod, Quilandy and Mananthody was found to be similar as the corresponding chi-square statistics were non significant for these centres. It was also observed that Irikkur and Quilandy have the same pattern of rainfall during the third season as was evidenced by the non significant chi-square value.

It is interesting to note that there had not been any marked dissimilarity among the centres with regard to the state of equillibrium condition. In the first season, the minimum length of weather cycle was noticed at Kozhikode. On an average, 6-7 wet days could be expected in an interval of 10 days during the first season while in the second season, 2-3 wet days alone could be expected in a fortnight. Length of weather cycle had also been drastically increased on account of change from winter to summer season. The expected length of weather cycle during the summer season varied between 17 days at Mananthody to 42 days at Kasaragod. The expected frequency of rainy days was greater at Mananthody and at Kozhikode when compared to other centres Kasaragod, Irikkur and Cannanore. Thus there were lesser chances for the occurrence of summer rains at these three places. This clearly indicated the need for strengthening irrigation facilities at these northern most regions of Kerala for getting better yield.

Among the different centres considered here, the highest mean rainfall of 661 mm was recorded at Irikkur during the 13th fortnight. In other centres also maximum rainfall was recorded either in the 13th fortnight or in the 12th fortnight.

At all centres, periods of high rainfall were associated with low coefficient of variation indicating greater consistency in the rainfall pattern during those periods. Maximum rainfall with minimum coefficient of variation was observed in the 13th fortnight in all the centres except at Quilandy where 12th fortnight satisfied the above condition. At all centres, rainfall distribution showed high variability during the earlier fortnights of the year. But variability reduced considerably towards the middle of the year and then showed a steady increase.

The incidence of relatively high total annual rainfall in Kerala during the past years has created a wrong notion in certain quarters that there is no need for strengthening irrigation facilities in Kerala. But this notion is based on the assumption that the annual rainfall is evenly distributed throughout the year. But the fact is that more than 2/3rd of the total rainfall is received during the south-west monsoon season of four months from June to September. A most important factor is the timely receipt of rainfall in the required amount at appropriate stages of crop growth. Thus the distribution of rainfall over the season is more important than its total intensity. The irrigation potential of the State should be properly exploited to cope with the requirement.

Information on maximum and minimum expected rainfall is of vital importance to the agriculturist because he cannot undertake a particular agricultural operation if the minimum assured rainfall in a place is not adequate. In such cases, he has to take decision on shifting agricultural operations suitably so that all the operations fall in line with the rainfall pattern of the region.

Avtar Singh and Pavate (1968) have reported that in India, rainfall being concentrated only to few months in an year and that it being not very high, 4:1 confidence limits would serve the purpose. However 9:1 confidence limits have also been given for comparison. In all the centres except at Quilandy, the 1st fortnight of July (13th fortnight) could be considered to be the wettest fortnight where minimum expected rainfall was the highest. This was followed by the immediately preceding or succeeding fortnights of the year. At Quilandy, the highest minimum expected rainfall was recorded in the 12th fortnight followed by the 13th fortnight. Minimum assured rainfall at Mananthody and at Kasaragod in the 9th fortnight was relatively lower than that at other centres. It is also interesting to note that the amount of assured rainfall at Mananthody during the 10th, 11th and 12th fortnights were very low when compared to that at other centres. The minimum expected rainfall during the 11th fortnight at Mananthody was about 143 mm while that at Kasaragod was about 371 mm. The amount of assured rainfall at Kasaragod during the 19th and 20th fortnights was less than 70 mm while that at Irikkur exceeded 100 mm.

Upper confidence limits give the estimates of risk of obtaining heavy rainfall during a particular period. In most of the centres, the incidence of heavy rainfall was concentrated around the 13th fortnight with Irikkur and Mananthody experiencing the greatest risk than the other places.

Probability estimates reveal that in the earlier fortnights (8th and 9th), there was slightly higher chance at Irikkur and Mananthody for getting sufficiently high rainfall. In the case of later fortnights, Kasaragod and Mananthody are likely to be more prone to drought conditions than the other centres.

The results of the study exphasize the need for providing adequate irrigation facilities for successful farming during the early fortnights of the year. Proper surface drainage systems should be provided during the months of July and August. Supplementary irrigation should be provided during the fortnight with inadequate lower limit of expected rainfall. Sowing date should be so adjusted to cope with the onset of monsoon and the occurrence of pre-monsoon showers. Short duration varieties could be coupled with delayed sowing at places where drought conditions prevail especially during the 8th and 9th fortnights.

SUMMARY

SUMMARY

A study was undertaken to investigate the pattern of occurrence of rainfall and to estimate the rainfall probabilities and confidence limits at six selected centres of the northern districts of Kerala. The results obtained from the study are summarised below.

The analysis of daily rainfall data revealed that the pattern of occurrence of wet and dry days in a fortnight could be well described by a two state Markov chain model. It was found that at all the centres, there would be more chances for a wet day to be preceded by a wet day than by a dry day. The system was found to settle down to a condition of statistical equillibrium in which the state occupation probabilities were independent of the initial condition of the weather. The number of days to attain equillibrium in various fortnights at different centres varied from 5 to 15 days. The state occupation probability at equillibrium for a wet day (π_1)

showed a steady increasing trend towards the middle of the year and thereafter recorded a steady decline. This probability was found maximum during 13th fortnight in most of the centres. Since the number of wet days during the first six and the last two fortnights of the year were negligibly small, the estimates on expected length of dry and wet spells were not found to be reliable. The 3rd fortnight of the year was found to be the extremely dry fortnight of the year at all the centres, since the amount of rainfall received was negligible. The expected length of dry runs in other fortnights varied between 1 to 14 days whereas that for wet runs varied between 1 to 11 days. At all the centres except at Kasaragod and Irikkur, the fortnights in the range between serial no. 11 to serial no. 16 could be considered to be the 'wettest' fortnights in the sense that these fortnights have greater expected length of wet spell than that of dry spell. At Kasaragod and Irikkur, the wettest period in the time span was from 11th to 17th fortnights.

For the comparison of centres in respect of the pattern of occurrence of rainfall, the data were analysed seasonally and chi-square test was applied. It was found that $\chi^2_{p_{12}}$ and $\chi^2_{p_{22}}$ were non-significant for Mananthody centre in the first season, Kasaragod, Quilandy and Mananthody centres with second season and Irikkur and Quilandy centres in the third season. Hence it may be concluded that during the first season, the rainfall pattern was different from centre to centre while in the second season, Kasaragod, Quilandy and Mananthody exhibited similar pattern of rainfall. But during the third season, similar rainfall pattern was seen only at two centres viz. Irikkur and Quilandy.

Among the different centres considered, the highest fortnightly mean rainfall of 661 mm was received at Irikkur during the 13th fortnight. At all other centres except at Quilandy, heavy down pour was during 13th fortnight. At Quilandy, a maximum rainfall of 516 mm was received during the 12th fortnight.

It was observed that the periods of high rainfall were associated with low coefficient of variation. At Quilandy, the minimum coefficient of variation with the maximum rainfall was noted in the 12th fortnight whereas at all other centres, it was during the next fortnight. The coefficient of variation had high values during the early fortnights, reduced considerably towards the middle of the year and then increased gradually towards the end fortnights.

It is a characteristic of the pattern of rainfall in India that the rainfall is restricted only to few months in an year and has not been found to be very high. So in order to get the minimum and maximum expected rainfall, the 4:1 confidence limits would serve the purpose of the present study. However 9:1 confidence limits have also been given for comparison. On the basis of the minimum expected rainfall, 13th fortnight recorded the highest amount at all the centres except at Quilandy where the highest minimum expected rainfall was recorded in the

12th fortnight. A study of the upper confidence limits revealed that in most of the centres, the incidence of heavy rainfall was concentrated around the 13th fortnight.

Probability estimates reveal that in the 8th and 9th fortnights, the chances of getting sufficiently high rainfall at Irikkur and Mananthody was slightly higher when compared to other centres. In later fortnights, there are more chances at Kasaragod and Mananthody to prevail drought conditions.

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PATTERN OF OCCURRENCE OF RAINFALL AND ESTIMATION OF RAINFALL PROBABILITIES IN NORTHERN DISTRICTS OF KERALA

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ABSTRACT OF A THESIS
submitted in partial fulfilment of the requirement
for the degree
MASTER OF SCIENCE IN AGRICULTURAL STATISTICS
Faculty of Agriculture
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1987

ABSTRACT

A study was undertaken with a view to characterize the pattern of occurrence of rainfall and to estimate the rainfall probabilities and confidence limits at six reporting stations of the northern districts of Kerala viz. Kasaragod, Irikkur, Cannanore, Kozhikode, Quilandy and Mananthody. Daily rainfall data of the past 30 years were used to investigate the pattern of fortnightly and seasonal rainfall occurrence by fitting a first order Markov chain model to the sequence of wet and dry days. The rainfall probabilities and confidence limits were computed by fitting appropriate probability distributions to fortnightly rainfall amounts.

The results of the analysis showed that at all the centres, there were more chances for a wet day to be preceded by a wet day than by a dry day. The maximum expected length of wet spell at different centres was observed during 12th to 14th fortnight of the year. The state occupation probability at equillibrium for a wet day was also found

maximum during the same period. It could be seen that at all the centres, the likely commencement of south-west monsoon would be in the 11th fortnight.

Suitable probability distributions from among normal, root normal, log normal and gamma distribution were selected and fitted to fortnightly amounts of rainfall. Rainfall probabilities of getting a fixed amount or less of rainfall were worked out together with the 80% and 90% confidence limits of the mean fortnightly rainfall. The 3rd fortnight of the year all over the centres was found to be the driest fortnight and the 12th or 13th fortnight was found to be the wettest fortnight of the year.

The results of the analysis emphasized the need for introducing drainage systems in fortnights with more chances of heavy rainfall and providing supplementary irrigation facilities during fortnights with less chance of rainfall.