

# **RAINFALL MODELLING OF SOUTHERN RAJASTHAN**

**नमः कृषि एवं प्रौद्योगिकी विश्वविद्यालय, उदापुर**

**BY**

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**CERTIFICATE - I**

This is to certify that **Mr. Mukteshwar Prasad** has successfully completed the comprehensive examination held on 29<sup>th</sup> April 2005 as required under the regulations for Master of Engineering in Soil & Water Conservation Engineering.

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Dated: / / 2005

**CERTIFICATE - II**

This is to certify that this thesis entitled “**Rainfall Modelling of Southern Rajasthan**” submitted for the degree of **Master of Engineering** in agriculture in the subject of **Soil & Water Conservation Engineering** embodies bonafide research work carried out by **Mr. Mukteshwar Prasad** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on

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## ABSTRACT

A detailed statistical analysis of daily rainfall during the months June to September, weekly rainfall and annual rainfall at Southern Rajasthan was carried out. In the present study daily rainfall data were collected for Udaipur, Kota and Bhilwara

The variation in daily rainfall pattern was found to be more consistent during monsoon season. A cycle of 5 to 6 years was found to occur in annual rainfall amounts. If rainfall on a particular day was more than or equal to 2.5 mm, that day was considered as rainy day. Number of rainy days on monthly, seasonally and annually basis were calculated. For forecasting the weekly rainfall, Normal, Log-normal and Gamma probability distribution functions were fitted. Calculated chi-square values were compared with tabular values at 5 per cent level of significance. Forecasting of dry and wet spells were done using Markov Chain model. Initial and transitional dry and wet week probability analysis, consecutive dry and wet week probability analysis were carried out in the study.

Using Wiebull's plotting position method weekly rainfall was predicted at various probability levels. It was found that dependable rainfall is available during 24th to 35th weeks. Rainfall at various probability levels were predicted for each of month of the year using gamma probability distribution. Six probability distributions were fitted to predict one day maximum rainfall at the study area. Gumbel distribution was found to be fitted well for prediction of one day maximum rainfall. Suitability of the study area was assessed on the basis of moisture availability index and the study area was found to be suitable for dry land agriculture.

Weekly rainfall was analysed using Markov chain model and initial and conditional probabilities were estimated for 5, 10 and 20mm rainfall amount. Weather spells and weather cycles were predicted using Markov chain based geometric model. It was found that the model predicted the wet spells and weather cycles efficiently. Weekly forecasting of rainfall indicated that expected rainfall is scarce from the month of November to May at all probability levels. Probability of occurrence of dry week is higher from week no. 1 to 21 and also from week no.43 to 52. The range of probability of occurrence of dry week in these weeks vary from 42.8 to 99.99 per cent for all the three stations at Southern Rajasthan. Probability of occurrence of wet week is higher from week no. 22 to 41. The range of probability of wet week vary from 45 to 99.99 per cent. Week no. 1 to 21 and 43 to 52 of the year remains under stress on an average as there is 50 to 92.8 per cent chances of occurrence of 2 consecutive dry weeks. The analysis showed that monsoon starts effectively from 24<sup>th</sup> week (10<sup>th</sup> June to 16<sup>th</sup> June) in Southern Rajasthan. 25<sup>th</sup> week (24<sup>th</sup> June to 30<sup>th</sup> June) is ideal time for initiation of land preparation of fields for kharif.

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# I - INTRODUCTION

## 1.1 General

One third of the world's land surface has been classified as arid or semi-arid. The world's total population has increased four times in the past 150 years and may double again in the next 30 years.

Agricultural development rests heavily on the management of natural resources, which have to be utilized optimally to obtain food, nutrition and environmental security for the future generation. Till now agricultural development of our country is confined to irrigated areas, that too, medium and low lands. But in India, about 65% area is still rainfed. If agricultural production has to be increased through sustainable manner, it is essential that our agricultural practices make economical and efficient use of land, water and other natural resources in both irrigated and rainfed areas. The natural resources of arid and semi-arid regions, particularly soil and water are limited and are often in a delicate environmental balance. Dry lands constitute about 70 percent of the total cultivated area (143 Mha) in India and contribute about 42 percent of the total agriculture production. The contribution of dry land agriculture in the production of pulses and oil seeds, rice, wheat, sorghum, pearl millet and cotton in India is about 75, 60, 50, 95, 96 and 75 percent respectively (Singh and Singh, 1987). The role of the dry lands in the national economy is obvious. Stabilizing and elevating crop production in such areas would, therefore hold the key to achieve stability of agricultural production and for ensuring a steady supply of industrial raw materials. Such efforts will help in removing poverty from dry land areas, by providing scientific package of practices, designed primarily for increasing per hectare yields. This is precisely the reason why the Government of India has laid a great emphasis on the development of dry land farming.

India receives adequate amount of rainfall annually through the four different types of weather phenomena, South-West monsoon (74%), North-East monsoon (3%), pre-monsoon (13%) and post-monsoon (10%). The distribution in time and space is erratic, thus resulting in a limitation on the length of crop-growing periods or the occurrence of floods. Rainfall is one of the most important natural resource for human beings. The rainfall and its distribution throughout the year are important for every cultivator, both for deciding the cropping pattern and for providing irrigation. Intensity pattern and distribution of rainfall may be used by engineers for designing structures for flood control and irrigation projects.

The important feature of dry lands is the scanty rainfall conditions, with its erratic distribution. About 90 percent of annual rainfall in these areas is spread over 2 to 3 months.

Looking into the water budget of the Indian sub-continent, it will be seen that the estimated annual precipitation of 417 million hectare meter, received by the land surface is distributed in the following manner:

- Nearly  $70 \times 10^6$  ha-m are lost by evaporation immediately after precipitation.
- Around  $150 \times 10^6$  ha-m is absorbed by the soil, out of which about  $110 \times 10^6$  ha-m is retained as soil moisture and  $40 \times 10^6$  ha-m get into deeper strata as ground water. Around  $180 \times 10^6$  ha-m find its way as runoff and get into the natural drainage systems along with tones of valuable soil, organic matter and nutrients.
- A very small fraction of the total runoff, around  $17 \times 10^6$  ha-m is impounded in large irrigation projects.

This situation is an indicator of the urgent necessity to minimize the wastage of such a valuable resource by water management techniques in dry rainfed areas.

The dry land watersheds are faced with the following serious handicaps for which possible but simple remedies are required.

- (i) Rainfall factors: intensity and erratic distribution, causing floods or droughts, etc., rainfall data is analyzed to attack the problem systematically.
- (ii) Timeliness of crop production activity: package of practices and technology is to be identified.
- (iii) Mechanical manipulations: for soil management, anti-erosion terracing, ravine protection and disposal of drainage water, practices have to be identified.
- (iv) Agricultural input factor: availability of inputs must be taken into account before recommending cropping systems.

Out of these, the rainfall factors have to be analyzed systematically before attacking any of the later problems.

It is an established fact that the crop development will be affected if the dry spells coincide with the sensitive phenological stage of the crop. On the other hand, dry periods at the ripening stage of the crop are sometimes beneficial. Hence, for the purpose of crop planning and to carry out the agricultural practices it is important to know the sequence of dry and wet periods. Markov Chain probability model has been extensively used to find the long-term frequency behavior of wet and dry weather spells (Victor and Sastry, 1979). Pandarinath (1991) used Markov Chain model to study the probability of dry and wet spells in terms of the shortest period like week. A number of research workers have demonstrated its practical utility in agricultural planning.

Another aspect of crop planning is backward and forward accumulation of rainfall to determine the onset and termination of the wet season based on precipitation data. Cropping strategies are greatly influenced by the variability of the onset and end of the rainy season. Generally farmers opt for planting or broadcasting their seed when a certain amount of rainfall has sufficiently moistened the top soil. However, 75 mm accumulation of rainfall has been considered as the onset time for the growing season for dry seeded crops and 200 mm accumulated rainfall for initiation of puddling i.e. wet land preparation of rice fields. Similarly, the end of the wet season is determined by backward summing of rainfall data. It is considered that 500 mm accumulated values represent the pentad after which sufficient rain water would be expected to sustain a second rice crop or other short duration field crops, assuming a fully charged soil profile at planting (W. M.O, 1982).

The philosophy of dry land agriculture revolves around the principle that water in these areas being scarce and one has to maximize the use of rain water for agricultural production. The strategy for this agriculture is to narrow down the inter-annual variation, stabilize outturns in favorable years to build up buffer stock. Research therefore, should be directed to evolve means to face variety of conditions, arising out of abnormal weather. The present study **“Rainfall Modelling of Southern Rajasthan”** is a modest attempt to analyze the behavior of rainfall in semi arid zone of Rajasthan.

## **1.2 Justification**

Crop production in semi arid region is largely determined by climatic and edaphic features. Development of an improved crop production technology, to increase and stabilize food production in these areas requires a more complete and quantitative effort.

In Rajasthan the rainfall is so erratic and variable that, in the south-east it is 1000 mm and in west it is merely about 120 mm. Major parts (about 90%) of this rainfall occurs during the months of June to September, which is not only inadequate but also uncertain. Because of the high evaporative demand during most of the growing season, variations in the timing and amount of rainfall are generally key factors, influencing the agricultural production potential of major parts of Rajasthan, including Udaipur region.

Several scientists have laid stress on the need for the quantification of the variability of climatic factors. For semi-arid tropical area like Udaipur, the most commonly considered element is rainfall. These are characterized by seasonal wet and dry climates. The crop growing season, which usually coincides with the length of the humid period, is subject to great fluctuation. Therefore, for agricultural development planning, knowledge of the reliability of duration and characteristics of rainfall at a particular location is very essential.

In order to have description of the principal characteristics of the climate of any location, meteorologists tend to base their observation on average values which are convenient for calculation. Climatic descriptions based on average, might be suitable for stations where climate for each of the individual years follows the average pattern. However, this generally is not true, because of uncertainties inherent in rainfall patterns.

Presentation of rainfall data in the form of simple arithmetic average therefore, provides a very general understanding for a generalized application. Considerable difficulty is experienced if one has to apply the data for certain specific operations. For example, design engineers and hydrologists require maximum daily rainfall of different frequencies and medium hydraulic structures such as design of small dams, bridges, storm water drainage works and to know the drainage coefficients, in the design of drainage systems for agricultural lands.

Many agricultural operations which revolve around the probability of receiving given amounts of rainfall can be used for a number of agricultural planning purposes such as, land use planning, choice of crops and cropping systems and resource allocation problems. Such knowledge could greatly help in the transfer of farming systems technology.

The rainfall model can be of great use to develop a watershed model for reliable planning of water resources development projects. From the view point of agriculture, the time pattern as well as rainfall amounts are important and the study of these characteristics through several rainfall sequences becomes indispensable.

The important aspects of this study are to analyze and forecast the rainfall patterns of southern Rajasthan, so that watershed management projects can be planned and evaluated as economic alternatives in resource planning and managerial decisions can be drawn well in advance. Such consideration cannot be made without the knowledge of rainfall patterns at southern Rajasthan. In this research work, the following broad objectives have been set towards this approach.

- (i) To analyze the rainfall data of southern Rajasthan, viz. Udaipur, Kota and Bhilwara on weekly, fortnightly, monthly and annual basis.
- (ii) To estimate the frequency of weekly rainfall using various probability distribution functions.
- (iii) To forecast dry and wet spells using Markov Chain Model
- (iv) To estimate the time of onset and withdrawal of monsoon.

## II - REVIEW OF LITERATURE

### 2.1 General

Many hydrologic processes are highly erratic, complex and random in nature. The information to investigate these processes is contained in the records of hydrologic observations. Since hydrological data is the only source of information, upon which quantitative hydrologic investigations are generally based, their measurements have been continuously expanding and resulting in ever increasingly large amount of sample data. The mounting quantities of hydrologic data can be expressed in statistical terms and can be treated with probability theories. There are many probability distributions that have been found to be useful, for hydrologic frequency analysis. Various scientists have used different probability distributions for rainfall analysis.

Generating synthetically, the rainfall time series is equally important for forecasting, which either becomes useful information in many fields like planning agricultural operations, water resources planning, etc. or may become an input series in watershed simulation. Various approaches and models are available for the purpose.

A brief review of the work done by many workers has been dealt with, in subsequent sections of this chapter. This chapter presents a critical review of the available literature on probability analysis of rainfall, dry/wet spell (using Markov Chain model) and prediction of onset and termination of monsoon.

### 2.2 Application of Statistical and Probability Analysis

Various distributions have been extensively used for frequency analysis of rainfall and other meteorological events.

An extensive rainfall frequency study in United States was first made by Yernell (1936). This study produced a well known Yernell frequency data. Chow (1953) applied extreme value type - I distribution for the study of rainfall intensity frequency in Chicago for approximate determination of rainfall frequencies in the Continental United States.

Matalas (1963) investigated the first of four theoretical probability distributions namely, Gumbel's limited distribution of the smallest value, 3 - parameter lognormal distribution, Pearson type - III distribution and Pearson type - V distribution to low flows at United States. He carried out a study to determine the desirability of estimating parameters of probability distributions by the method of maximum likelihood. It was observed that the Gumbel and Pearson type - III distributions fitted the data equally well and that, the parameters can be best estimated by using maximum likelihood method.

Gupta *et. al.* (1968) gave a graphical representation of monthly, seasonal and annual rainfall data of Dehradun for 97 years. It was based on the simple array of numerical data in order of magnitude. They found that such analysis are useful to predict expected rainfall amount in a particular month, season and year for a desired recurrence interval and percent chance.

Kundu (1973) analyzed annual maximum rainfall data of Ludhiana for 48 years using three different theoretical distributions namely, log-normal, log - Pearson type - III and Gumbel. It was concluded that log normal curve seemed to give the closest fit to the observed data and any of the distributions fitted, might be used for the prediction of daily maximum precipitation with a reasonable accuracy.

Bernard (1975) conducted a statistical study to observe the flexibility and limitations of log Pearson type - III distribution. The proposed method was compared, with that proposed by Hydrology Committee of the Water Resources Council, U.S.A. It was observed that an appreciable deviation in the results obtained by the two methods exists for the events with large return periods. It was concluded that the proposed method gives a better fit of the data.

Ray *et. al.* (1980) analyzed statistically seven years of daily rainfall data at Gopalpur, Orissa. Weibull's method of frequency analysis was used and rainfall amounts on weekly intervals at 3 levels of probability, was predicted.

Bhattacharya and Sarkar (1982) analysed 40 years of daily rainfall data of Hoshangabad, Madhya Pradesh for the month of June, July, August, and September and determined one day and consecutive 2, 3, 4 and 5 days maximum rainfall of 5 years recurrence interval. The adequacy of rainfall records length was also studied for the purpose and it was observed that, the deviations of the predicted 5 years value from the true mean were between  $\pm 10$  and  $\pm 5$  percent for fifteen years and thirty years record, respectively.

Ray *et. al.* (1985) determined the drainage coefficients of 30, 54 and 86 mm per day for the design periods of 5, 10 and 20 years, respectively, from the analysis of 30 years of maximum rainfall data of Bhubaneshwar.

Mishra and Satyanarayana (1987) analyzed statistically 26 years daily rainfall data at Kharagpur and worked out mean, standard deviation and coefficient of variation on weekly, monthly and yearly basis. The effect of extreme events on the various statistical parameters, was also studied.

Khandelwal (1988) analyzed 25 years daily rainfall data of Canning and compared one day annual maximum rainfall distribution with theoretical frequency distributions of lognormal, Gumbel and log Pearson type III. The drainage coefficients based on 5 days

annual maximum rainfall of 5 years return period with a removal time of 7 days was worked out. It was observed that the frequency distribution of one day annual maximum rainfall by log Pearson type III ( $C_v=0.3842$ ) and log normal were close to the observed distribution ( $C_v=0.439$ ) than by Gumbel distribution ( $C_v=0.675$ ) and the drainage coefficient from 5 day, 5 years depth duration curve was 40 mm per day.

Shih (1988) analyzed the rainfall variation at South Florida by studying rainfall data from Lake Alfred, Fort Myers Clewiston, Belle Glade and West Palm Beach weather stations and observed that the chance of rainfall occurrence was about 25 percent during dry season (November - October) and 75 per cent during wet season (May - October).

Kumar and Kumar (1989) analyzed 26 years rainfall data of Pantanagar and worked out distribution pattern of 5 days antecedent rainfall under monsoon, post monsoon and summer seasons. It was observed that antecedent rainfall condition II, occurred for the occasion, amounting to 10.96 percent of total data analyzed. Four probability distributions i.e., normal distribution, log normal distribution, Pearson type-I and log Pearson type-III distributions were compared for in predicting 5 days antecedent rainfall of the location and it was concluded that Pearson type-I distribution fitted well in all cases except for, antecedent rainfall condition - II of summer and post monsoon season.

Singh *et. al.* (1989) carried out probability analysis of the maximum one day rainfall of Khandong in Meghalaya and Umrangsu in Assam and estimated maximum one day rainfall for different return periods. It was observed that the probability of weekly normal rainfall equalling or exceeding the normal in any year is less during January to mid February, mid March to first week of April and October to December and the highest probability of normal rainfall occurrence was during May to September. Comparing the rainfall pattern and evaporation, it was observed that average rainfall during Kharif was 6.3 times the evaporative demand and during Rabi the evaporative demand exceeded 1.5 times amount of rainfall received.

Sharma and Bohra (1990) carried out probability analysis of 31 years rainfall at Bikaner and indicated that maximum two days rainfall for 1.01 to 5 years return period vary from 18 to 82 mm with 2 to 24 days as the corresponding length of dry spell which could be taken as design storms for rainwater harvesting projects, maximum 4 days rainfall of 10 years return period (108 mm) could be taken as the design storm for planning of soil and water conservation measures and that the probability of growing pasture and rainfed crops are 99 percent and 40 percent, respectively.

Tambile *et. at.* (1991) carried out frequency analysis of rainfall data of 45 years at Parabhani (Maharashtra) on weekly basis using Weibull's method and predicted rainfall

amounts at different probability levels. Considering the rainfall at 70 per cent probability, they observed that an appreciable amount of rainfall is available from 24 to 36 week and pointed out that dry sown crops may be sown during 24th week, first weeding and hoeing during 29th week and short duration crops have to be harvested during 40th and subsequent weeks. It was concluded that Rabi crops should not be taken unless there is irrigation facility.

Suresh and Thakur (1992) analyzed 25 years rainfall data of Pusa, Bihar statistically. Using Weibull's method of frequency analysis, and rainfall on weekly basis at 3 levels i.e. 10, 50 and 99 per cent probability was predicted. It was concluded that the sowing of paddy should be done, during 22th and 25th weeks in low lands and up lands, respectively.

Mishra (1992) analyzed 39 years daily rainfall data of Sehore and fitted two distributions i.e. extreme value and log probability for 1 to 7 days consecutive maximum rainfall. By testing the goodness of fit of the distributions, it was observed that, the log probability distribution has poor fit for all the seven cases, as compared to extreme value distribution.

Suresh and Thakur (1993) analysed 26 years rainfall data at Pusa, Bihar statistically and evaluated extreme events and their effects on statistical parameters for weekly, monthly and annual rainfall values. It was observed that the January and November months fall under extreme events and that the rainfall parameters for the two months being greatly affected by extreme events.

Dabral and Rao (1995) fitted gamma function for the weekly rainfall data (1956-89) of Mohurgong and Gulma Tea Estates, Gulma, Darjeeling (W.B.) and forecasted the weekly rainfall.

Bhatt *et al.* (1996) carried out the frequency analysis of one day maximum rainfall data of 24 years (1968-1991) of Datia. The observed values were estimated by Weibull's formula and expected values were estimated by extreme value Type - I, Log Normal and Log Pearson Type - III distributions. The values obtained by three different probability distribution functions were compared with the observed values. The analysis indicates that Log Pearson Type - III distribution gave the closest fit to the observed data.

Panigrahi (1998) used the rainfall data for 61 years (1935-1995) of monsoon period for coastal Orissa (Balasore, Chadbali, Cuttack, Bhubaneswar, Puri and Gopalpur) for probability analysis. Four models *viz.*, linear, semi-logarithmic, exponential and power form were used. It was observed that semi-logarithmic model holds good for all the pentads of all the stations.

Mishra *et al.* (1999) used long-term rainfall records of Kokrajhar, Dhubri (Assam) and Cooch-Bihar (W.B.) for stochastic rainfall forecasting for weekly water resource assessment in Lower Assam. A range of homogeneous probability distributions were fitted in meteorological weeks in active monsoon period using VTFIT-subroutine. The fitted distributions and parameters of distribution for all the three stations indicated that no single distribution could be successfully fitted to all weeks. However, Gamma distribution could be satisfactorily fitted to almost all the weeks with some exceptions.

Devendra Kumar *et al.* (2000) compared various probability distributions for analysis of rainfall data of Pantnagar. Rainfall data of 31 years (1960-1990) were used for the study. The monthly dry day data series was used to compare commonly used distributions and transformation for probability analysis. The observed values were computed by Weibull's formula at different probability levels. The expected values were estimated by Normal distribution with no transformation, Normal distribution with Log transformation, Normal distribution with Log-Log transformation, Normal distribution with Smemax transformation, Normal distribution with Power transformation, Gumbel distribution and Log Pearson Type II distribution. The comparison was made at 0.10, 0.20, 0.50, 0.80 and 0.95 probability levels. Kolmogorov-Smirnov (K-S) test and percentage deviation were used to find the goodness of fit of the distributions. The Normal distribution with Smemax transformation was found to be best fit for monthly dry days data series.

Anil Kumar (2000) used daily rainfall data from 1985 to 1997 to predict annual maximum daily rainfall of Ranichauri (Tehri Garhwal) based on probability analysis. It was found that Log normal distribution gave the best fit for the prediction of annual maximum rainfall values at Ranichauri.

Prasad *et al.* (2000) used 34 years rainfall data of Ranchi (Kanke) and forecasted the weekly rainfall by using Weibull's method as different distribution (Pearson Type III, Normal, Log-Normal, Exponential) did not fit for the rainfall data. Weekly forecasted rainfall was used for the planning of rainfed crops.

Rizvi *et al.* (2001) carried out the probability analysis of annual maximum daily rainfall for Bundelkhand region of Uttar Pradesh. They used different distributions. It was observed that Log Normal distribution is the best-fit distribution for predicting the maximum one-day rainfall of the region.

Singh (2001) forecasted annual maximum daily rainfall of Tadong(Sikkim) for different recurrence interval using Lognormal, Log Pearson type - III and Gumbel distribution functions. It was observed that annual maximum daily rainfall of Tadong could be predicted from regression model of Log normal distribution equation.

Gouranga Kar and Singh (2002) used thirty-one years rainfall data of Arnapurapur village of Dhenkanal district (Orissa) and forecasted monsoon and post monsoon month's rainfall at different probability levels. Normal, Lognormal, Log Pearson and Extreme value Type-I distribution functions for the analysis were used.

Ali *et al.* (2002) analyzed annual one day and 2 to 4 consecutive days maximum rainfall data of six stations in Eastern Ghats high land (EGHL) zone of Orissa state, Five probability distribution functions were tested by comparing the residual sum of squares. Two parameters lognormal distribution was found to be the best fit frequency distribution function for the region. From the study simple regression models for 1 day as well as 2 to 4 consecutive days maximum rainfall were developed from two parameter lognormal estimate.

Mishra *et al.* (2004) studied that  $f$  (TND), the transformed normal distribution can be used as a deterministic approach towards frequency analysis. It was observed that the behavior of rainfall extremes for different stations of Vindhya plateau of Madhya Pradesh can be well described by function of TND for the power  $Y$  less than 0.2. All the powers of  $Y$  can be used in describing the behavior of extremes when coefficient of variation ( $C_v$ ) of rainfall extremes is less than 0.39 such as for Damoh and Vidisha (except 6 days and 7 days extend). The rainfall amount estimated by the normal distribution so fitted to the power transformed data can be used in design of hydraulic structures for the area. It was observed that the Gumbel distribution representing greater departure from the observed rainfall from the weibull plotting position formula, was not suitable for the region. The weibull plotting formula gave good results when applied on the power transformed series associated with the least  $C_v$  since, probability function was linear in the entire range of variation due to reduction in  $X_i$ , the minima  $X_n$ , the maxima and hence  $R_n$ , the range of the variable the relationship between  $F_m$ , the plotting position and rainfall can be expressed by the linear model with correlation coefficient as high as -0.981.

Sethy *et al.* (2005) applied five commonly used probability distributions (viz. normal, log normal, extreme value type-I, pearson type III and log pearson type III) and tested by comparing the chi-square values. Two parameters log normal distribution was found to be the best fit frequency distribution function for the region. Simple regression models were developed for one day as well as 2 to 5 consecutive days annual maximum rainfall for the region. Their's U-statistic indicated that consecutive days annual maximum rainfall model estimate was not statistically different from two parameters lognormal estimate.

Karija *et al.* (2005) studied the time stochastic structure of daily precipitation in Japan and Myanmar using data for 30 years from 1962 to 1991. In this analysis, the daily precipitation data generation method, which consisted of two rainy seasons, was making it

possible to be used for Myanmar, which has one rainy season. It was expected that the data generation of daily precipitation for the dry season in Myanmar could be the same as Japan, because simulation of continuous dry days is more reasonable than the simulation of continuous rainy days for the dry season in Myanmar. On the other hand, simulation of continuous rainy days is more reasonable than the simulation of continuous dry days for the rainy season in Myanmar, in addition, the time independency of daily precipitation of the rainy season in Myanmar was found to be as large as that in Japan. Therefore, the effect of daily precipitation on the next days precipitation was confined to be small in both places.

### **2.3 Rainfall Probability by Markov Chain Process**

The concept of estimating probabilities with respect to a given amount, is extremely useful for agricultural planning. Fitzpatrick and Krishnan (1967) applied the first order Markov model to assess the rainfall continuity in Australia. For six stations in Australia, daily rainfalls were combined over a period of five days or pentads and were classified as wet and dry according to whether a total of at least 2.54 mm of rain had occurred; and used the model to find the rainfall for different probabilities.

Feyersherm and Bark (1967) conducted detailed investigation of short-term sequences of wet and dry days at Garden city, U.S.A. to study the adequacy of a first order Markov Chain model. They remarked that, the adequacy of first-order Markov Chain model for computing probabilities may not be satisfactory for longer sequences especially for prolonged dry spells, when a different set of meteorological forces may be operative and for case while computing probabilities for all possible sequences, in which length of sequences will be relatively short and that the first-order Markov chain appeared quite adequate.

Hershfield (1971) presented a procedure for estimating the wet-dry conditional probabilities and a method for generating estimates of conditional probability information for unconditional probability statistics. He considered four thresholds days with precipitation greater than or equal to 0.25, 2.5, 6.2 and 12.7 mm for ten years of daily rainfall data at U.S.A. for the study. A nomogram was developed as an aid in estimating conditional probabilities of wet sequences from the statistics, mean and annual number of precipitation days above a selected threshold. The results generated by this method were found to be quite reasonable and less time consuming.

May *et al.* (1982) used Markov model to study the rainfall probabilities for selected levels at Magarini, Kenya. Weekly probabilities for two stations were computed viz., Marafa and adu.

Viramani *et al.* (1982) used the Markov model to compute the rainfall probabilities greater than 5, 10 and 20 mm level for 77 rain gauge stations in semi arid regions of India.

They used the conditions (i) initial probabilities of wet week; (ii) conditional probability of wet week and (iii) the conditional probability of a wet week preceded by a dry week.

Agarwal *et al.* (1984) analysed 22 years rainfall data at Pantanagar using Markov chain model and estimated initial and conditional probabilities for each of the 52 standard weeks, which they used for planning different agricultural operations.

#### **2.4 Estimation of Weather Spells and Weather Cycles Using Markov Chain Model**

Successful crop planning, development of befitting agrotechniques, recommendation of suitable crop seed varieties, design of earthen dams and other soil conservation structures necessitate the probability analysis of occurrence of weather cycles, wet spells and dry spells.

Gabriel and Neuman (1957) have shown that a dry and wet spell follow geometric distribution. Again Gabriel and Neuman (1962) used Markov chain model to study the spell distribution and other properties of rainfall occurrence. The same procedure was adopted by Basu (1971) to study the daily rainfall at Calcutta, and by Bhargava *et al.* (1973) to study the occurrence of rainfall in Raipur district. Later, it was applied by Sundararaj and Ramachandra (1975) to study the weather spells and weather cycles at Hebbal, by Kulkarni *et al.* (1976) to study the distribution of rainfall at Parabhani, and by Victor and Sastri (1979) to study the dry spell probability at Delhi for different crop development stages. Manohar and Siddappa (1984) applied the same Markov chain based geometric model to the rainfall of monsoon month (June - October) at Raichur to study the wet and dry spells and weather cycles. They observed that the model seemed to fit better for wet spells than for dry spells.

Agnihotri (1993) studied the occurrences of wet and dry spells and weather cycles at Chandigarh using daily rainfall data (from 1958 to 1989) with the help of Markov chain model of order one (MC-I) and order two (MC-II). From Chi-Square tests it was observed that MC-I was significantly different than MC-II at 1 percent level of significance.

HariPriya Rath *et al.* (1996) forecasted dry wet spells for Boudh district of Orissa for agricultural management and planning.

Singh and Bhandari (1998) worked on wet and dry spells analysis using Markov Chain Model for mid Hill region of Himachal Pradesh.

Panigrahi and Panda (2002) used 30 years (1969-98) daily rainfall data of meteorological observatory of I.I.T, Kharagpur (W.B.) for predicting dry spell probability by using Markov Chain model. The forward and backward accumulation of weekly rainfall for predicting the period of onset and termination of monsoon also worked out respectively.

### III - MATERIAL AND METHODS

The present study has been undertaken to analyze the rainfall statistically and to fit Markov Chain models for prediction of rainfall characteristics under the climatic conditions of Southern Rajasthan viz. Udaipur, Kota and Bhilwara. This chapter deals with the theoretical considerations and statistical methods adopted to achieve the set objectives.

#### 3.1 GENERAL DESCRIPTION OF THE STUDY AREA

##### 3.1.1 Location

Udaipur is located at 24<sup>0</sup>N latitude and 75<sup>0</sup>42'E longitude at an elevation of 582 meter from mean sea level. Kota is located at 24<sup>0</sup>11'N latitude and 75<sup>0</sup>51'E longitude at an elevation of 256.9 meter from mean sea level and Bhilwara is located at 25<sup>0</sup>20'N latitude and 74<sup>0</sup>20'E longitude at an elevation of 432.6 meter from mean sea level, and are situated in Southern part of Rajasthan.

##### 3.1.2 Climate

Climatologically the area is subhumid and is characterized by the following four seasons (Viramani et al., 1982)

- (i) Pre-monsoon season (22-23 standard weeks)
- (ii) Monsoon season (24-39 standard weeks)
- (iii) Post-Monsoon season (40-41 standard weeks)
- (iv) Dry season (42-21 standard weeks)

##### (a) Rainfall

The average annual rainfall of the Udaipur is 625 mm and for Kota is 724 mm and for Bhilwara is 620 mm. The area gets most of its rain from South-West monsoon, spread over four months (June-September). Occasional showers are received in post-rainy season and dry season.

##### (b) Temperature

The period of March to June is one of continuous rise in temperature. May and first half of June being the hottest part of the year. The mean daily maximum temperature during this period ranges between 40<sup>0</sup>C to 41<sup>0</sup>C. Although the mean daily minimum temperature is slightly lower in December than in January, January is generally the coldest month with daily temperature around 24.2<sup>0</sup>C and mean daily minimum temperature being 9.3<sup>0</sup>C.

**(c) Humidity**

Except in the brief south-west monsoon season, when the relative humidity are generally about 70 percent or more, the air is very dry. The summer months are driest part of the year when the relative humidity goes down to 30 to 35 percent, particularly in the afternoon.

**(d) Cloudiness**

In the south-west monsoon season, specially in July and August, sky is often moderately to heavily clouded to overcast. During the rest of the year sky is generally clear or occasionally clouded. In winter season, which is generally marked by clear bright weather, brief spells of cloudy weather, occurs, in association with the passage of western disturbance.

**(e) Sunshine**

Sunshine hours during March to May are more than 10 to 11 hours/day while, during July to August they drop to 4 to 5 hours/day due to cloudy weather.

**(f) Wind**

Winds are generally light, with some strengthening in the later half of summer and the south-west monsoon season. In the period from May to September, winds blow from directions between south and west. In the post rainy season, the winds are predominantly from directions between north-east and north-west. By the beginning of summer, south-westerly and westerly winds begin to blow and they become predominant with the advance of season. Wind velocity is high during months of May to June (9 to 10 Km/hr) and low during December (3 to 3.5 Km/hr).

**(g) Special weather phenomenon**

During the south-west monsoon season, depressions which originate in the Bay of Bengal and move across in the westerly or north-westerly direction, reach the area and cause wide spread heavy rains and dusty wind. Dust storms and thunder storms sometimes accompanied with squalls occur in the hot months. Even during the monsoon season, rainfall is associated with thunder.

**3.2 COLLECTION AND COMPILATION OF DATA**

To analyze the rainfall, the daily rainfall records were taken from the Meteorological Observatory being maintained by the Department of SWE, CTAE Udaipur. The length of records considered for the study was from 1921-2004 and daily rainfall records from Kota were taken from the CSWRDI, Dadwara. The length of records was 35 years (1970-2004), and the daily rainfall records of Bhilwara were taken from the Zonal director research farm,

Arajia. To achieve the objectives the original rainfall records were compiled in to three categories.

- (i) Daily rainfall series for the months June to September.
- (ii) Weekly rainfall series for standard weeks 1 to 52, and
- (iii) Annual rainfall series.

### 3.3 STATISTICAL ANALYSIS OF RAINFALL

The statistical behavior of any hydrological series can be described on the basis of certain parameters. Generally mean, standard deviation, coefficient of variation and skewness coefficient are taken as measures of variability of any hydrologic series. All these parameters have been used to describe the variability of rainfall in the present study.

#### 3.3.1 Mean

Mean represents measures of central tendency. Arithmetic mean is given by

$$\bar{X} = \frac{1}{N} \sum_{i=1}^N X_i \quad \dots(3.1)$$

Where,

$\bar{X}$  = mean

$X_i$  = variate and

$N$  = total number of observations

#### 3.3.2 Standard Deviation

This parameter, as a measure of variability is most adaptable to statistical analysis. It is computed by

$$S = \sqrt{\frac{\sum_{i=1}^N (X_i - \bar{X})^2}{N - 1}} \quad \dots(3.2)$$

where,

$S$  = standard deviation

#### 3.3.3 Coefficient of Variation

This is a dimensionless dispersion parameter usually expressed as percent. It is given by

$$C_v = \frac{S}{\bar{X}} \quad \dots(3.3)$$

where,

$C_v$  = coefficient of variation

### 3.3.4 Skewness and Kurtosis

Normal arithmetic probability paper facilitates the use of a normal distribution, since a sample from a normal population theoretically should plot as a straight line. It may be said that a linear plot is the exception rather than the rule. If the non-linearity of the plot is due to chance, the skewness and kurtosis will be determined for each set of data and tested for significance for normal population (Matalas et al., 1963). The skewness is given by

$$C_s = \frac{N^2}{(N-1)(N-2)} \frac{M_3}{S^3} \quad \dots(3.4)$$

In order to test the kurtosis for significance, it is conventional to express it in a form, so that it equals zero for a normal population. The estimate of the kurtosis is given by

$$C_k = \frac{N^2(N+1)}{(N-1)(N-2)(N-3)} \frac{M_4}{S^4} - \frac{3(N-1)^2}{(N-2)(N-3)} \quad \dots(3.5)$$

Where,

$C_k$  = kurtosis and

$C_s$  = coefficient of skewness

$$M_3 = \frac{1}{N} \sum_{i=1}^N (X_i - \bar{X})^3 \text{ and} \quad \dots(3.5a)$$

$$M_4 = \frac{1}{N} \sum_{i=1}^N (X_i - \bar{X})^4 \quad \dots(3.5b)$$

## 3.4 PROBABILITY ANALYSIS OF RAINFALL

Total rainfall in a week particularly in the crop growing seasons is very important in planning many agricultural operations. Like-wise annual one day maximum rainfall is important in decision making while designing many hydraulic structures. In view of this, the probability analysis of following rainfall series was carried out.

As the rainfall at Udaipur occurs mainly during southwest monsoon, the probability analysis is carried out only for monsoon period (23-41 standard weeks). The observed total

rainfall during different weeks was analyzed using Weibull's plotting position formula. The Weibull's plotting position is given by

$$T = \frac{N + 1}{m} \quad \dots(3.6)$$

Where,

**T** = return period (years),

**m** = ranking number and

**N** = the number of values in the series (25- in the present study).

The steps followed in the analysis are as follows :

- a. Rainfall for each period of the record to be analyzed were tabulated in the descending order from largest to smallest.
- b. Rank number (m) was assigned to each value of the period (1—25 in the present study)
- c. Plotting position T was estimated using Equation (3.6).

Having estimated the plotting positions of observed rainfall, these were plotted on lognormal probability paper and line of best fit was drawn. Rainfall for given probability was read directly from the fitted curve.

### **3.4.1 Monthly Rainfall Series**

Mooley (1974) suggested that the two parameter gamma probability distribution is a good fit to monthly and seasonal rainfall over Asian summer monsoon area. Also he viewed that, the gamma distribution probability covers a wide range of skewness and kurtosis and can be applied to rainfall, to obtain the rainfall probabilities required by a variety of user interests. In view of this the two parameter gamma probability distribution was used to analyze rainfall during each of four-week period taking chronologically from standard weeks 1 to 52 in a year.

### **3.4.2 Annual One Day Maximum Rainfall Series**

The following probability distributions were employed to estimate the depth of rainfall at given probability levels, for annual one day maximum rainfall.

- (i) log-normal distribution.
- (ii) log-Pearson type-III distribution and
- (iii) Extreme value type-I (Gumbel) distribution.

### 3.4.3 Theoretical Consideration of Probability Distributions

The theory of different probability distributions, given under Sections 3.4.2. and 3.4.3. A computer Software Package VT-FIT which is available at the Computer Center of CTAE Udaipur was used to fit the probability distributions.

#### (i) Probability Distributions

One of the important problems in hydrology deals with interpreting a past record of rainfall events, in terms of future probabilities of occurrences. There are many probability distributions that have been found to be useful for hydrologic frequency analysis. These can be summarized as below.

##### (a) Normal distribution

This is a symmetrical, bell shaped, continuous distribution, theoretically representing the distribution of accidental errors about their mean, or the so called law of errors. The probability density function is expressed as

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-\mu)^2/2\sigma^2} \quad \dots(3.7)$$

Where,

$x$  = variable;

$\mu$  = mean value of variable ;and

$\sigma$  = the standard deviation.

In this distribution mean, mode and median are same. The total area under distribution is equal to unity.

##### (b) Gamma distribution

The probability density of this distribution is

$$p(x) = \frac{x^a e^{-x/b}}{b^{a+1} \Gamma(a+1)} \quad \dots(3.8)$$

Where,

$a, b$  = constants ;and

$\Gamma(a+1) = a!$  ; is a gamma function,

The statistical parameters are

Mean =  $b(a+1)$  and

Variance =  $b^2(a+1)$

**(c) Pearson distribution**

**(i) Type III distribution**

This is a skewed distribution with limited range in the left direction; usually bell shaped, but may be J- shaped. its probability density function with origin at the mode is given as

$$P(x) = P_0 \left(1 + \frac{x}{a}\right)^c e^{-cx/a} \quad \dots(3.9)$$

Where,

$$C = \frac{4}{\beta_1} - 1 \quad \dots(3.9a)$$

$$a = \frac{C \mu_3}{2 \mu_2} \quad \dots(3.9b)$$

$$P_0 = \frac{N}{a} \frac{C^{c+1}}{e^c \Gamma(C+1)} \quad \dots(3.9c)$$

The statistical parameters are

$$\text{Mean} = \text{mode} - \mu_3/2\mu_2$$

$$\text{Standard deviation} = \sqrt{\mu_2} \text{ and}$$

$$\text{Pearson skewness} = \sqrt{\beta_1}/2$$

**(d) Extremal Distributions**

**(i) Type I distributions**

This distribution results from any initial distribution of exponential type, which converts to an exponential function, as x increases. The examples of such initial distributions are normal, chi-square and log normal distributions. The probability density function of type I distribution is

$$P(x) = \frac{1}{C} e^{-(a+x)/c} e^{-e^{-(a+x)/c}} \quad \dots(3.10)$$

Where,

$$A = \gamma c - \mu$$

$$C = \sqrt{6/\pi} \times \sigma$$

$$\gamma = 0.57721 ; \text{ a Euler's constant}$$

$$\mu = \text{mean and}$$

$$\sigma = \text{standard deviation.}$$

The distribution results from an initial coefficient of skewness equal to  $C_s = 1.139$ .

**(e) Logarithmically transformed distribution**

**(i) Log normal distribution**

This is a transformed normal distribution in which the variable is replaced by its logarithmic value. Its probability density function is

$$P(X) = \frac{1}{\sigma_y e^y \sqrt{2\pi}} e^{-(y/\mu_y)^2 / 2\sigma_y^2} \quad \dots(3.11)$$

Where,

$Y = \ln x$ ;

$X =$  a variable;

$\mu_y =$  mean of  $y$  ;and

$\sigma_y =$  standard deviation of  $y$ .

This is a skewed distribution of unlimited range in both directions.

**(ii) Log extreme value distribution**

If the variable  $x$  in extreme value type I distribution is replaced by a linear function of the logarithm of  $x$  and  $x - \epsilon$ , the resulting logarithmically transformed distribution become log extremal type II and type III distributions respectively.

**(iii) Truncated log normal distribution**

Its probability density function is

$$P(x) = ae^{-c^2 (\ln(x+b))^2} \quad \dots(3.12)$$

The parameter  $a, b, c$  and  $d$  are determined empirically.

**(iv) Log Pearson type III distribution**

The probability density function of log Pearson type III distribution is given by

$$P(x) = \frac{1}{\alpha \sqrt{\beta}} \left( \frac{\ln x - \gamma}{\alpha} \right)^{\beta-1} e^{-(\ln x - \gamma)/\alpha} \quad \dots(3.13)$$

Where  $\alpha, \beta$  and  $\gamma$  are scale, shape and location parameters, respectively.

**3.4.4 Selection of Probability Distribution Function**

To extrapolate the data series for extreme event and to minimize the statistical errors that may occur from observed frequencies, the theoretical probability density function gives better estimates.

It becomes necessary to test the goodness of fit of a probability distribution for selection, to extrapolate a data series. The following goodness of fit tests were carried out to test the goodness of fit of the theoretical probability distributions employed in the present study.

**(a) Chi-square test**

Chi-square test is one of the tests to check the goodness of fit of probability distribution function with the observed one. The test statistic was calculated from the relationship

$$\chi^2 = \sum_{i=1}^k (\mathbf{O}_i - \mathbf{E}_i)^2 / \mathbf{E}_i \quad \dots(3.14)$$

Where,

K = no. of class interval; and

$\mathbf{O}_i, \mathbf{E}_i$  = the observed and expected number of observations in the i class interval respectively.

**(b) Variance ratio test**

Mooley (1974) suggested the variance ratio test to test the goodness of fit of Gamma probability distribution. This has been employed to test the goodness of fit of the Gamma probability distribution under study. The test statistic is given by

$$\mathbf{X}_y^2 = \frac{\sum_{i=1}^n (\mathbf{X}_i - \bar{\mathbf{X}})^2}{\hat{\beta}^2 \hat{\gamma}} \quad \dots(3.15)$$

Where,

N = the number of occasions of non-zero rainfall

$\bar{\mathbf{X}}$  = arithmetic mean of non-zero rainfall amounts and

$\hat{\beta}, \hat{\gamma}$  = the maximum likelihood estimates of  $\beta$  and  $\gamma$  respectively.

**(c) Graphical method**

Often, to compare and test the goodness of fit of different probability distributions along with other tests, graphical method is employed. Graphical method gives visually the better fit of different probability distributions. The Weibull's plotting formula was selected to fit graphically the probability distributions. Chow (1954) has shown that this formula is theoretically suitable for plotting the annual maximum series.

**3.4.5 Frequency analysis using frequency factors.**

Chow (1951) has shown that many frequency analyses can be reduced to the form

$$\mathbf{X}_T = \bar{x} (1 + \mathbf{Cv} \mathbf{K}_T) \quad \dots (3.16)$$

Where,

Cv=coefficient of variation

$K_T$ = frequency factor

$X_T$ = is the magnitude of the event having a return period T

$\bar{x}$  = Mean value of X

For Normal and Lognormal distribution, the frequency factor can be expressed by following equation:

$$K_T = (x_T - \bar{x}) / \sigma \quad \dots (3.17)$$

Where,

$K_T$ = Frequency factor

$\bar{x}$  = mean of the sample

$\sigma$  = standard deviation of sample

$x_T$  = magnitude of hydrological event

This is the same as the standard normal variable z. The value of z corresponding to probability of exceedence p ( $p=1/T$ ) can be calculated by finding the value of an intermediate variable w:

$$w = [ \ln(1/p^2) ]^{1/2} \quad (0 < p \leq 0.5) \quad \dots (3.18)$$

Then calculating z using the approximation

$$z = w - ( 2.515517 + 0.802853w + 0.010328 w^2 ) / ( 1 + 1.432788w + 0.189269w^2 + 0.001308 w^3 ) \quad \dots (3.19)$$

When  $p > 0.5$ ,  $1-p$  is substituted for p in (equation 3.18) and the value of z computed by (Equation 3.19) is given a negative sign.

### 3.4.6 Adequacy of length of record

The adequacy of the length of record for a given level of significance is given by Mockus (1960) as

$$Y = (4.30t \cdot \log R)^2 + 6 \quad \dots (3.20)$$

Where,

Y = minimum acceptable years of record,

t = Student's statistical value at the 90 per cent level of significance with (Y-6) degree of freedom,

R = ratio of magnitude of the 100-year event to the 2-year event.

### 3.5 MOISTURE AVAILABILITY INDEX (MAI)

In order to assess the suitability of the study area for dry land cropping, MAI was calculated. Virmani et al. (1982) suggested that, for dry land cropping, MAI should be greater than or equal to 0.34. MAI, given by them was used for the estimation.

$$\text{MAI} = \frac{\text{DP}}{\text{PE}} \quad \dots(3.21)$$

Where,

DP = dependable precipitation (mm) calculated at 75 percent probability

PE = potential evapotranspiration (mm)

MAI was computed for each of the 4-standard weeks, using the dependable precipitation calculated as explained in section 3.4.2 and weekly PE values as estimated by Shirahatti (1994).

### 3.6 RAINFALL PROBABILITIES BY MARKOV CHAIN PROCESS

The concept of estimating probabilities with respect to a given amount of rainfall is extremely useful for agricultural planning. In a crop growing season, many times decisions have to be taken based on the probability of receiving certain amount of rainfall during a given week [P(W)], which are called “initial probabilities”. Then the probability of rain next week, if we had rain this week [P(W/W)] ; and the probability of next week being wet, if this week is dry [P(W/D)] are very important and are called “Conditional probabilities”. Analogously, initial and conditional probabilities for a dry week will be defined. These initial and conditional probability approaches would help in determining the relative chance of receiving a given amount of rainfall. This becomes the basis for the analysis of rainfall using Markov chain process.

The parameters estimated for the analysis were as follows.

- a. initial probability of a week being wet, [P(W)]
- b. Conditional probability of a wet week preceded by a wet week, [P(W/W)] and
- c. Conditional probability of a wet week preceded by a dry week, [P(W/D)]

The following formulae were employed for calculation, considering two phenomena,

- a. dry conditions  $D_i$  at the  $i$ th period and
- b. Wet condition  $W_j$  at the  $j$ th period.

The probabilities can be defined as follows.

$$P(W_j) = \frac{N(W_j)}{N} \quad \dots(3.22)$$

Where,

$N(W_j)$  = no. of occurrences of W in jth period,

$N(D_j)$  = no. of occurrences of D in jth period and

$N = N(W_j) + N(D_j)$

Similarly,

$$P(D_i) = \frac{N(D_i)}{N} \quad \dots(3.23)$$

Also knowing the probability of ith dry period, given jth wet period i.e.  $P(D_i/W_j)$ , the change in the probability of  $W_j$  given the additional information that  $D_i$  has actually occurred can be written as

$$P(W_j, D_i) = \frac{P(W_j)P(D_i/W_j)}{P(D_i)} \quad \dots(3.24)$$

Further knowing the joint probability distribution of  $P(W_j, D_i)$  the conditional probability  $P(W_j/D_i)$  can be written as

$$P(W_j/D_i) = \frac{P(W_j, D_i)}{P(D_i)} \quad \dots(3.25)$$

Using the above relationships the initial and conditional probabilities of rainfall were calculated during each week (standard weeks 1-52) for three levels of weekly rainfall viz., 5mm, 10mm and 20mm. A computer programme written in Fortran IV was used for the analysis. The computer programme is given in Appendix-A.

### **3.7 ANALYSIS OF WEATHER SPELLS AND WEATHER CYCLES BY MARKOV CHAIN MODEL**

The same daily rainfall data for the monsoon season June to September collected at CTAE Udaipur, used in the previous chapters was employed in this section also. The following definitions have been employed in this section.

- a. A day receiving at least 2.5 mm or more rainfall from 0830 to 0830 IST the next day, is defined as a wet day. Otherwise the day is counted as a dry day (Agarwal et al., 1984).

- b. A wet spell (or a dry spell) is included in a month if any day of this particular spell falls within that month, no matter whether the spell ends or does not end in the month.
- c. In case of weather cycles, the whole length of the cycle which overlaps two successive months is assigned to that month which shares more than half of its length. In case of equality it is arbitrarily assigned to the previous month.

The above definitions give a sequence of wet and dry days which can be regarded as a two-state Markov chain with wet and dry days as the two states. Each day of this sequence is classified as one of the following probabilities:

- (i) a dry day preceded by a dry day (D/D)
- (ii) a dry day preceded by a wet day (D/W)
- (iii) a wet day preceded by a dry day (W/D)
- (iv) a wet day preceded by a wet day (W/W).

A wet spell of length  $W$  days is defined as, a sequence of  $W$  wet days followed and preceded by dry days and a dry spell of length  $D$  days, as a sequence of  $D$  dry days followed and preceded by wet days. An occurrence of a wet spell and an adjacent dry spell (or vice-versa) together constitute a weather cycle and their total length defines the length of the weather cycle itself.

The daily rainfall data covering from 31 May to 30 September was classified into a chain of dry (or wet) days, if the amount of rainfall during a day is less than equal to or greater than 2.5 mm respectively. From this sequence, four possible transitional (conditional) probabilities can be obtained from the following classifications:

- (i) dry day preceded by a dry day,  $\pi(D/D) = a/n_1$
- (ii) dry day preceded by a wet day,  $\pi(D/W) = b/n_1$
- (iii) wet day preceded by a dry day,  $\pi(W/D) = c/n_1$
- (iv) wet day preceded by a wet day,  $\pi(W/W) = d/n_1$

Where,

$n_1 = a+b$  = the total number of dry days, and

$n_2 = c+d$  = the total number of wet days.

Hence the transitional probability matrix  $P$  which describes the two-state Markovian model is :

$$\mathbf{P} = \begin{bmatrix} \pi(\mathbf{D}/\mathbf{D}) & \pi(\mathbf{W}/\mathbf{D}) \\ \pi(\mathbf{D}/\mathbf{W}) & \pi(\mathbf{W}/\mathbf{W}) \end{bmatrix} \quad \dots(3.26)$$

The probabilities of obtaining the three events viz., a wet spell of length W days, a dry spell of length D days and a weather cycle of length n days could be obtained from the four transitional probabilities using the following probability generating expressions (Manohar,1983):

$$p(\mathbf{x} = \mathbf{W}) = [\pi(\mathbf{W}/\mathbf{W})]^{w-1} \times [1 - \pi(\mathbf{W}/\mathbf{W})] \quad \dots(3.27)$$

$$p(\mathbf{y} = \mathbf{D}) = [\pi(\mathbf{D}/\mathbf{D})]^{d-1} \times [1 - \pi(\mathbf{D}/\mathbf{D})] \quad \dots(3.28)$$

$$p(\mathbf{z} = \mathbf{n}) = [\pi(\mathbf{D}/\mathbf{W})] \times [\pi(\mathbf{W}/\mathbf{D})] \times \frac{[\pi(\mathbf{W}/\mathbf{W})]^{n-1} - [\pi(\mathbf{D}/\mathbf{D})]^n}{[\pi(\mathbf{W}/\mathbf{W})] - [\pi(\mathbf{D}/\mathbf{D})]} \quad \dots(3.29)$$

where,

$P(\mathbf{x} = \mathbf{W})$  = probability of a wet spell of length W days;

$P(\mathbf{y} = \mathbf{D})$  = probability of a dry spell of length D days; and

$P(\mathbf{z} = \mathbf{n})$  = probability of a weather cycle of length n days.

By employing these probabilities (Eq. 3.27 to Eq. 3.29 ) one can generate the expected relative frequencies for the lengths of wet spells, dry spells and weather cycles respectively and which when multiplied by the appropriate sample sizes will result in the expected frequencies for the lengths of wet and dry spells and weather cycles.

The P matrix (Eq. 3.26) enables to estimate the equilibrium or steady state probabilities  $\pi_1$  and  $\pi_2$  corresponding to dry and wet days respectively and are given by

$$\pi_1 = \frac{1 - \pi(\mathbf{W}/\mathbf{W})}{1 - \pi(\mathbf{W}/\mathbf{W}) + \pi(\mathbf{W}/\mathbf{D})} \quad \dots(3.30a)$$

$$\pi_2 = \frac{\pi(\mathbf{W}/\mathbf{D})}{1 - \pi(\mathbf{W}/\mathbf{W}) + \pi(\mathbf{W}/\mathbf{D})} \quad \dots(3.30b)$$

Which gives the expected number of dry (wet) days as;

$$\text{expected number of dry days} = n\pi_1$$

$$\text{expected number of wet days} = n\pi_2$$

Where n is the number of days constituting the month (30 or 31).

Another important result derived from the model is the days to equilibrium, giving the time required by the system (i.e., rainy month under consideration) to attain its original state

before the disturbance by rains i.e., dry. The number of days after which the state of equilibrium is achieved, is equal to, the number of times the P matrix is powered till the elements of the column of a powered matrix become equal.

It is further possible to predict in advance, the priori probabilities of a rainy day (or a dry day) K days after a rainy day ( or a dry day ). These probabilities are given by the following expressions (Manohar, 1983).

$$\pi_k(W/W) = \frac{[1 - \pi(W/W)] \times [\pi(W/W) + \pi(D/D) - 1]^k}{1 - \pi(W/W) - \pi(D/D)} + \frac{1 - \pi(D/D)}{2 - \pi(W/W) - \pi(D/D)} \quad \dots(3.31)$$

$$\pi_k(D/D) = \frac{[1 - \pi(D/D)] \times [\pi(D/D) + \pi(W/W) - 1]^k}{1 - \pi(D/D) - \pi(W/W)} + \frac{1 - \pi(W/W)}{2 - \pi(D/D) - \pi(W/W)} \quad \dots(3.32)$$

$$\pi_k(D/W) = 1 - \pi_k(W/W) \quad \dots (3.33)$$

$$\pi_k(W/D) = 1 - \pi_k(D/D) \quad \dots(3.34)$$

Where,

$\pi_k(W/W)$  = the conditional probability that a day, K days after wet days, would be a rainy day,

$\pi_k(D/D)$  = the conditional probability that a day, K days after dry days, would be a dry day,

$\pi_k(W/D)$  = the conditional probability that a day, K days after wet days would be a dry day and

$\pi_k(D/W)$  = the conditional probability that a day K days after dry days, would be a wet day.

The other properties of Markov chain probability model describing the number of length of wet and dry spells have also been calculated. The expected length of wet run is given by:

$$E(W) = \frac{1}{1 - \pi(W/W)} \quad \dots(3.35)$$

Similarly the expected length of a dry run is given by

$$E(D) = \frac{1}{1 - \pi(W/D)} \quad \dots(3.36)$$

The expected length of a weather cycle is obtained by:

$$\mathbf{E(C) = E(W) + E(D) = \frac{1}{1 - \pi(W/W)} + \frac{1}{1 - \pi(W/D)}} \quad \dots(3.37)$$

For larger n, the distribution of the number of wet days ( $X_n$ ) tends to normalcy with mean and variance given by:

$$\mathbf{E(X_n) = \frac{n\pi\pi(W/D)}{1 - \pi(W/W) + \pi(W/D)}} \quad \dots(3.38)$$

$$\mathbf{V(X_n) = \frac{n\pi(W/D)[1 - \pi(W/W)] \times [1 + \pi(W/W) - \pi(W/D)]}{[1 - \pi(W/W) + \pi(W/D)]^3}} \quad \dots(3.39)$$

Also the probability of a wet day (or a dry day) were estimated directly from the observed frequency distribution for wet (or dry) spells viz., the assumption of geometric distribution. If U has a geometric distribution namely:

$$\mathbf{P(U = K) = P^{k-1}(1 - P) \quad , \quad k=1,2,3,\dots} \quad \dots(3.40a)$$

Then

$$\mathbf{E(U) = \frac{1}{1 - P}} \quad ;$$

$$\mathbf{var(U) = \frac{P}{(1 - P)^2}} \quad \dots(3.40b)$$

Then for wet spells, p is the probability of a wet day and for dry spells, the same represents the probability of a dry day. The maximum likelihood estimates of these probabilities were obtained from the reciprocal values of the sample means of the respective observed frequency distribution.

## IV - RESULTS AND DISCUSSIONS

Crop production under dry land agriculture is largely determined by the climatic features. Water being a scarce resource under dry land agriculture it is almost important to use every drop of water judiciously, to optimize crop production. Rainfall being the only source of water under such conditions, a more complete and quantitative understanding of the time and spatial variation of this natural resource, provides a lot more insight for proper planning with respect to agriculture.

The present study has been carried out, under conditions of southern Rajasthan namely Udaipur, Kota and Bhilwara and a crop planning has been suggested. Markov chain model have been used to predict weather spells and weather cycles. The results have been discussed to cover the following aspects:

- Statistical behaviour of rainfall.
- Probability distribution of rainfall.
- Assessment of water availability.
- Probability of rainfall by Markov chain process.
- Prediction of weather spells and weather cycles.

### 4.1 STATISTICAL BEHAVIOR OF RAINFALL

To analyze the statistical behaviour of rainfall series, the rainfall series viz. daily, weekly, monthly and annual rainfall were considered. Further the deviation of rainfall series was confined only for period June to September.

The analysis of statistical behaviour of rainfall series was achieved by computing the parameters like mean, standard deviation, coefficient of variation, skewness and kurtosis. These parameters were estimated by using the equations/ relationships described under Section 3.3.

#### 4.1.1 Analysis of Daily Rainfall Series

Since more than 80 percent of the rainfall is received during the months June to September at the study area, the selected statistical parameters were estimated for this duration at three stations considered in this study. Estimated parameters of daily rainfall from June to September are given in Tables 4.1 to 4.12.

From Table 4.1 it may be seen that the daily mean rainfall varies from 0.3 to 7.4mm and daily maximum rainfall varies from 9.3 to 262.2mm with the monthly mean rainfall of 79.2mm. The coefficient of variation ranges from 206 to 715.5 per cent and this wide range indicates the uncertainty of rainfall in month of June is very high. The standard deviation

ranges from 1.2 to 31.1mm and this wide range indicate amount of rainfall received in June month is unevenly distributed and unexpected. Coefficient of skewness ranges from 2.6 to 7.1 therefore the value of rainfall is positively skewed from the normality. The value of coefficient of kurtosis ranges from 6.2 to 80.4, its wide and higher value indicates the sharpness of kurtosis curve and rainfall in the month of June at Udaipur is very erratic.

From Table 4.2 for the month of July at Udaipur it may be seen that the value of daily mean rainfall ranges from 2.5 to 10.1mm and the daily maximum rainfall varies from 34.2 to 258.2mm with the monthly mean rainfall of 193.1mm. The coefficient of variation ranges from 155.9 to 290.1 per cent and this difference is not more then the previous month so it shows that in the month of July rainfall at Udaipur is more consistent then other months. The standard deviation ranges from 6.2 to 24.7mm and its variability shows that the rainfall distribution over the month of July is more even then previous month and the amount of rainfall received in the month of July is more then June. The coefficient of skewness ranges from 1.4 to 4.9 which shows the value of rainfall is positively skewed from the normal rainfall. The coefficient of kurtosis ranges from 0.9 to 29.4, and it shows the sharpness of kurtosis curve and the sharpness is less then the month of June and it indicates the rainfall at Udaipur in the month of July is not much erratic like June.

From Table 4.3 it may be seen that the value of daily mean rainfall ranges from 3.3 to 10.3 mm and daily maximum rainfall varies from 37.8 to 265.1 mm with the monthly mean rainfall of 189.98 mm. the standard deviation ranges from 7.4 to 26.3 mm and coefficient of variation ranges from 163.7 to 310.3 mm. these ranges shows that the amount of rainfall received at Udaipur is not much consistent in the month of August like in July and the distribution of rainfall over this month is also uneven then previous month but less then the June. The coefficient of skewness is ranges from 2.2 to 6.3 therefore the value of rainfall positively skewed and the rainfall received in month of August is approximately equal or more than normal. The coefficient of kurtosis ranges from 5.9 to 48 and it represents the shape of kurtosis curve and the sharpness in August is more then July and less then June so that the rainfall received in August is more erratic in August.

At Udaipur from Table 4.4 for the month of September it may be seen that the daily mean rainfall ranges from 0.8 to 6.9 mm with the monthly mean rainfall of 107.04 mm and daily maximum rainfall ranges from 19 to 183.9 mm with the monthly maximum rainfall of 418.34 mm. the value of standard deviation ranges from 3.2 to 21.7 mm with the coefficient of variation 210.5 to 442.7 per cent, the wide range of standard deviation and coefficient of variation indicates the distribution of rainfall and the amount of rainfall received in September are not evenly

**Table 4.1: Daily rainfall statistics of June for Udaipur**

Date	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
1	0.3	9.3	1.2	6.2	43.8
2	1.9	49.2	7.9	4.8	23.4
3	0.8	23.9	3.2	5.7	36.9
4	0.8	51.7	5.7	8.9	80.4
5	0.4	10.6	1.6	5.0	26.0
6	0.9	38.1	4.6	7.1	55.1
7	1.5	60.5	7.7	6.6	46.1
8	1.3	29.7	5.2	4.5	20.5
9	2.5	61.2	10.1	5.0	25.7
10	2.9	60.2	9.3	4.2	19.5
11	1.2	31.8	4.1	5.7	39.1
12	2.5	36.6	7.5	3.3	10.9
13	2.8	46.2	8.7	3.9	15.3
14	2.7	60.5	9.1	4.7	24.2
15	1.9	36.8	5.9	4.0	17.3
16	3.4	46.0	8.3	3.2	10.9
17	2.6	80.8	10.3	6.0	41.7
18	1.1	29.2	4.2	4.8	26.2
19	2.3	48.3	7.6	4.4	21.1
20	2.6	37.8	7.4	3.7	14.1
21	2.5	91.2	11.4	6.4	46.7
22	3.9	64.8	10.3	3.7	16.2
23	3.6	51.4	8.7	3.3	12.8
24	2.8	31.8	6.9	2.9	8.0
25	3.9	40.6	9.3	2.6	6.2
26	3.1	52.4	8.0	3.8	18.2
27	6.1	63.0	12.6	3.0	9.8
28	4.4	48.4	9.9	2.9	8.6
29	5.4	64.8	11.7	3.1	11.2
30	7.4	262.2	31.1	7.1	56.3

**Table 4.2: Daily rainfall statistics of July for Udaipur**

Date	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
1	2.5	35.6	6.2	3.2	11.2
2	3.4	46.0	9.3	3.2	9.7
3	5.6	75.4	12.9	3.6	15.4
4	5.9	65.5	12.7	3.1	10.7
5	5.9	80.0	13.3	3.2	12.2
6	8.0	95.0	17.3	3.5	14.4
7	4.3	57.6	9.7	3.5	13.9
8	6.5	58.2	14.3	2.3	4.3
9	4.8	34.3	8.9	2.1	3.4
10	5.2	54.2	12.5	2.7	6.7
11	9.1	125.0	20.2	3.6	15.3
12	7.2	105.4	16.0	3.7	17.7
13	6.6	63.5	13.5	2.4	5.5
14	6.9	90.7	14.4	3.3	13.9
15	5.9	65.2	11.4	3.0	10.4
16	7.5	70.2	15.7	2.6	6.6
17	6.1	46.5	11.5	2.2	4.0
18	6.1	56.7	11.9	2.6	7.3
19	5.9	75.6	12.8	3.2	11.7
20	4.8	41.1	9.3	2.1	3.8
21	5.4	72.1	13.8	3.4	12.0
22	4.5	50.8	9.6	3.2	11.1
23	5.1	54.1	10.5	2.7	7.6
24	6.5	66.4	14.3	2.7	7.0
25	4.6	96.5	13.2	4.9	29.4
26	5.5	67.8	11.7	3.0	10.2
27	10.1	56.9	15.7	1.4	0.9
28	10.1	158.2	24.7	4.3	21.5
29	6.5	105.9	16.1	4.1	19.7
30	8.5	91.9	19.1	2.9	8.4
31	8.1	100.8	19.0	3.3	11.6

**Table 4.3: Daily rainfall statistics of August for Udaipur**

Date	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
1	6.7	104.1	17.1	4.2	20.2
2	4.3	99.7	12.8	5.6	38.4
3	4.0	48.0	8.7	3.1	11.0
4	5.8	56.6	11.6	2.5	6.0
5	7.2	89.7	15.1	3.2	11.9
6	7.5	86.4	15.3	2.9	9.8
7	4.8	64.3	9.8	3.6	16.8
8	4.7	45.2	9.1	2.5	6.7
9	5.2	72.4	11.9	3.6	14.8
10	6.0	62.2	11.9	2.7	7.9
11	9.5	119.6	23.7	3.6	13.2
12	8.5	115.6	19.7	3.5	14.1
13	6.6	165.9	20.3	6.2	46.1
14	4.7	71.2	13.0	3.8	14.7
15	6.8	98.8	15.1	3.6	16.6
16	3.3	40.4	7.9	3.1	9.6
17	8.0	93.6	16.9	3.1	10.8
18	4.4	46.2	9.4	3.1	10.3
19	4.3	55.6	10.0	3.4	12.6
20	6.7	82.2	14.3	3.0	10.1
21	7.7	93.6	17.4	3.1	10.0
22	6.0	98.8	16.0	3.9	17.5
23	6.8	77.5	16.1	2.9	8.6
24	8.2	105.7	19.9	3.2	10.5
25	6.4	69.8	11.8	2.8	10.4
26	5.7	72.6	14.0	3.3	11.6
27	4.5	37.8	7.4	2.2	5.9
28	10.3	165.1	26.3	4.2	19.9
29	4.9	63.8	11.0	3.1	11.0
30	5.0	103.1	13.9	5.0	30.5
31	5.8	135.1	16.3	6.3	48.0

**Table 4.4: Daily rainfall statistics of September for Udaipur**

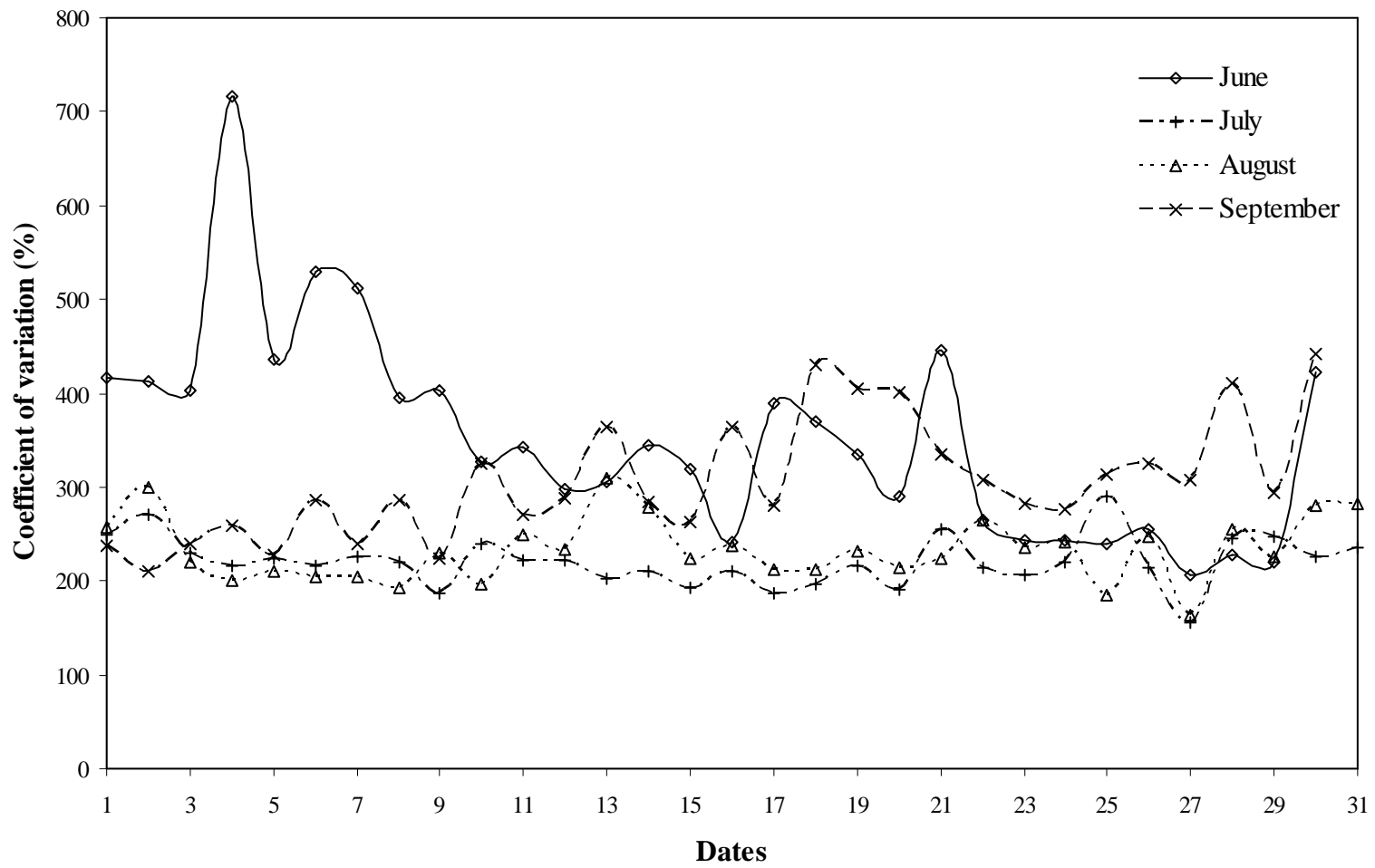
Date	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
1	6.9	86.4	16.3	3.1	10.0
2	6.5	63.0	13.7	2.6	6.4
3	3.7	47.5	8.7	3.3	11.4
4	5.5	81.2	14.3	4.1	18.2
5	3.5	45.6	8.1	3.2	11.6
6	5.3	122.2	15.2	5.8	42.3
7	5.6	65.0	13.4	3.1	9.5
8	6.8	138.4	19.4	4.7	26.5
9	3.3	34.2	7.5	2.5	5.7
10	5.5	145.0	17.7	6.3	47.0
11	2.8	46.0	7.7	3.7	15.0
12	3.6	60.3	10.4	3.5	13.4
13	2.6	80.3	9.5	6.9	54.5
14	1.6	29.0	4.6	4.2	19.1
15	2.0	30.7	5.2	3.8	15.6
16	1.5	41.9	5.5	5.8	37.9
17	3.2	54.0	9.0	3.6	14.3
18	5.0	183.9	21.7	7.2	57.6
19	3.7	114.6	15.1	5.9	38.0
20	2.7	82.6	10.9	6.1	40.2
21	1.5	34.2	4.9	4.8	26.6
22	3.1	67.0	9.5	4.7	26.7
23	2.8	50.6	7.9	4.6	23.2
24	4.3	87.4	11.9	4.8	29.3
25	4.5	95.3	14.0	4.9	26.7
26	2.0	45.7	6.5	4.9	27.5
27	2.0	33.5	6.1	3.8	15.0
28	0.8	19.0	3.2	5.0	25.5
29	2.0	29.2	6.0	3.1	9.0
30	2.6	92.0	11.4	6.4	46.7

distributed over the entire month and the uncertainty of rainfall occurrence in September is very high. The value of coefficient of skewness ranges from 2.5 to 7.2 and the coefficient of kurtosis varies from 6.4 to 57.6 therefore the value of rainfall in September is positively skewed from the normal rainfall and the shape of the kurtosis curve is sharper than the July and August and approaches equal to June. So, it may be concluded that the climate of Udaipur is unstable at the onset and termination of the monsoon.

From the study of Fig. 4.1 for Udaipur it may be seen that the coefficient of variation in June month ranges from 206 to 715.5 per cent with the monthly value of 75.84 per cent and in July it ranges from 155.9 to 290.1 per cent with the monthly variation of 53.89 per cent. Whereas in the case of August variation in rainfall ranges from 163.7 to 310.3 per cent with a monthly variation of 65.33 per cent and in September it ranges from 210.5 to 442.7 per cent with monthly value of 92.17 per cent. From these monthly curves in Fig. 4.1 it may be seen that in case of June and September the range of Coefficient of variation almost same and in the case of July and August the range of coefficient of variation approximately same and follows the similar trend. Therefore it may be concluded that the variation in rainfall at onset and withdrawal of monsoon is same. From the Fig. 4.1, interesting trend is observed that the variation in rainfall in July and August remains same but in case of June variation in rainfall decreases from starting to end of the month and in case of September it increases from starting to end of the month. Therefore it may be said that the onset and withdrawal of monsoon follows the same trend in Udaipur.

From Table 4.5 it may be seen that the daily mean rainfall varies from 0.05 to 8.49 mm with monthly mean of 70.1 mm and daily maximum rainfall ranges from 1-124 mm with monthly maximum rainfall of 219.8 mm. standard deviation ranges from 0.21 to 20.93 mm and the coefficient of variation ranges from 201.62 to 591.61 per cent with monthly variation of 99.59 per cent. Due to this wide range it may be concluded that distribution of rainfall in month of June is unevenly distributed and the amount of rainfall is uncertain at Kota. The value of coefficient of skewness ranges from 1.73 to 5.99 and the coefficient of kurtosis ranges from 1.24 to 35.0, so it indicates that the amount of rainfall received is positively skewed and the shape of kurtosis curve is sharpest in June for monsoon season at Kota. Therefore it may be concluded that at Kota in the month of June the rainfall is much erratic uncertain and also unevenly distributed over entire month.

Whereas in the month of July it may be seen from Table 4.6 at Kota the daily mean rainfall ranges from 1.71 to 20.56 mm with monthly mean rainfall of 254.7 mm and daily maximum rainfall ranges from 20.40 to 252.00 with the monthly maximum rainfall of 665.5 mm.



**Fig 4.1: Coefficient of Variation ( $C_v$ ) of daily rainfall for monsoon season at Udaipur**

The standard deviation of July ranges from 4.33 to 43.78 mm and coefficient of variation ranges from 137.82 to 345.43.78 per cent with the monthly value of 61.43 per cent. It indicates that the amount of rainfall which received in July month at Kota is very much uncertain and also the variability of occurrence of rainfall in the month of July is very high but the fraction of rainfall amount received is higher than the month of June. The coefficient of skewness varies from 1.4 to 5.36 and coefficient of kurtosis ranges from 1.07 to 29.67 which shows the value of rainfall is positively skewed from normality and the shape of kurtosis curve is sharp but less than the previous month. Therefore it may be concluded from the Table 4.6, however rainfall received at Kota in month of July is erratic, uncertain and unevenly distributed but more consistent than the month of June.

From Table 4.7 it may be seen that daily mean rainfall varies from 2.39 to 17.16 mm with the monthly mean rainfall of 247 mm and the daily maximum rainfall ranges from 21.20 to 167.40 mm with the monthly rainfall of 410.1 mm. Standard deviation for the month of August at Kota ranges from 4.73 to 40.51 mm and coefficient of variation varies from 127.46 to 287.32 per cent with monthly value of 38.93 per cent. It indicates that the rainfall received in month of August at Kota is more consistent and evenly distributed than June and July and the variation in amount is also lowest in August. Coefficient of skewness varies from 1.02 to 5.16 and coefficient of kurtosis ranges from -0.50 to 28.03. Therefore it may be said that the value of rainfall is positively skewed and the shape of kurtosis curve is similar to July but the peak value is slightly differs from the month of July. So it may be concluded by this Table that the rainfall received in August at Kota is evenly distributed over the entire month, consistent and have similar trend as in July.

From table 4.8 it may be seen that daily mean rainfall varies from 0.11 to 14.07 mm monthly mean rainfall of 85.4 mm and daily maximum rainfall ranges from 2 to 167.9 mm with the monthly value of 412.9 mm. standards deviation ranges from the 0.47 to 36.33 mm and coefficient of variation ranges from 167.93 to 591.61 per cent, so it means that the rainfall in the month of September is consistent and distributed evenly in starting but in the ending of September it doesn't remains consistent. Coefficient of Skewness varies from 1.68 to 5.99 and coefficient of kurtosis ranges from 1.48 to 35.00. It indicates that value of rainfall positively skewed and the shape of kurtosis curve become sharper again just like in June. Therefore it may be concluded from Table 4.5 to 4.8 for Kota that the rainfall received at this region have similar trend in month of June and September for onset and withdrawal of monsoon and in July and august receives the same and consistent amount of rainfall with similar trend. Also it may be

**Table 4.5: Daily rainfall statistics of June for Kota**

Date	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
1	1.7	39.9	6.90	5.39	29.69
2	0.2	7.8	1.32	5.99	35.00
3	1.1	23.4	4.59	4.38	18.70
4	0.0	1.0	0.21	4.13	15.76
5	0.4	16.5	2.79	5.99	34.99
6	0.8	17.2	3.38	4.25	17.95
7	1.4	14.0	3.99	2.64	5.27
8	2.0	24.8	6.24	3.25	9.27
9	2.1	22.2	5.04	2.75	7.48
10	0.9	22.6	3.96	5.23	28.14
11	1.2	13.5	3.53	2.93	7.19
12	1.4	24.3	5.68	4.02	14.62
13	2.3	16.0	4.79	2.03	2.76
14	1.3	33.5	5.86	5.31	28.78
15	1.0	13.2	3.20	3.12	8.77
16	0.2	4.0	0.76	4.15	18.50
17	3.2	19.8	6.47	1.73	1.24
18	3.9	63.4	13.28	3.96	15.01
19	1.8	36.2	6.72	4.55	21.46
20	2.7	67.6	11.64	5.47	30.48
21	4.3	46.4	10.67	3.13	9.47
22	1.7	30.0	6.08	4.04	16.03
23	0.3	3.8	0.89	3.12	9.16
24	2.7	37.8	7.46	3.73	14.99
25	1.2	8.5	2.65	1.86	1.90
26	4.9	124.0	20.93	5.82	33.53
27	3.1	56.1	11.33	4.20	16.95
28	4.9	52.4	12.25	2.94	7.99
29	7.9	78.0	18.59	2.82	7.33
30	8.4	79.0	19.34	2.56	5.79

**Table 4.6: Daily rainfall statistics of July for Kota**

Date	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
1	4.4	33.8	8.07	2.18	4.67
2	12.7	252.0	43.78	5.20	28.12
3	13.6	190.0	36.78	3.87	16.16
4	4.9	39.0	10.50	2.54	5.51
5	1.7	20.4	4.33	3.20	10.56
6	5.3	92.2	16.70	4.57	22.60
7	2.8	23.0	5.74	2.46	5.31
8	7.7	67.0	15.58	2.74	7.53
9	8.0	92.0	19.91	3.43	11.63
10	4.1	35.4	9.85	2.71	6.10
11	9.2	73.6	18.84	2.56	6.18
12	5.5	51.0	10.78	2.77	8.83
13	4.4	40.0	8.33	2.81	9.26
14	8.1	59.6	14.34	2.36	5.32
15	8.0	122.5	22.41	4.42	21.08
16	9.2	106.6	22.31	3.33	11.51
17	3.2	33.2	7.81	3.25	10.17
18	4.9	28.4	8.54	2.00	2.60
19	6.8	67.0	14.31	2.96	9.20
20	6.6	40.2	11.67	1.86	2.21
21	12.6	188.5	35.05	4.23	19.48
22	16.5	171.2	33.51	3.57	14.07
23	10.0	103.8	23.44	3.38	11.08
24	20.5	94.60	28.33	1.40	1.07
25	13.9	123.6	26.80	2.80	8.33
26	7.9	56.0	15.56	2.32	4.26
27	9.7	96.1	19.57	3.06	10.85
28	8.6	174.0	29.88	5.36	29.67
29	5.3	48.1	11.60	2.65	6.58
30	8.5	93.7	19.83	3.19	10.51
31	9.0	86.5	21.60	2.93	8.09

**Table 4.7: Daily rainfall statistics of August for Kota**

Date	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
1	5.6	51.6	12.75	2.59	5.84
2	6.7	54.0	11.98	2.79	8.19
3	9.2	85.5	19.02	2.72	7.64
4	9.3	51.8	14.16	1.69	2.03
5	8.7	91.5	18.00	3.46	13.43
6	5.1	36.4	9.00	2.16	4.14
7	9.6	87.0	18.59	3.02	9.64
8	6.7	113.4	19.51	5.16	28.03
9	5.3	55.6	13.08	3.14	9.23
10	10.5	68.8	16.49	1.85	3.45
11	6.3	73.0	14.93	3.50	12.66
12	6.6	71.7	17.32	3.15	9.02
13	8.6	91.4	18.37	3.33	12.31
14	6.6	46.8	13.08	2.31	4.04
15	7.0	62.0	13.36	2.60	7.81
16	13.1	101.0	25.67	2.48	5.44
17	9.4	36.2	12.05	1.02	-0.50
18	4.2	28.2	7.19	2.14	4.04
19	8.3	69.9	16.18	2.54	6.26
20	8.7	80.4	19.23	2.94	8.27
21	7.6	93.6	19.92	3.38	11.43
22	5.2	56.9	11.82	3.14	10.79
23	10.1	61.8	17.02	1.71	1.87
24	9.9	63.8	15.03	1.94	3.91
25	9.6	55.6	14.31	1.62	2.08
26	7.0	75.9	15.70	3.30	11.71
27	10.6	115.5	25.85	3.11	9.41
28	4.6	28.5	8.29	1.99	2.98
29	2.3	21.2	4.73	2.62	7.28
30	6.1	38.3	10.77	1.92	2.65
31	17.1	167.4	40.51	3.27	10.15

**Table 4.8: Daily rainfall statistics of September for Kota**

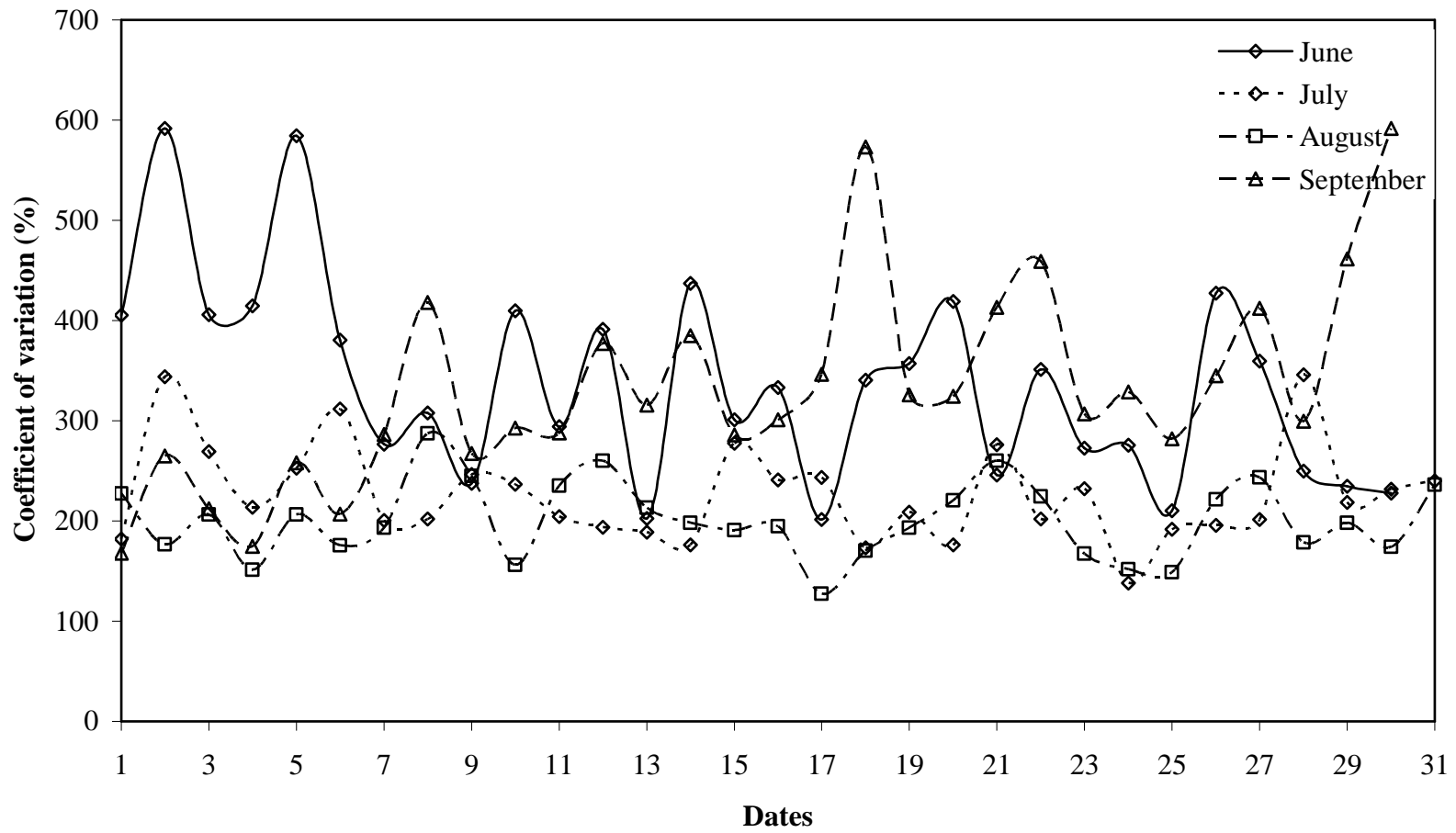
Date	Rainfall (mm)		Standard deviation (mm)	Cs	Ck
	Mean	Max			
1	6.6	43.4	11.16	2.03	3.62
2	3.9	50.7	10.56	3.55	12.74
3	8.4	71.8	17.97	2.45	5.30
4	5.1	30.4	9.05	1.68	1.48
5	14.0	167.9	36.33	3.60	12.52
6	5.9	43.0	12.32	2.21	3.65
7	4.0	63.4	11.66	4.35	20.65
8	4.3	105.0	18.14	5.45	30.09
9	3.9	52.0	10.46	3.54	13.54
10	1.1	17.0	3.41	3.67	14.26
11	1.6	18.1	4.78	2.79	6.32
12	2.5	53.5	9.51	4.99	25.95
13	4.0	69.2	12.78	4.40	20.83
14	1.5	31.5	5.82	4.69	22.45
15	1.4	17.4	4.00	3.02	8.43
16	3.3	44.8	10.00	3.72	13.05
17	0.7	13.8	2.47	4.78	24.41
18	0.7	25.2	4.26	5.98	34.92
19	0.4	7.8	1.55	3.88	15.51
20	1.8	31.0	6.06	3.97	16.56
21	0.1	2.3	0.51	4.08	15.15
22	0.8	22.3	3.96	5.17	27.15
23	2.6	44.4	8.20	4.34	20.58
24	2.2	40.6	7.28	4.78	24.08
25	1.9	23.2	5.50	3.06	8.54
26	0.9	15.7	3.16	3.99	15.88
27	0.1	2.0	0.47	4.04	14.75
28	0.1	2.0	0.51	3.08	8.47
29	0.1	3.5	0.62	5.21	27.55
30	0.1	6.4	1.08	5.99	35.00

concluded that at the time of onset and withdrawal of monsoon the climate of Kota becomes unstable.

In Fig. 4.2 the comparison of coefficient of variation of different months in monsoon season may be seen, from Fig. it may be seen that coefficient of variation of June varies from 201.62 to 591.61 per cent, in July it varies from 137.82 to 345.79 per cent and in August whereas in September it varies from 167.93 to 591.61 per cent. It may be observed from this figure that the variation in rainfall is more in month of June and September. In the month of July and August the variation remains less and almost same. Therefore it may be concluded that at the time of onset and withdrawal the variation in rainfall is very high and in remaining part of the monsoon season the variation in rainfall remains lowest at Kota. It is interesting to observe that in first two weeks of June the variation is very high and after it up to the second week of September variation remains lowest, after second week in September the variation again becomes high so it may be said that the climate of Kota is unstable at onset and withdrawal of monsoon.

From Table 4.9 it may be seen that the daily mean rainfall ranges from 0.02 to 7.99 mm with monthly mean rainfall of 61.48 mm for June at Bhilwara and daily maximum rainfall varies from 0.4 to 69.2 mm with monthly value of 235.6 mm. Standard deviation ranges from 0.07 to 19.35 and coefficient of variation ranges from 164.76 to 374.17 per cent, it indicates that the variation in rainfall received at Bhilwara in the month of June is very high and the uncertainty of occurrence of rainfall in June is very high. The coefficient of skewness varies from 1.4 to 3.74 and the coefficient of kurtosis ranges from 0.45 to 14.00. So it may be observed that the rainfall in the month of June is positively skewed and the shape of kurtosis curve is sharp and the rainfall in the month of June is not so much consistent and the weather in this month is unstable. Therefore it may be concluded that the rainfall received at Bhilwara in the month of June is very much erratic, inconsistent and unevenly distributed over the entire month and also the variability in amount of rainfall received is very high.

From Table 4.10 it may be seen that the daily mean rainfall ranges from 0.47 to 25.24 mm with the monthly mean value of 263.43 mm for July and daily maximum rainfall varies from 3 to 262.4 mm with monthly maximum value of 562.0 mm for July. Standard deviation ranges from 0.98 to 70.89 mm with the coefficient of variation of 132.61 to 371.17 per cent. It indicates that the amount of rainfall received at Bhilwara in July is unevenly distributed and uncertainty of occurrence of rainfall is very high but less than the month of June and also the variation of rainfall is very high. Coefficient of skewness varies from 1.17 to 3.74 and coefficient of kurtosis varies from 0.09 to 14.00, it indicates the rain in the month of July is positively skewed and the



**Fig 4.2: Coefficient of Variation ( $C_v$ ) of daily rainfall for monsoon season at Kota**

shape of kurtosis curve is sharp. Therefore it may be concluded for the month of July at Bhilwara that the rainfall is uncertain, uneven and positively skewed but consistent than the month of June.

From the Table 4.11 it may be observed that the daily mean rainfall ranges from 0.83 to 19.97 mm with the month mean rainfall of 203.74 mm for August and the daily mean rainfall for August month 4.0-133.0 mm with monthly maximum value of 622.20 mm. Standard deviation ranges from 1.39 to 37.88 mm with coefficient of variation 149.92-344.42 percent, it indicates the uncertainty and variation in the amount of rainfall in August. Coefficient of skewness varies from 1.34 to 3.71 and coefficient of kurtosis ranges from 0.22 to 13.84, it indicates the rainfall value is positively skewed in this month and the shape of the kurtosis curve is sharp but the peak value is less than the previous months. Therefore it may be concluded that the amount of rainfall received in the month of August is unevenly distributed, uncertain but more consistent than the June and July and also the variability in the amount of rainfall is lowest.

From Table 4.12 it may be seen that the daily mean rainfall ranges from 0.14 to 5.60 mm with the monthly mean value of 48.93 mm and daily maximum values range from .0 to 38.0 mm with the monthly maximum value of 121.0 mm for September month. Standard deviation ranges from 0.36 to 11.70 mm and the coefficient of variation ranges from 173.26 to 374.17 per cent, which indicates the uneven distribution, uncertainty of occurrence and variation in amount of rainfall received at Bhilwara is very high. Coefficient of skewness varies from 1.73 to 3.74 and coefficient of kurtosis ranges from 1.43 to 14 and these values are highest value in monsoon season at Bhilwara. Therefore it may be concluded that the rainfall received at Bhilwara in September is unevenly distributed, most erratic and uncertain. It is interesting to observe that the rainfall is positively skewed but amount received is less than other months in monsoon season and the variation in rainfall after half of the September is very high. So it may be said for Bhilwara that in monsoon season the rainfall is erratic and frequent droughts may be observed.

From Fig. 4.3 the monthly variation of rainfall in monsoon season may be observed and compared. In the month of June the coefficient of variation ranges from 374.17 to 164.76 per cent, in the month of July it varies from 132.61 to 371.17 per cent, in the month of August it ranges from 149.92 to 344.42 per cent and for September it observed 173.26 to 374.17 per cent. When the trend of coefficient of variation of various months in monsoon season compared it found that variation of rainfall in June is very high and after June in the month of July variation in rainfall decreases steadily and same trend is observed in August and after August in September the variation again becomes high. Therefore it may be concluded at Bhilwara in monsoon season on onset and withdrawal the variation in rainfall is very high and very erratic. Although in the month of July and August the rainfall is not so much erratic and variation is also lower than the June and

**Table 4.9: Daily rainfall statistics of June for Bhilwara**

Date	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
1	1.9	27.2	7.27	3.74	14.00
2	0.0	0.4	0.11	3.74	14.00
3	0.0	0.0	0.07	3.74	14.00
4	0.5	7.6	2.03	3.74	14.00
5	1.0	15.0	4.01	3.74	14.00
6	0.5	8.0	2.14	3.74	14.00
7	0.5	8.0	2.14	3.74	14.00
8	1.5	18.2	4.87	3.56	12.93
9	1.7	20.8	5.52	3.65	13.51
10	1.0	10.6	2.84	3.36	11.80
11	2.0	25.4	6.77	3.68	13.63
12	0.6	5.0	1.67	2.33	4.11
13	2.4	18.0	6.29	2.30	3.86
14	3.4	26.6	7.45	2.71	7.80
15	0.7	3.20	1.22	1.40	0.45
16	1.8	12.6	4.13	2.18	3.65
17	0.1	1.6	0.43	3.41	11.93
18	1.1	10.6	3.00	2.96	8.80
19	1.7	20.0	5.37	3.52	12.63
20	0.8	10.0	2.67	3.59	13.11
21	2.0	14.3	5.10	2.30	3.81
22	2.1	24.4	6.57	3.47	12.35
23	4.4	50.6	13.45	3.59	13.11
24	7.9	69.2	19.35	2.86	8.57
25	5.5	43.6	12.35	2.65	7.38
26	2.7	21.6	6.94	2.41	4.65
27	6.5	67.0	18.58	3.13	10.02
28	0.3	5.0	1.33	3.73	13.94
29	2.2	19.8	5.56	2.90	8.63
30	3.5	26.4	8.59	2.35	4.33

**Table 4.10: Daily rainfall statistics of July for Bhilwara**

Date	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
1	3.6	19.0	6.21	1.58	1.56
2	25.2	262.4	70.89	3.34	11.53
3	7.1	86.0	22.85	3.66	13.55
4	1.4	15.6	4.17	3.51	12.65
5	5.1	38.4	12.85	2.34	4.12
6	1.9	26.6	7.11	3.74	14.00
7	0.4	3.6	0.98	2.94	9.39
8	0.7	6.5	1.83	2.76	8.00
9	5.7	31.2	10.92	1.81	1.99
10	2.6	26.4	7.02	3.45	12.31
11	16.1	120.0	31.66	3.11	10.37
12	8.9	51.8	15.93	2.10	3.79
13	9.7	48.2	15.04	1.59	2.01
14	6.6	44.0	12.31	2.49	6.76
15	1.9	10.1	3.57	1.68	1.32
16	12.8	82.2	24.22	2.32	5.15
17	4.5	27.0	7.71	2.17	5.18
18	6.2	52.2	13.77	3.28	11.34
19	9.8	43.8	14.90	1.66	1.77
20	0.4	3.0	1.00	2.01	2.86
21	11.1	84.0	24.58	2.42	5.88
22	8.9	57.0	15.70	2.50	7.08
23	11.5	66.4	21.03	1.98	3.10
24	16.1	89.0	24.95	2.21	5.42
25	15.6	66.0	21.96	1.44	1.02
26	10.8	54.6	18.06	1.75	2.05
27	16.6	81.3	27.40	1.77	2.14
28	8.3	80.0	21.37	3.35	11.67
29	5.8	21.2	7.69	1.17	0.09
30	14.3	102.2	32.88	2.33	4.31
31	12.6	83.0	26.52	2.02	3.18

**Table 4.11: Daily rainfall statistics of August for Bhilwara**

Date	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
1	8.1	105.0	27.95	3.71	13.84
2	3.9	24.0	6.95	2.36	5.42
3	1.9	22.2	5.94	3.54	12.78
4	1.7	9.6	3.35	1.79	1.88
5	7.9	46.8	14.22	2.15	4.09
6	8.5	63.0	19.13	2.47	5.35
7	13.8	85.0	23.36	2.47	6.88
8	8.3	88.6	23.46	3.55	12.92
9	2.8	23.0	6.42	2.84	8.37
10	9.5	37.4	14.26	1.34	0.22
11	7.4	45.2	14.40	2.01	3.18
12	0.8	4.0	1.39	1.50	0.87
13	5.5	61.0	16.88	3.47	12.21
14	5.6	40.8	12.21	2.45	5.93
15	4.4	30.4	9.73	2.21	4.11
16	10.2	113.0	31.00	3.55	12.72
17	19.9	133.0	37.88	2.60	7.18
18	5.8	56.0	15.72	3.18	10.44
19	15.7	126.0	35.54	2.93	8.97
20	6.8	45.0	13.83	2.12	3.94
21	9.5	45.0	16.02	1.56	0.84
22	8.8	51.8	17.24	1.83	2.10
23	12.5	140.0	37.40	3.52	12.69
24	8.6	42.0	13.24	1.50	1.67
25	3.2	16.5	5.72	1.75	1.72
26	4.6	31.8	8.58	2.76	8.46
27	3.3	20.8	6.31	1.99	3.72
28	2.6	23.4	6.42	3.03	9.58
29	1.1	9.0	2.57	2.64	7.27
30	2.3	20.4	5.51	3.11	10.27
31	2.2	10.5	3.73	1.52	0.76

**Table 4.12: Daily rainfall statistics of September for Bhilwara**

Date	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
1	1.6	13.0	3.61	2.78	8.29
2	1.4	8.4	2.57	1.86	3.13
3	5.6	35.0	11.70	2.14	3.43
4	2.5	20.0	6.41	2.40	4.65
5	3.1	24.4	6.93	2.67	7.30
6	2.7	21.4	5.97	2.74	7.98
7	2.7	23.0	6.61	2.73	7.43
8	4.7	26.0	8.49	1.90	2.70
9	2.9	38.0	10.11	3.71	13.82
10	3.2	30.6	8.26	3.21	10.88
11	0.6	5.0	1.65	2.36	4.32
12	1.6	19.6	5.20	3.68	13.64
13	3.0	35.0	9.29	3.61	13.22
14	1.6	21.0	5.60	3.66	13.54
15	1.4	15.0	4.10	3.24	10.80
16	0.1	2.2	0.59	3.74	14.00
17	2.6	37.2	9.94	3.74	14.00
18	0.9	7.8	2.46	2.43	4.90
19	0.9	7.2	2.46	2.43	4.90
20	0.1	1.0	0.36	2.29	3.79
21	1.2	15.4	4.10	3.68	13.67
22	0.5	7.0	1.87	3.74	14.00
23	1.3	19.4	5.18	3.74	14.00
24	0.3	4.6	1.23	3.74	14.00
25	1.9	11.0	3.91	1.73	1.43
26	1.9	0.0	3.91	1.73	1.43
27	1.9	0.0	3.91	1.73	1.43
28	0.2	0.0	1.07	-	-
29	0.2	4.0	1.07	3.74	14.00
30	0.2	0.0	1.07	-	-

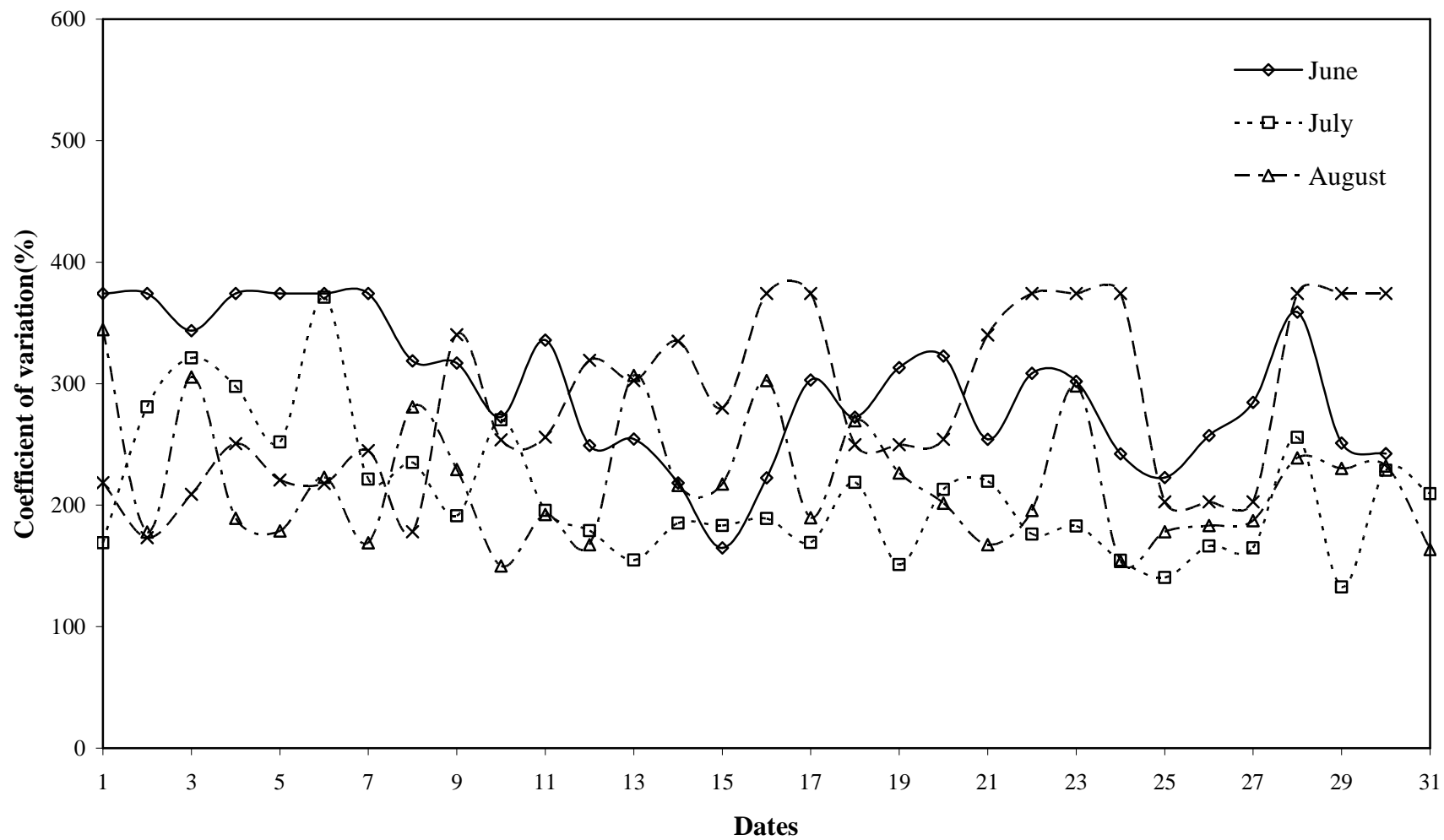


Fig 4.3: Coefficient of Variation ( $C_v$ ) of daily rainfall for monsoon season at Bhilwara

September. Through the study of Figure it may also be said that the rainfall in monsoon season is erratic and the climate of Bhilwara at onset and withdrawal of monsoon is unstable.

From these Tables (4.1 to 4.12), it can be inferred that the range of variation in the daily rainfall events for monsoon period was maximum during June and minimum in the months of July to September. This indicates that during the on-set of monsoon period the rainfall both in time and quantity is much erratic as compared to the peak and the withdrawal of monsoon period. Further on comparative analysis of daily means of rainfall it was observed that the variation of daily rainfall period (July and August) exhibited almost similar range of daily mean rainfall. During these months the rainfall were almost similar for onset and withdrawal periods of monsoon, whereas the peak monsoon June and September, about 96 and 86% of the rainfall events respectively, resulted in less than 5mm rainfall. On the other hand, for the months July and August, about 70 to 90% rainfall events were of amount 5mm to 10mm.

These results indicate that the rainfall pattern is comparatively more consistent during July and August than the rest of monsoon period. This is also supported by the results of standard deviation of daily rainfall events. Variations in coefficient of variation ( $C_v$ ) of daily rainfall events for the months June to September are given in Figs. 4.1 to 4.3. These figures indicate that the variation in daily rainfall distribution was lowest during August and highest during June. Almost similar range in  $C_v$  was obtained for July and September for all the three stations considered. This may probably be due to significant difference in maximum amounts of rainfall on the day, at which minimum  $C_v$  was found in the respective months.

In order to quantify the deviation of daily rainfall events from normality the coefficient of skewness ( $C_s$ ) were estimated and are given in Tables 4.1 to 4.12 for months June to September for all stations. The obtained values indicate that for all the months of study period the rainfall distribution of daily rainfall was positively skewed. From the analysis of kurtosis it can be inferred that the rainfall distribution is more peaked than normal for all the months (June to September).

#### **4.1.2 Analysis of Weekly Rainfall Series**

Estimated statistical parameters of weekly rainfall (1 to 52 standard weeks) are given in Tables 4.13 to 4.15. These tables indicate that about 88% of the average annual rainfall occurred during monsoon period (24 to 39 standard weeks) and the rest was distributed along the pre-monsoon period (22 to 23 standard weeks). It is also observed that occasional maximum events were recorded during dry season; otherwise, the rainfall is more concentrated in the monsoon period.

**Table 4.13: Weekly rainfall statistics at Udaipur**

Week	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
1	1.5	65.5	8.15	6.57	47.82
2	1.7	36.2	6.55	4.38	18.96
3	0.7	26.6	3.44	6.27	42.72
4	1.0	32.0	4.61	5.59	32.97
5	0.6	16.5	2.34	4.83	27.29
6	0.8	35.0	4.14	7.17	57.42
7	0.7	20.0	2.84	4.93	27.90
8	0.9	16.0	2.89	3.79	14.68
9	0.8	32.2	4.21	6.12	40.85
10	0.2	10.1	1.18	7.74	63.76
11	0.4	29.0	3.30	8.16	69.68
12	2.0	115.2	12.90	8.40	73.68
13	1.4	84.4	9.37	8.61	76.58
14	0.3	14.4	1.64	7.94	67.37
15	0.4	22.0	2.56	7.62	62.63
16	0.9	26.9	3.35	6.18	44.99
17	0.7	13.4	2.69	3.99	15.01
18	0.9	18.8	3.27	4.14	17.49
19	1.7	85.8	10.47	7.20	54.17
20	2.1	36.4	5.93	3.76	16.21
21	1.4	27.5	4.60	4.11	18.48
22	5.0	50.5	10.57	2.62	7.06
23	10.2	72.6	20.08	2.03	2.92
24	17.1	104.1	25.04	2.05	3.82
25	18.8	143.5	26.19	2.04	5.57
26	32.6	307.2	46.88	3.04	14.00

Week	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
27	39.7	215.6	46.78	1.87	3.86
28	45.6	174.3	47.37	1.06	0.25
29	40.3	147.5	39.22	0.97	0.01
30	48.3	214.3	51.53	1.11	0.52
31	44.3	320.6	51.64	2.41	9.31
32	46.1	240.7	52.85	1.69	2.70
33	38.0	185.9	43.55	1.40	1.59
34	47.5	240.0	56.10	1.38	1.58
35	43.8	236.9	53.19	1.80	3.05
36	33.7	188.7	47.63	1.79	2.62
37	19.6	147.5	29.97	2.07	4.74
38	22.0	328.4	42.04	5.05	34.01
39	18.1	182.6	31.01	2.95	10.85
40	5.8	107.4	17.22	4.72	23.85
41	3.5	94.4	12.26	5.66	37.86
42	2.2	74.2	9.53	6.20	42.40
43	1.4	41.4	5.85	5.05	28.61
44	2.0	66.8	10.06	5.44	29.97
45	1.6	112.5	12.37	8.89	80.38
46	1.2	40.4	5.62	5.49	32.87
47	3.8	135.2	17.35	6.11	41.81
48	0.5	16.0	2.54	5.23	26.74
49	0.6	34.2	3.90	8.02	68.53
50	0.8	37.2	4.23	7.93	67.80
51	1.4	52.5	7.68	6.23	38.47
52	0.1	4.6	0.71	5.02	26.13

From Table 4.13 it may be seen that the minimum weekly rainfall observed in 52<sup>nd</sup> week and the maximum weekly rainfall in 30<sup>th</sup> week whereas the minimum value of standard deviation is observed in 52<sup>nd</sup> week and maximum standard deviation in 34<sup>th</sup> week with the minimum value of coefficient of variation are observed in 29<sup>th</sup> week and maximum value observed in 45<sup>th</sup> week. Normally the higher values of standard deviation with the lower values of coefficient of variation are observed in monsoon season i.e. from 22<sup>nd</sup> week to 41<sup>st</sup> week. Due to the frequent occurrence of wet days and dry days in the week with consistent rainfall following a trend the value of standard deviation goes higher. Coefficient of skewness found minimum in 29<sup>th</sup> week and maximum in 45<sup>th</sup> week with the coefficient of kurtosis minimum in 29<sup>th</sup> week and maximum in 45<sup>th</sup> week. Therefore it may be said by observing Table 4.13 that the weekly rainfall at Udaipur is positively skewed and the effective monsoon commences normally in 23-26 week. In monsoon season the weeks are observed having a higher range of standard deviation due to frequent consecutive wet and dry days with consistent rainfall occurrence. Normally monsoon withdrawals in 39-46 week at Udaipur so the higher range of coefficient of variation, coefficient of skewness and coefficient of kurtosis are observed in these weeks.

For Kota it may be seen from the Table 4.14 that the weekly mean rainfall minimum in first week and maximum in 34<sup>th</sup> week with the values of 0.1 and 81.1 mm, respectively. In the dry season (1-21 week and 42-52 week) value of standard deviation remains low and in monsoon season (22-41 week) standard deviation takes the higher values with lower values of coefficient of variation and vice versa. Coefficient of skewness is observed in 33<sup>rd</sup> week lowest and in 44<sup>th</sup> week highest with the highest value of coefficient of kurtosis. So it may be concluded that normally the onset of monsoon is in 23-29 week and after that the rainfall remains consistent up to 31 week, after 35<sup>th</sup> week normally the consistency of rainfall decreases and around the 44<sup>th</sup> week the monsoon normally withdrawals from Kota.

For Bhilwara from Table 4.15 it may be seen that minimum value of weekly mean rainfall falls in 10<sup>th</sup> week and maximum value takes place in 31<sup>st</sup> week. It indicates the maximum consistent rainfall normally occurs around 31<sup>st</sup> week and rainfall occurs rarely around 10<sup>th</sup> week. Minimum value of standard deviation is observed in 10<sup>th</sup> week due to most of the days in this week are dry and rarely any wet day is found and maximum value of standard deviation is found in 30<sup>th</sup> week due to the maximum fluctuation of dry and wet day alternatively and also it may be observed that lowest value of coefficient of variation in 32<sup>nd</sup> week so, it may be inferred that the maximum consistent rainfall takes place around 30-32<sup>nd</sup> week at Bhilwara. Coefficient of skewness is found minimum in 34<sup>th</sup> week and maximum in 48<sup>th</sup> week. Therefore it may be

**Table 4.14: Weekly rainfall statistics for Kota**

Week	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
1	0.1	2.50	0.60	3.25	9.46
2	1.8	28.2	5.44	3.89	16.86
3	0.3	4.0	0.99	3.37	10.61
4	1.2	36.0	6.13	5.69	33.03
5	0.6	14.5	2.92	4.24	17.64
6	2.2	56.5	9.69	5.48	31.16
7	0.8	14.3	3.00	3.96	15.29
8	0.1	5.1	0.88	5.43	30.50
9	1.2	10.6	2.80	2.48	5.17
10	0.2	2.7	0.64	3.27	10.28
11	0.4	13.6	2.33	5.58	31.93
12	0.2	3.6	0.76	3.95	15.10
13	0.6	16.5	2.82	5.58	32.02
14	0.6	9.0	1.98	3.61	12.71
15	0.6	16.6	3.04	4.81	23.97
16	0.5	12.2	2.25	4.60	22.31
17	2.7	67.8	12.03	5.10	27.13
18	1.0	19.6	3.55	4.68	23.62
19	1.1	16.5	3.45	3.58	13.21
20	3.8	46.8	11.21	3.05	8.63
21	19.9	600.0	101.24	5.86	34.52
22	5.7	60.2	14.53	3.09	8.87
23	7.97	54.9	13.39	1.92	3.56
24	10.8	64.8	14.72	2.17	5.74
25	16.5	96.0	26.08	1.67	1.85

Week	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
26	35.0	160.0	52.99	1.52	0.78
27	48.9	464.9	83.27	3.92	18.75
28	47.3	207.7	52.96	1.57	1.81
29	60.1	293.6	67.62	2.03	4.44
30	76.2	391.4	90.51	1.72	3.48
31	57.2	166.9	48.01	0.67	0.42
32	51.9	176.5	45.42	1.33	1.17
33	57.4	171.6	48.52	0.52	0.81
34	81.1	980.9	165.45	5.00	27.45
35	51.0	236.8	62.36	1.74	2.88
36	47.9	399.3	76.98	3.26	12.96
37	13.6	86.4	21.60	1.85	3.16
38	7.6	67.5	14.33	2.85	9.18
39	5.4	54.9	12.40	2.81	7.81
40	4.7	42.8	11.24	2.55	5.80
41	12.4	225.0	42.18	4.25	19.86
42	2.5	52.1	9.55	4.61	22.77
43	2.5	58.2	9.96	5.45	30.95
44	1.1	39.4	6.66	5.92	35.00
45	3.3	108.9	18.39	5.90	34.85
46	1.3	28.4	5.48	4.41	19.72
47	3.2	114.9	19.42	5.92	35.00
48	0.9	13.0	3.23	3.37	10.50
49	3.4	117.4	19.84	5.91	34.97
50	1.7	33.7	7.35	4.04	15.33
51	0.4	5.3	1.29	2.91	7.60
52	0.5	9.4	2.06	3.99	15.04

concluded that mostly the rainfall occurs during the period of 26-41<sup>st</sup> week at Bhilwara and after that normally the monsoon withdrawals around 48<sup>th</sup> week with higher values of coefficient of variation, coefficient of skewness and coefficient of kurtosis and most erratic rainfall.

The variation in the standard deviation ranged from 0.71 to 17.35 during dry season and 10.57 to 56.10 for monsoon season at Udaipur, and from 0.6 to 101.24 during dry season and 11.24 to 165.45 during monsoon season at Kota whereas for Bhilwara it ranged from 0.21 to 25.31 during dry season and 4.97 to 125.16 for monsoon season. This indicates that the variation is more pronounced during rainy season than dry season. This may probably be due to, the more number of dry days during the weeks, which recorded maximum rainfall.

From the coefficient of skewness, it was observed that the rainfall is skewed positively for all the weeks at all the three stations considered. The distribution of weekly rainfall was observed to be closer towards normality during the weeks of monsoon season (22 to 41 weeks) as compared to weeks of dry season (42 to 21 weeks). From the values of coefficient of kurtosis ( $C_K$ ), it was observed that the distribution curve is steeper during weeks of dry season as compared to the weeks of monsoon season.

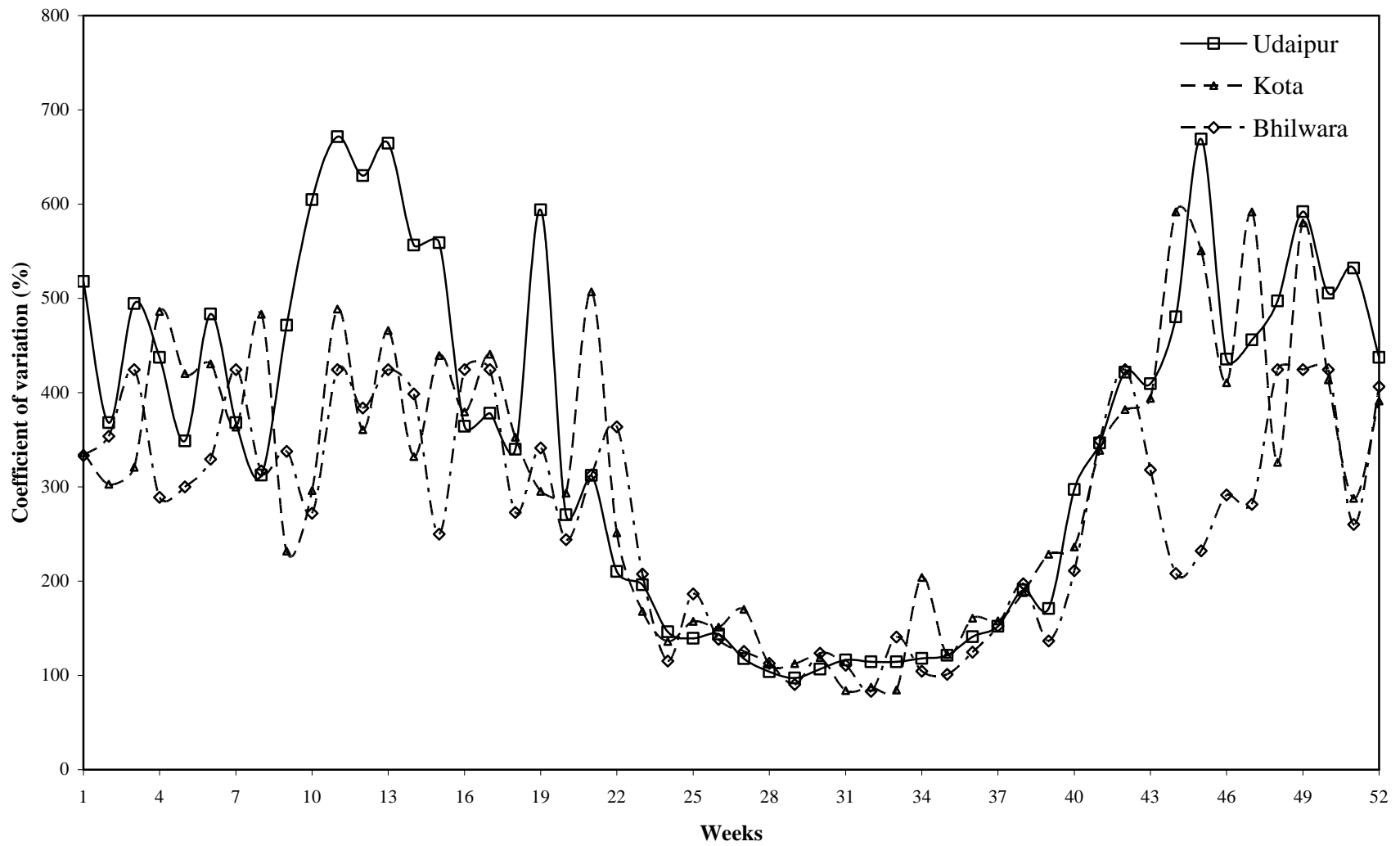
A more reliable estimate of variation of weekly rainfall from their means can be made through the analysis of coefficient of variation ( $C_V$ ) for Udaipur, Kota and Bhilwara which is shown in fig. 4.4. From the figure it is observed that the variation in  $C_V$  is almost same during pre-monsoon and post-monsoon periods. Whereas, it ranged from 270.77 to 673.46 during dry season and from 97.17 to 346.32 during monsoon at Udaipur, at Kota it ranged from 231.90 to 591.61 during dry season and from 83.90 to 338.73 during monsoon, and at Bhilwara it ranged from 208.00 to 424.26 during dry season and 83.09 to 363.84 during monsoon season. From this, it can be inferred that the rainfall is more consistent during monsoon season than, during dry season.

In case of the dry season of the year from week 1 to 22<sup>nd</sup> higher variation is found for the Udaipur station than the other stations and specially in the case of march month the variation is higher and this characteristics found up to the period of pre monsoon. In case of the pre monsoon duration maximum variation is observed in Bhilwara station than the other stations for the period of week 22<sup>nd</sup> to 25<sup>th</sup>. After the withdrawal of the monsoon season the variation in the rainfall is again goes high for all stations and specially Kota and Udaipur station shows the similar variation from 43<sup>rd</sup> week to 52 week. From the analysis of fig. 4.4 it may also be seen that the rainfall is most scare in the period from 8<sup>th</sup> week to 17<sup>th</sup> week. And in case of the monsoon season the all the stations show the similar lower range of the coefficient of variation and consistent rainfall received by the all stations.

**Table 4.15: Weekly rainfall statistics for Bhilwara**

Week	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
1	0.3	4.5	1.09	3.72	14.33
2	7.1	107.0	25.31	4.05	16.70
3	0.4	7.9	1.86	4.24	18.00
4	0.2	3.2	0.84	-	-
5	0.2	3.8	0.79	-	-
6	0.2	3.6	0.88	3.66	13.88
7	0.4	7.9	1.86	4.24	18.00
8	0.2	3.8	1.09	-	-
9	0.3	4.2	1.01	3.79	14.83
10	0.0	1.0	0.21	-	-
11	0.0	1.0	0.24	4.24	18.00
12	0.3	5.7	1.34	4.17	17.53
13	0.1	3.0	0.71	4.24	18.00
14	2.1	36.8	8.66	4.22	17.83
15	0.1	2.8	0.69	-	-
16	0.1	2.8	0.66	4.24	18.00
17	0.2	4.8	1.13	4.24	18.00
18	0.9	8.1	2.47	2.68	5.98
19	1.3	18.8	4.46	3.99	16.33
20	0.3	5.4	1.29	-	-
21	0.4	6.1	1.55	3.34	11.29
22	1.3	21.0	4.97	4.06	16.77
23	7.0	45.3	14.67	2.22	3.99
24	24.8	87.3	28.69	0.90	-0.21
25	24.2	189.3	45.24	3.19	11.36
26	34.2	150.8	47.26	1.43	1.01

Week	Rainfall (mm)		Standard deviation (mm)	C <sub>s</sub>	C <sub>k</sub>
	Mean	Max			
27	47.9	154.0	60.12	0.96	0.85
28	60.8	223.7	68.64	1.18	0.53
29	64.4	235.2	58.14	1.74	3.53
30	101.2	394.8	125.16	1.40	0.93
31	102.7	403.0	113.95	1.29	1.26
32	69.0	242.2	57.37	1.71	4.01
33	45.5	276.0	64.12	2.96	10.50
34	54.7	191.4	57.18	0.87	0.01
35	44.3	145.0	44.92	1.10	0.61
36	54.5	198.7	67.97	1.09	0.05
37	21.5	101.6	32.91	1.59	1.50
38	25.0	185.7	49.32	2.55	6.58
39	10.9	50.0	15.00	1.32	0.99
40	5.3	44.6	11.32	2.82	8.75
41	7.7	114.9	26.96	4.13	17.32
42	1.7	32.0	7.54	4.24	18.00
43	2.0	26.5	6.45	3.66	13.88
44	0.8	7.9	1.90	-	-
45	0.9	8.2	2.30	-	-
46	0.9	9.0	2.77	2.72	6.12
47	3.6	41.8	10.19	3.51	13.01
48	0.1	2.3	0.54	4.24	18.00
49	0.4	8.0	1.89	4.24	18.00
50	0.5	9.8	2.31	4.24	18.00
51	0.6	8.2	3.43	-	-
52	2.1	37.7	8.87	4.23	17.92



**Fig 4.4: Coefficient of Variation ( $C_v$ ) of weekly rainfall**

#### **4.1.3 Analysis of Fortnight, Monthly and Annual Rainfall**

Variation in fortnightly and monthly rainfall has been shown in Tables 4.16 to 4.21. From the Tables 4.16 it may be seen for the Udaipur fortnightly mean rainfall ranges from 0.7 mm in first fortnight of the month of April to 105.2 mm in second fortnight of the month of July. Minimum standard deviation was observed in first fortnight of April and maximum standard deviation was observed for second fortnight of August with the minimum coefficient of variation in first fortnight of July and maximum in second fortnight of March month. It indicates that the maximum rainfall amount was found in the period of first fortnight of June to first fortnight of October and in the period of first fortnight of February to first fortnight of May rarely any shower of rainfall received at Udaipur. Coefficient of skewness is varies from the minimum values of 0.85 in first fortnight of July and the maximum value is 8.73 found in the second fortnight of march with maximum value of kurtosis coefficient is 78.29 in second fortnight of March, minimum value is 0.10 in first fortnight of July. Which indicates that the in the period of June and July the rainfall pattern is more consistent than the other months and in the period of February to may the rainfall is scare but the rainfall is positively skewed for all months.

For Kota from the Table 4.17 it may be seen that the minimum standard deviation was observed in second fortnight of March and maximum standard deviation was found for second fortnight of July with the minimum coefficient of variation in first fortnight of august and maximum value of coefficient of variation found in the second fortnight of November. Whereas the coefficient of skewness is observed minimum in first fortnight of august and maximum value of skewness coefficient is found in first fortnight of December with the maximum value of kurtosis coefficient, minimum value of coefficient of kurtosis is observed in first fortnight of the August month. By these observations it can be concluded that the most of the rainfall in this region is received in the period of second fortnight of June to first fortnight of the October with a consistent amount, distribution and least variation. Whereas in the period of first fortnight of the November to first fortnight of May the rainfall is very much scare and erratic.

For Bhilwara from the Table 4.18 it may be seen that the fortnightly mean rainfall minimum in second fortnight of the January and maximum in the second fortnight of the august month. Standard deviation was observed minimum for the second fortnight of January and maximum standard deviation was found for the second fortnight of August with the minimum coefficient of variation in first fortnight of the August, maximum value of coefficient of variation found in second fortnight of the November and January and also in first fortnight of December.

**Table 4.16: Fortnightly rainfall statistics at Udaipur**

<b>Fortnight</b>	<b>Mean Rainfall(mm)</b>	<b>Standard deviation (mm)</b>	<b>C<sub>V</sub> (%)</b>	<b>C<sub>s</sub></b>	<b>C<sub>k</sub></b>
1	3.3	10.18	303.66	4.02	18.49
2	2.2	6.98	307.66	4.32	21.67
3	1.3	4.66	337.65	5.57	35.66
4	1.9	4.09	212.36	2.47	5.87
5	0.9	3.69	394.20	5.14	29.83
6	3.4	22.07	631.79	8.73	78.29
7	0.7	3.07	406.25	5.47	32.44
8	1.6	4.38	268.75	3.76	16.11
9	3.13	11.29	360.53	5.70	37.15
10	5.31	9.20	173.22	2.30	5.54
11	24.2	29.45	121.31	1.16	0.17
12	55.0	51.82	94.18	1.62	4.58
13	87.8	68.37	77.81	0.85	0.10
14	105.2	83.68	79.50	1.13	1.57
15	91.9	80.23	87.23	1.26	1.91
16	98.0	89.28	91.07	1.14	1.06
17	65.3	73.78	112.93	1.76	3.78
18	41.7	52.07	124.83	2.81	12.05
19	9.4	27.83	295.57	5.30	31.72
20	4.6	14.08	301.51	3.84	14.86
21	3.5	14.34	409.54	6.09	42.17
22	4.7	21.23	445.19	6.58	48.94
23	1.3	6.03	440.90	5.76	34.00
24	1.7	8.04	463.63	6.09	37.64

**Table 4.17: Fortnightly rainfall statistics for Kota**

<b>Fortnight</b>	<b>Mean Rainfall(mm)</b>	<b>Standard deviation (mm)</b>	<b>C<sub>v</sub>(%)</b>	<b>C<sub>s</sub></b>	<b>C<sub>k</sub></b>
1	2.0	5.60	283.68	3.63	14.59
2	2.1	7.91	375.48	5.07	27.29
3	4.3	13.97	322.39	3.83	13.93
4	1.0	2.66	272.77	3.07	8.91
5	1.5	3.31	219.24	2.24	3.89
6	1.2	5.11	423.85	5.63	32.59
7	1.5	3.80	248.23	2.69	7.17
8	3.6	12.95	360.89	5.00	26.58
9	3.3	10.31	313.46	4.53	22.21
10	8.2	14.80	179.56	2.18	4.23
11	18.4	19.26	104.59	1.64	3.01
12	51.7	62.23	120.29	1.13	0.14
13	100.8	106.07	105.26	3.42	15.59
14	153.9	125.56	81.56	1.14	1.14
15	112.3	61.45	54.70	0.21	0.94
16	134.7	85.93	63.80	0.50	0.74
17	68.9	80.43	116.65	2.54	8.94
18	16.5	24.19	146.94	1.47	0.87
19	17.5	44.20	252.40	3.66	15.05
20	5.1	13.54	267.05	3.25	10.31
21	4.8	19.38	402.51	4.99	26.26
22	4.6	20.51	446.67	5.39	30.10
23	5.0	20.52	412.35	5.20	28.45
24	1.8	5.22	291.74	4.32	21.07

**Table 4.18: Fortnightly Rainfall Statistics for Bhilwara**

<b>Fortnight</b>	<b>Mean Rainfall(mm)</b>	<b>Standard deviation (mm)</b>	<b>C<sub>v</sub> (%)</b>	<b>C<sub>s</sub></b>	<b>C<sub>k</sub></b>
1	4.4	11.06	249.67	2.87	8.38
2	0.0	0.13	374.17	3.74	14.00
3	2.5	8.02	312.03	3.56	12.89
4	2.5	4.91	191.01	2.71	8.19
5	0.2	0.75	310.13	3.49	12.44
6	1.0	2.68	264.38	2.87	8.20
7	2.9	5.54	189.19	1.74	1.65
8	6.3	12.99	204.40	2.66	7.29
9	3.2	6.24	191.09	2.08	3.36
10	5.1	9.15	179.11	1.52	0.58
11	18.3	19.01	103.58	1.05	0.09
12	43.1	59.92	138.95	2.02	4.15
13	97.3	94.80	97.36	1.30	1.65
14	166.0	109.35	65.85	-0.46	1.18
15	89.5	57.94	64.68	0.79	0.86
16	114.1	144.74	126.79	1.90	2.99
17	39.3	34.69	88.17	1.08	0.81
18	9.5	21.81	227.69	3.27	11.25
19	7.7	18.56	239.05	2.80	7.77
20	4.2	14.12	334.03	3.71	13.85
21	0.9	2.64	269.78	2.85	8.04
22	0.5	2.03	374.17	3.74	14.00
23	2.6	9.84	374.17	3.74	14.00
24	0.6	1.87	297.92	3.50	12.58

Also the maximum value of the coefficient of skewness and kurtosis is found in the first fortnight of December and in second fortnight of November and January, minimum value of coefficient of skewness is found in second fortnight of July and the minimum value of the coefficient of kurtosis is found in the first fortnight of June. Similarly, from these tables it may be observed that minimum coefficient of variation  $C_v$  for Udaipur was observed in first fortnight of July and maximum coefficient of variation was observed in second fortnight of March. For Kota minimum coefficient of variation was observed in first fortnight of August and maximum coefficient of variation was observed in second fortnight of March, whereas for Bhilwara minimum coefficient of variation was observed in first fortnight of August and maximum coefficient of variation was found in first fortnight of December.

From the Table 4.19 the mean monthly, seasonal and annual rainfall and rainy days analysis may be observed for Udaipur station, by this analysis it may be seen that the maximum amount of mean monthly rainfall received in the month of July (193.2 mm) and the monsoon rainfall received in the month of June to September and in case of the dry season the minimum monthly mean rainfall is found in the month of the April (2.4 mm). Maximum coefficient of rainfall is observed in the month of the March (503.99 per cent) and the minimum value of variation is found in the month of July (53.88 per cent). Minimum rainy days are observed in the month of April (0.20 days) with the maximum value of coefficient of variation (403.79 per cent)

**Table 4.19: Mean monthly, seasonal and annual rainfall/rainy days of Udaipur.**

Month/season/annual	rainfall			Rainy days		
	Mean (mm)	CV	% of total	Mean	CV	% of total
<b>January</b>	5.6	209.49	0.91	0.48	237.55	1.46
<b>February</b>	3.3	206.09	0.53	0.37	260.42	1.13
<b>March</b>	4.4	503.99	0.72	0.26	329.83	0.80
<b>April</b>	2.4	223.47	0.39	0.20	403.79	0.62
<b>May</b>	8.4	170.83	1.36	0.71	197.78	2.18
<b>June</b>	79.3	75.85	12.81	4.31	148.01	13.17
<b>July</b>	193.2	53.88	31.19	9.26	47.75	28.30
<b>August</b>	190.0	65.33	30.69	9.38	39.58	28.66
<b>September</b>	107.0	92.17	17.29	5.88	87.59	17.97
<b>October</b>	14.1	219.46	2.27	1.10	210.18	3.35
<b>November</b>	8.3	303.08	1.34	0.48	215.95	1.46
<b>December</b>	3.1	316.19	0.50	0.30	293.17	0.91
<b>Monsoon season (Jun to Sep)</b>	569.5	11.07	91.98	28.8	26.24	88.10
<b>Annual</b>	619.2	32.80		32.7	30.05	

and the percentage share for annual rainfall is 0.62 per cent. In case of the seasonal rainfall it may be seen that the mean seasonal rainfall (June to September) is 569.5 mm with the variation of 11.07 per cent and its share in annual rainfall is 91.98 percent. The mean value of rainy days in a year for Udaipur is 32.7 days and in the period of monsoon season the rainy are 28.8 days with the share of 88.10 per cent of annual value.

From the Table 4.20 it may be seen that the maximum part of the rainfall received in the period of month June to September. Minimum rainfall received in the month of March (2.7 mm) with the coefficient of variation 221.99 per cent and contributed in annual rainfall with the share of 0.37 per cent. Maximum rainfall observed in the month of August (247 mm) with the minimum value of coefficient of variation 38.93 per cent, which contributes in annual rainfall with the share of 34.09 per cent. Maximum rainy days observed in the month of August (11.2 day) and minimum rainy days are observed in the month of December (0.3 day). In the monsoon season Kota receives 657.3 mm rainfall with the coefficient of variation 20.73 percent, which contributes 90.70 per cent amount of annual rainfall and in the monsoon season 29.5 rainy days are observed out of the annual value of 33.7 rainy days, with the share of 87.69 per cent.

**Table 4.20: Mean, seasonal and annual rainfall/rainy days of Kota**

Month/season/annual	rainfall			Rainy days		
	Mean (mm)	CV	% of total	Mean	CV	% of total
<b>January</b>	4.1	252.59	0.56	0.4	180.93	1.10
<b>February</b>	5.3	268.42	0.73	0.4	154.09	1.10
<b>March</b>	2.7	221.99	0.37	0.4	180.93	1.10
<b>April</b>	5.1	256.84	0.71	0.4	170.36	1.19
<b>May</b>	11.5	191.64	1.59	0.9	100.98	2.63
<b>June</b>	70.1	99.59	9.68	3.9	64.50	11.46
<b>July</b>	254.7	61.43	35.15	10.1	26.62	29.88
<b>August</b>	247.0	38.93	34.09	11.2	21.62	33.36
<b>September</b>	85.4	92.92	11.79	4.4	85.67	12.99
<b>October</b>	22.5	201.18	3.11	1.0	108.54	2.97
<b>November</b>	9.4	310.13	1.30	0.4	169.02	1.27
<b>December</b>	6.8	306.53	0.93	0.3	175.21	0.93
<b>Monsoon season (Jun to Sep)</b>	657.3	20.73	90.70	29.5	15.70	87.69
<b>Annual</b>	724.8	15.08		33.7	13.73	

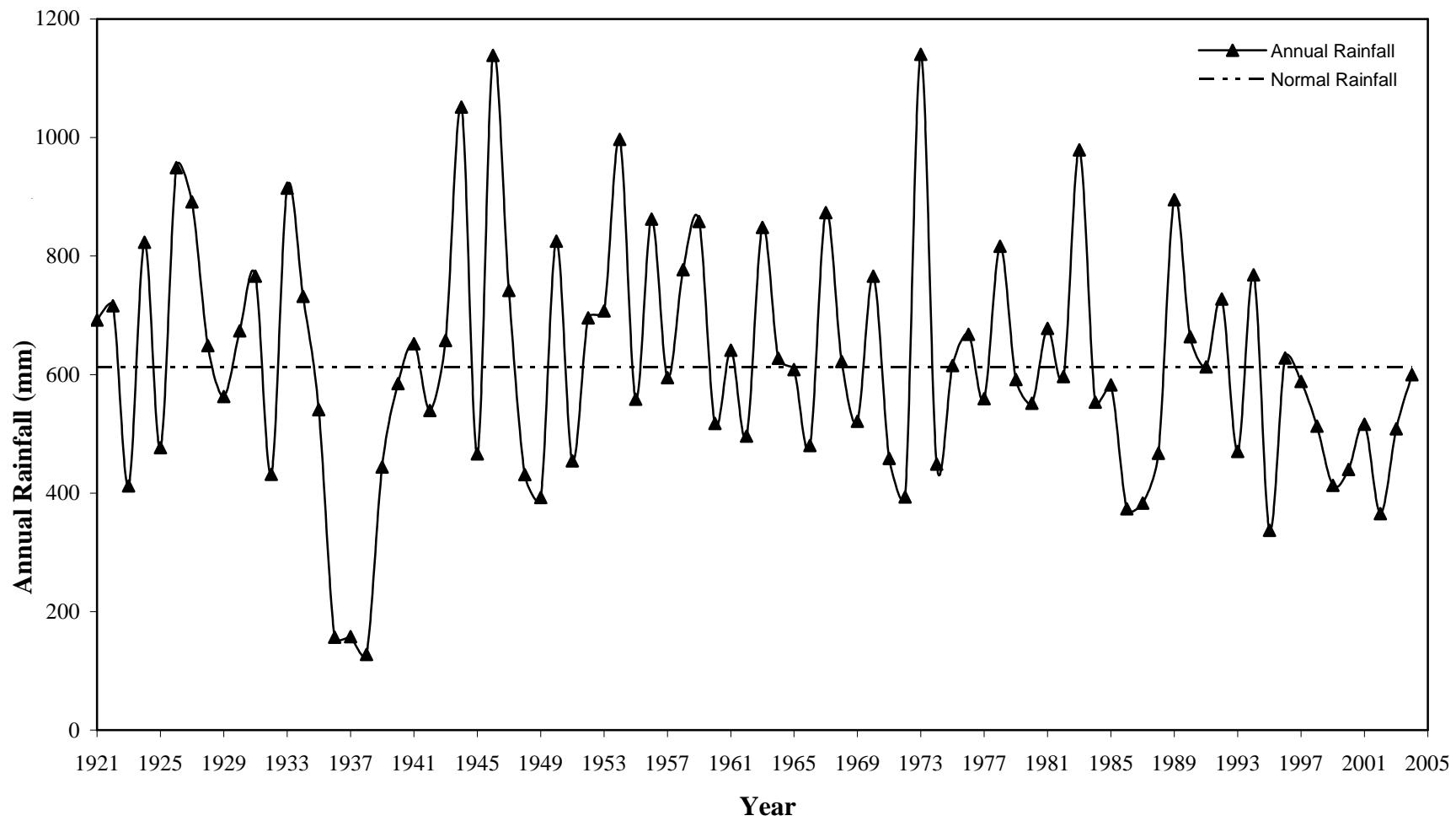
**Table 4.21: Mean, seasonal and annual rainfall/rainy days of Bhilwara**

Month/season/annual	rainfall			Rainy days		
	Mean (mm)	CV	% of total	Mean	CV	% of total
<b>January</b>	4.46	247.34	0.73	0.4	104.69	1.19
<b>February</b>	5.14	183.66	1.37	0.5	87.10	1.67
<b>March</b>	1.26	267.12	0.32	0.1	174.81	0.48
<b>April</b>	9.29	145.88	1.63	0.8	62.38	2.62
<b>May</b>	8.37	115.27	1.93	0.8	77.41	2.62
<b>June</b>	61.48	96.66	10.70	3.6	26.14	12.14
<b>July</b>	263.43	51.52	37.25	9.7	22.35	32.38
<b>August</b>	203.74	82.61	33.22	9.3	14.82	30.95
<b>September</b>	48.93	76.01	6.59	3.8	39.05	12.62
<b>October</b>	11.99	264.59	4.38	0.5	100.80	1.67
<b>November</b>	1.52	207.34	0.48	0.3	121.01	0.95
<b>December</b>	3.26	305.39	1.39	0.2	140.25	0.71
<b>Monsoon season (Jun to Sep)</b>	559.1	25.79	87.76	26.4	7.60	88.10
<b>Annual</b>	637.0	16.67		30.0	6.00	

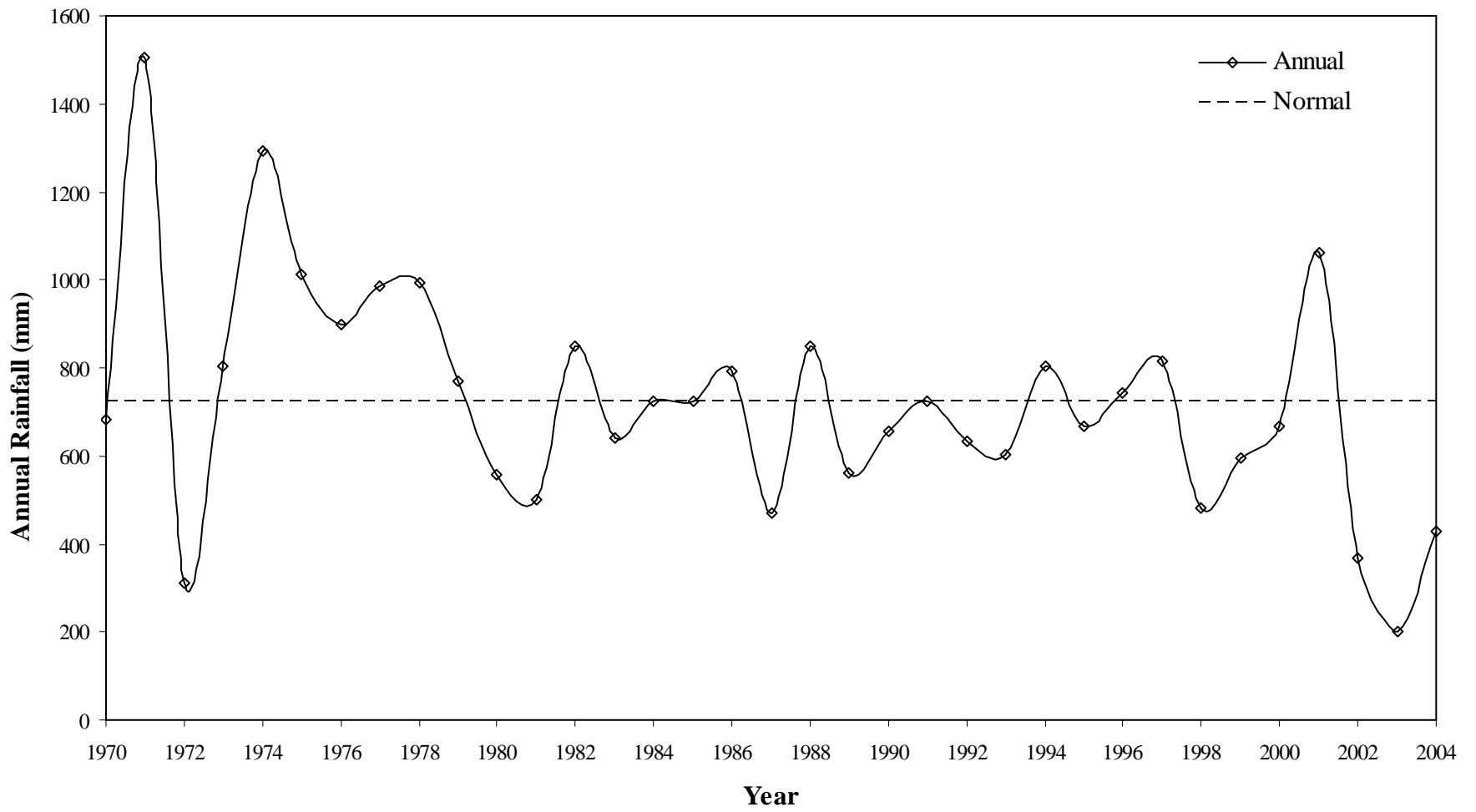
From the Table 4.21 it may be seen that the minimum rainfall received in the month of march (1.26 mm) and maximum rainfall in the month of July (263.43 mm) with the minimum value of coefficient of variation 51.52 per cent, which contributes in annual rainfall with the share of 37.25 per cent. Maximum rainy days are observed in the month of July (32.38) and minimum rainy days in March (0.1 day). In the monsoon season received amount of rainfall is 559.1 mm with the coefficient of variation of 25.79 per cent, which contributes the 87.76 per cent part of the annual rainfall. In the monsoon season 26.4 rainy days are observed out of the annual value of 30 days.

Variation in annual rainfall from 1921-2004 for Udaipur and from 1970-2004 for Kota and 1991-2004 for Bhilwara is shown in Figs. 4.5, 4.6 and 4.7, respectively. From these figures it is revealed that there exist 5-6 to 6-7 years cycle i.e. after every 5-6 to 6-7 years, there was more or less a regular recurrence of similar amounts of annual rainfall. Monthly rainfall analysis has been depicted in Table 4.19 to Table 4.21. From the Tables it may be inferred that the variation in rainfall from year to year is very less.

The data of every station were analyzed for adequacy of length of record for prediction and rainfall analysis using Mockus test described in section 3.4.6. It was found that the minimum 12 years data were required for Udaipur, 8 years for Kota and 7 years for Bhilwara stations, but in this analysis maximum available data were used for estimation.



**Fig 4.5: Distribution of annual rainfall at Udaipur**



**Fig 4.6: Distribution of annual rainfall at Kota**



**Fig 4.7: Distribution of annual rainfall at Bhilwara**

## 4.2 PROBABILITY ANALYSIS OF WEEKLY RAINFALL

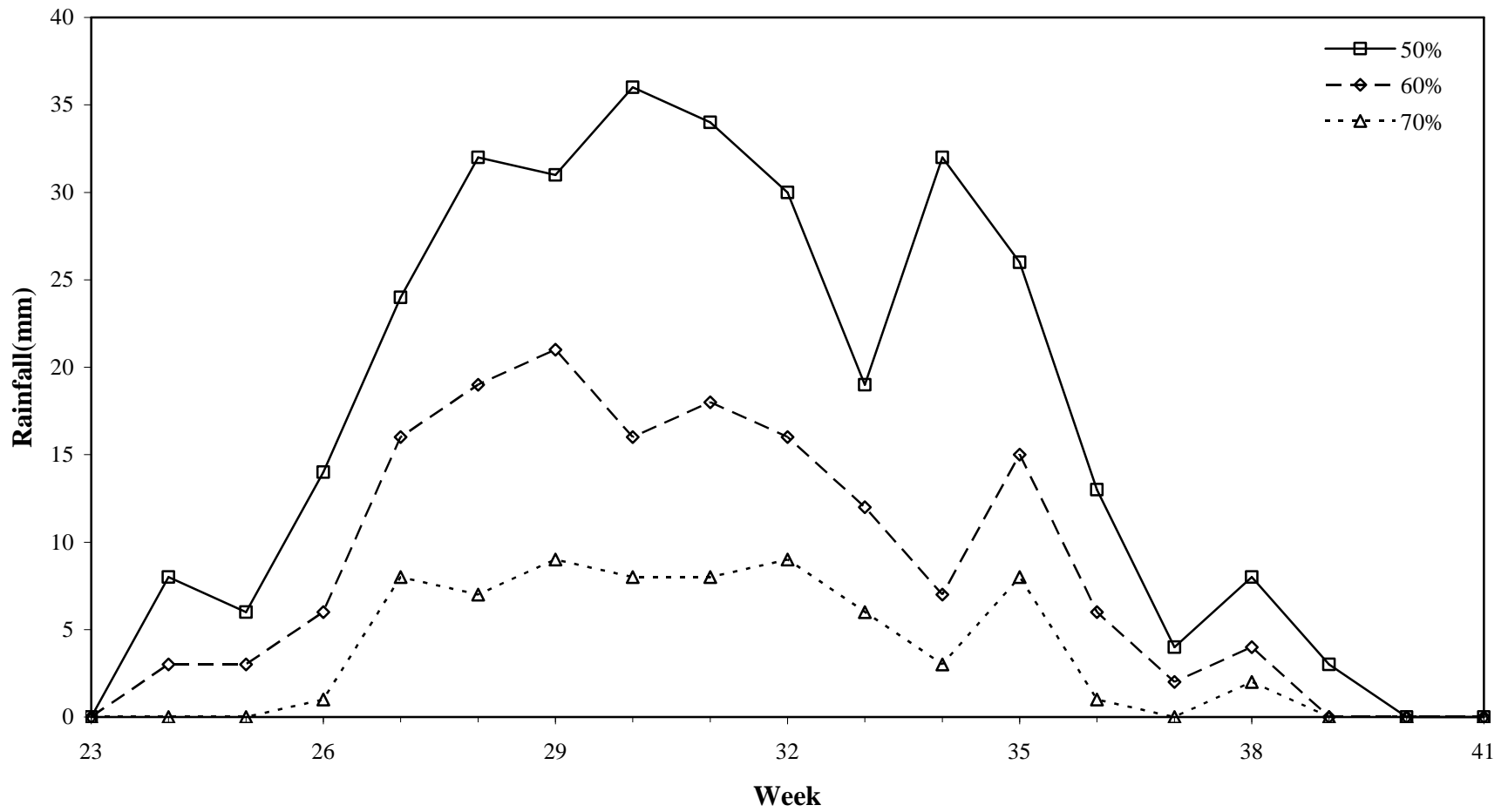
The choice of distribution for the estimation of rainfall amounts at different probability levels, mainly depend on the purpose for which the analysis is to be performed. For planning of many agricultural operations, the total expected rainfall in different weeks is required for planning and designing of hydraulic structures, the analysis is concentrated on annual one day maximum rainfall. Looking into varying needs, the observed rainfall series was transformed into weekly, monthly and annual one day maximum series and the probability analysis was carried out as explained under Section 3.4.

### 4.2.1 Probability of Occurrence of Weekly Rainfall

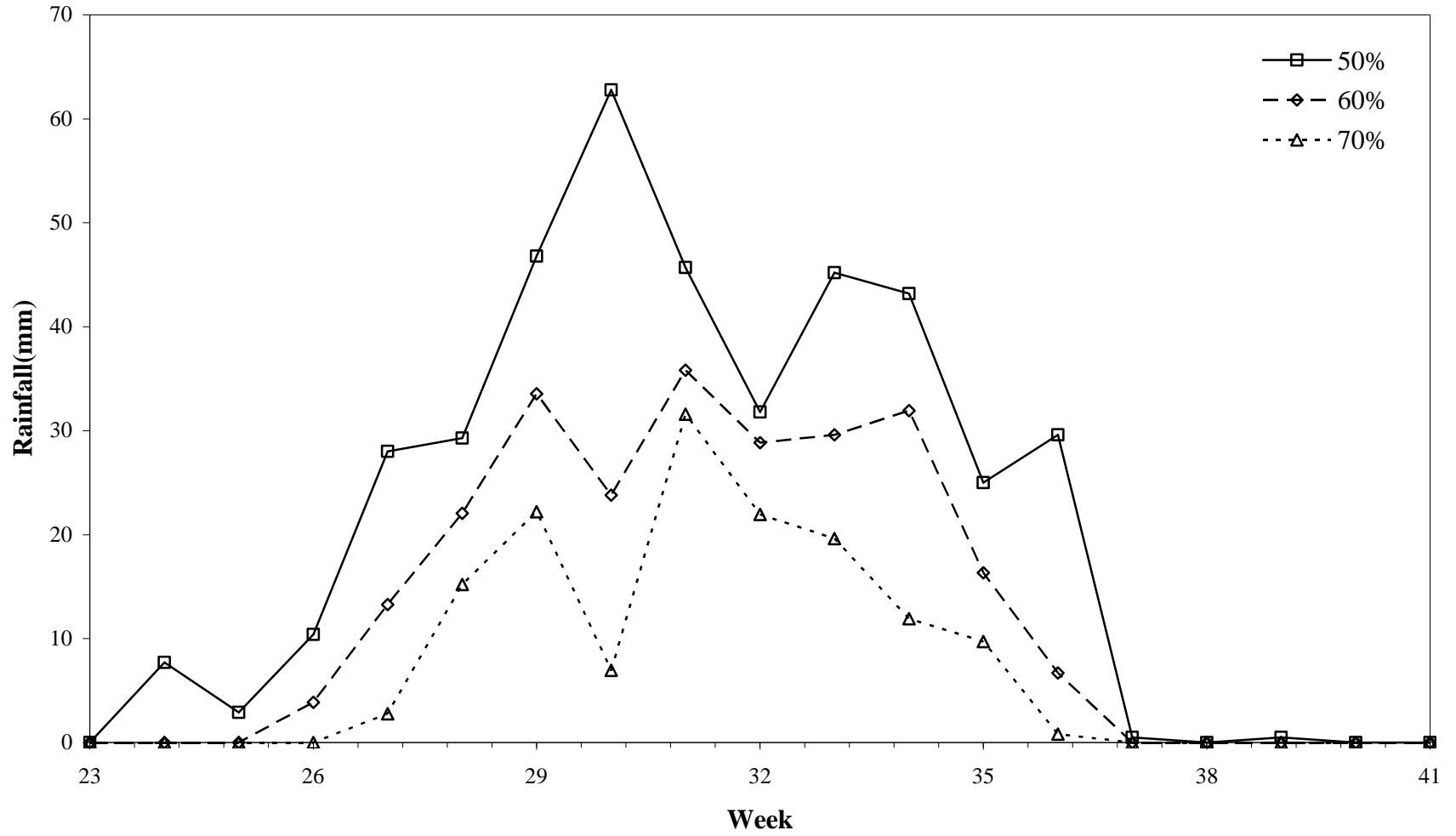
To know the total amount of rainfall available during different weeks in the crop growing season, probability analysis was carried out for weekly rainfall series in the monsoon season (Standard weeks 23-41) using Weibull's formula which is shown in Table 4.22 for Udaipur, Kota and Bhilwara. Rainfall depths during different weeks for 50, 60 and 70% probabilities were read from the Table 4.22 for various stations. Rainfall during different weeks of monsoon season for selected probability levels are depicted in Figs. 4.8, 4.9 and 4.10 respectively for Udaipur, Kota and Bhilwara.

**Table 4.22: Rainfall (mm) at different probabilities using Weibull's formula for Udaipur**

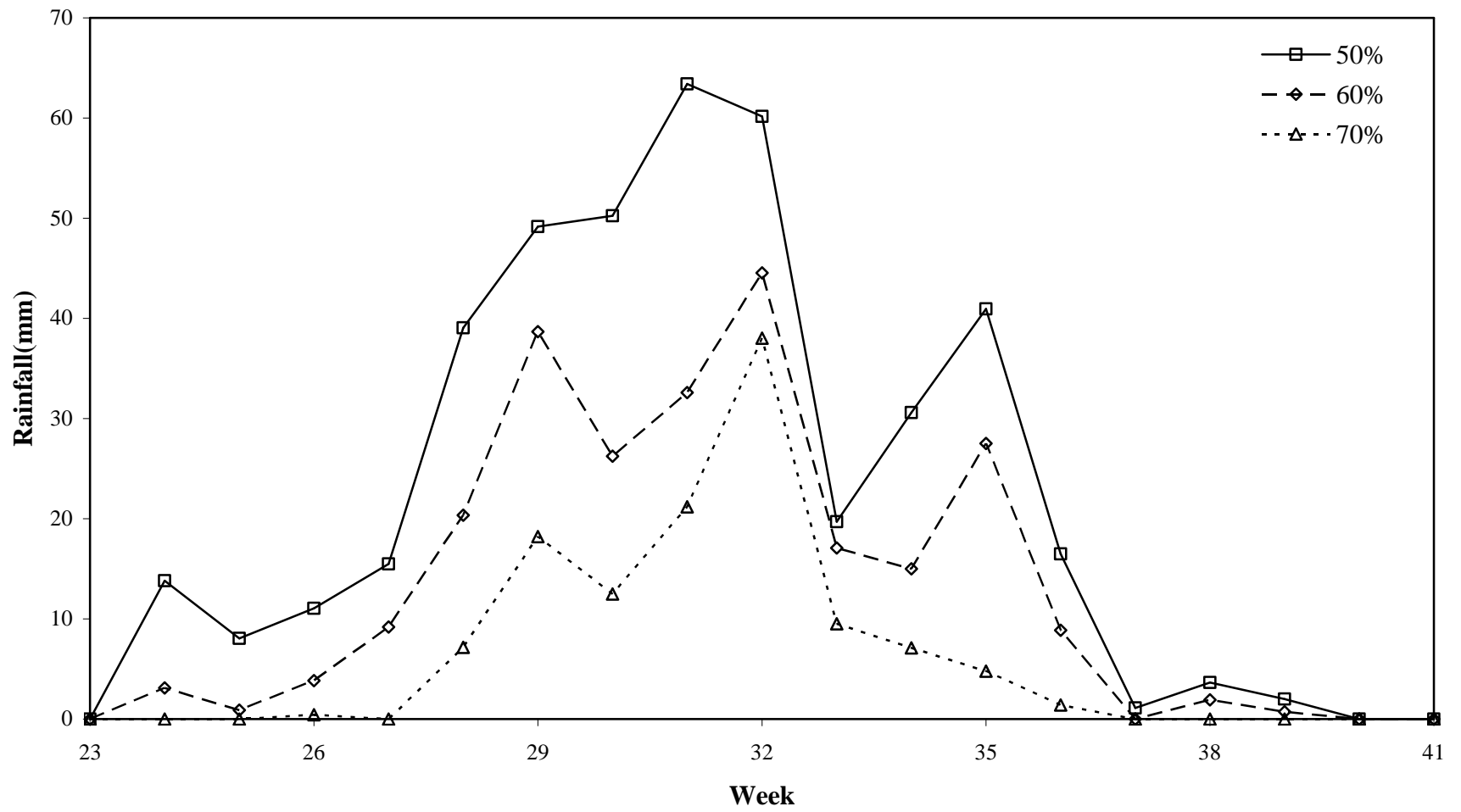
Week	Probability (%)								
	Udaipur			Kota			Bhilwara		
	50	60	70	50	60	70	50	60	70
23	0	0	0	0	0	0	0.0	0.0	0.0
24	8	3	0	7.7	0	0	13.8	3.12	0
25	6	3	0	2.9	0	0	8.05	0.9	0
26	14	6	1	10.4	3.88	0	11.05	3.84	0.42
27	24	16	8	28	13.28	2.76	15.5	9.2	0
28	32	19	7	29.3	22.06	15.2	39.05	20.34	7.17
29	31	21	9	46.8	33.54	22.2	49.15	38.68	18.22
30	36	16	8	62.8	23.8	6.94	50.25	26.24	12.48
31	34	18	8	45.7	35.82	31.6	63.4	32.6	21.19
32	30	16	9	31.8	28.84	21.96	60.15	44.54	38.04
33	19	12	6	45.2	29.6	19.62	19.7	17.08	9.52
34	32	7	3	43.2	31.92	11.92	30.6	15	7.11
35	26	15	8	25	16.34	9.72	40.95	27.52	4.78
36	13	6	1	29.6	6.7	0.8	16.5	8.86	1.4
37	4	2	0	0.5	0	0	1.1	0	0
38	8	4	2	0	0	0	3.65	1.92	0
39	3	0	0	0.5	0	0	2	0.72	0
40	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0



**Fig 4.8: Weekly rainfall at different probabilities at Udaipur**



**Fig 4.9: Weekly rainfall at different probabilities at Kota**



**Fig 4.10: Weekly rainfall at different probabilities at Bhilwara**

It is observed from the fig. 4.8 that rainfall at probabilities 50, 60, 70 percent, increases steadily from 23<sup>rd</sup> week to 28<sup>th</sup> week and from 28<sup>th</sup> to 33<sup>rd</sup> week the increasing trend continues and decreases in 34<sup>th</sup> week and then slightly increases in 35<sup>th</sup> week and then drops suddenly below 5 mm after 37<sup>th</sup> week. From 37<sup>th</sup> to 39<sup>th</sup> week the trend shows a slight increase in rainfall and after 39<sup>th</sup> week it drops almost to zero at Udaipur. For Kota, In fig. 4.9 it is observed that the rainfall increases from 25<sup>th</sup> week to 28<sup>th</sup> week, suddenly rises during 29<sup>th</sup> and 30<sup>th</sup> week and after that decreases steadily up to 32<sup>nd</sup> week and afterwards it slightly increase till 34<sup>th</sup> week and after that drops suddenly below 5 mm in 37<sup>th</sup> week. From 37<sup>th</sup> to 39<sup>th</sup> week the trend shows a slight increase in rainfall and after 39<sup>th</sup> week it drops almost to zero. For Bhilwara it is seen in fig. 4.10 that the rainfall amount increases steadily from 23<sup>rd</sup> to 29<sup>th</sup> week and in 29<sup>th</sup> to 31<sup>st</sup> week it increases rapidly and after that from 32<sup>nd</sup> week it decreases suddenly up to 20 mm in 33<sup>rd</sup> week after that it increases till 35<sup>th</sup> week and drops suddenly below 5 mm in 37<sup>th</sup> week. From 37<sup>th</sup> to 38<sup>th</sup> week the trend shows a slight increase in rainfall and after 39<sup>th</sup> week it drops almost to zero for all the three stations studied.

It is also observed from the Figs. 4.8 to 4.10 that, dependable rainfall (at 70 percent probability) is available from 24<sup>th</sup> to 35<sup>th</sup> week. At 50 and 60 percent level, the rainfall is available from 24<sup>th</sup> to 39<sup>th</sup> week extending the available cropping period by almost 4 weeks.

#### **4.2.2 Probability of Occurrence of Monthly Rainfall**

Rainfall amounts for selected probabilities (90, 75, 50, 25, 10 per cent), using Gamma probability distribution, for each month of the year, along with the results of goodness of fit tests statistics are shown in Table 4.23. It may be seen from Table that the monthly rainfall available from June to October month at 75 per cent probability. However at 50 per cent probability rainfall is available for a long duration and in a large quantity but it is not reliable for agricultural works, so the probability of rainfall at 75 per cent or more may be adopted for a estimate of time and quantity of rainfall. Therefore it may be concluded that the effective monsoon duration is available from June to October month but the significant amount of rainfall is available from June to September. The Gamma probability distribution fits fairly well the chi-square test at 1 percent significance level, except during the December month for all three stations.

#### **4.2.3 Probability of Occurrence of Annual One Day Maximum Rainfall**

In order to estimate annual one day maximum rainfall at different probability levels, six theoretical distributions namely Normal, Log Normal, Gamma, Pearson type III, Log Pearson type III and Extreme value type I (Gumbel) were considered and compared. The results of the

**Table 4.23: Rainfall at selected probabilities using Gamma distribution**

Month	Udaipur						Kota						Bhilwara					
	Probability levels (%)					Chi-square (DF=4)	Probability levels (%)					Chi-square (DF=4)	Probability levels (%)					Chi-square (DF=4)
	90	75	50	25	10		90	75	50	25	10		90	75	50	25	10	
<b>Jan</b>	0	1	3	8	16	10.8	0	1	3	6	11	11.7	0	1	4	12	25	13.3
<b>Feb</b>	0	1	3	6	10	12.3	0	1	3	7	13	12.3	0	1	1	2	4	11.4
<b>Mar</b>	0	1	3	6	12	11.6	0	1	2	4	7	10.9	0	1	1	2	3	10.6
<b>Apr</b>	0	1	2	6	10	10.6	0	1	2	5	8	11.6	0	1	2	5	9	11.5
<b>May</b>	0	1	4	9	17	18.8	0	1	5	13	26	15.8	0	1	2	5	8	12.3
<b>Jun</b>	0	13	34	57	77	4.4	0	0	45	118	184	4.3	0	12	34	57	78	1.4
<b>Jul</b>	39	86	137	190	236	1.2	0	64	148	234	311	1.8	29	95	167	242	308	1.7
<b>Aug</b>	44	109	179	252	316	1.6	65	150	244	340	425	1.4	114	220	338	457	563	1.3
<b>Sep</b>	30	65	128	225	345	1.2	65	116	201	321	461	1.8	57	100	170	268	383	1.9
<b>Oct</b>	5	17	44	92	158	11.2	1	5	17	44	85	13.1	2	10	34	87	166	6.3
<b>Nov</b>	0	1	5	14	28	13	0	1	7	25	55	11.9	0	1	6	16	34	12.9
<b>Dec</b>	0	1	3	11	23	18.2	0	1	4	13	28	19.2	0	1	3	8	14	15.1
<b>Annual</b>	360	460	592	746	907	12.8	409	540	717	928	1151	8.0	516	641	804	993	1185	6.86

**Note:** Chi-square value at 4 DF for 5 % significance level = 9.49, 1 % significance level = 13.3

**Table 4.24: Annual one day maximum rainfall (mm) at selected probability and chi-square values using various distributions for Udaipur**

Type of distribution	Probability (%)											Chi-square (DF=15)
	95	90	80	70	60	50	40	30	20	10	5	
<b>Normal</b>	18.75	32.85	49.92	62.23	72.74	82.57	92.40	102.92	115.23	132.30	146.39	42.10
<b>Log Normal</b>	36.80	43.07	52.11	59.79	67.23	75.03	83.74	94.17	108.04	130.72	153.00	20.76
<b>Gamma</b>	33.25	40.84	51.59	60.47	68.83	77.34	86.51	97.10	110.53	131.08	149.78	28.00
<b>Pearson Type III</b>	34.63	40.50	49.69	57.89	66.05	74.68	84.35	95.87	110.97	134.94	157.47	23.43
<b>Log Pearson Type III</b>	38.27	44.13	52.63	59.90	67.03	74.55	83.04	93.33	107.22	130.44	153.86	20.38
<b>Extream Value Type I ( Gumbel )</b>	36.27	43.42	53.14	61.03	68.44	76.02	84.31	94.07	106.80	127.18	146.73	17.71

**Note:** Chi-square value at 15 DF for 5 % significance level = 24.996,

1 % significance level = 30.578

**Table 4.25 : Annual one day maximum rainfall(mm) at selected probability and chi-square values using various distributions for Kota**

Type of distribution	Probability (%)											Chi-square (DF=6)
	95	90	80	70	60	50	40	30	20	10	5	
<b>Normal</b>	21.63	39.23	60.55	75.92	89.05	101.33	113.60	126.73	142.10	163.42	181.02	8.80
<b>Log Normal</b>	42.51	50.30	61.66	71.42	80.97	91.05	102.38	116.07	134.43	164.81	195.00	3.20
<b>Gamma</b>	37.01	46.52	60.22	71.69	82.61	93.80	105.95	120.08	138.11	165.89	191.35	8.00
<b>Pearson Type III</b>	40.27	43.63	51.06	59.57	69.45	81.20	95.62	114.27	140.63	185.79	231.05	10.00
<b>Log Pearson Type III</b>	42.11	50.00	61.51	71.38	81.02	91.18	102.58	116.33	134.70	164.95	194.85	3.2
<b>Extream Value Type I ( Gumbel )</b>	38.09	48.03	61.55	72.51	82.82	93.36	104.89	118.45	136.17	164.50	191.69	8

**Note:** Chi-square value at 6 DF for 5 % significance level = 12.592,

1 % significance level = 16.812

**Table 4.26 : Annual one day maximum rainfall (mm) at selected probability and chi-square values using various distributions for Bhilwara**

Type of distribution	Probability (%)											Chi-square (DF=2)
	95	90	80	70	60	50	40	30	20	10	5	
<b>Normal</b>	11.34	30.86	54.50	71.55	86.11	99.73	113.34	127.91	144.95	168.59	188.12	1.86
<b>Log Normal</b>	40.27	47.92	59.16	68.86	78.41	88.52	99.94	113.80	132.47	163.53	194.61	0.57
<b>Gamma</b>	30.33	39.82	53.96	66.13	77.94	90.20	103.70	119.55	140.04	172.03	201.68	1.86
<b>Pearson Type III</b>	37.99	40.90	47.76	55.99	65.81	77.71	92.55	111.99	139.76	187.89	236.52	1.00
<b>Log Pearson Type III</b>	42.92	49.37	59.07	67.69	76.41	85.91	96.95	110.84	130.35	164.97	202.26	0.57
<b>Extream Value Type I ( Gumbel )</b>	29.59	40.62	55.62	67.77	79.21	90.90	103.68	118.73	138.37	169.80	199.95	1.86

**Note:** Chi-square value at 2 DF for 5 % significance level = 5.991,

1 % significance level = 9.210

**Table 4.27: Plotting positions for annual one day maximum rainfall at Udaipur using Weibull's method.**

<b>Year</b>	<b>One day maximum rainfall (mm)</b>	<b>Corresponding dates</b>	<b>Values arranged in descending order</b>	<b>Rank M</b>	<b>Plotting position T (years)</b>
1921	93.2	31-Jul	262.2	1	85
1922	122.1	6-Sep	183.8	2	42.5
1923	47.2	17-Aug	165.8	3	28.33
1924	135.1	31-Aug	165.1	4	21.25
1925	91.9	30-Jul	158.2	5	17
1926	138.4	8-Sep	145.4	6	14.167
1927	75.4	3-Jul	138.4	7	12.146
1928	103.1	30-Aug	135.1	8	10.62
1929	94.9	6-Jul	133.5	9	9.44
1930	124.9	11-Jul	131.8	10	8.5
1931	118.6	11-Aug	124.8	11	7.73
1932	48.5	13-Jul	122.4	12	7.08
1933	131.3	28-Jul	119.6	13	6.54
1934	109.2	11-Aug	118.8	14	6.072
1935	46.4	22-Jul	109.2	15	5.67
1936	50.2	26-Aug	105.6	16	5.32
1937	20.5	9-Sep	104.1	17	5
1938	34.6	10-Jun	103.1	18	4.72
1939	66.5	1-Sep	100.8	19	4.47
1940	69.3	26-Aug	98.8	20	4.25
1941	165.8	13-Aug	96.2	21	4.04
1942	88.9	28-Aug	94.9	22	3.86
1943	74.4	30-Jul	94.2	23	3.69
1944	165.1	28-Aug	93.6	24	3.54
1945	48.7	2-Sep	93.6	25	3.4
1946	96.2	30-Jun	93.2	26	3.26
1947	98.6	22-Aug	92.9	27	3.14
1948	42.1	27-Jul	92	28	3.04
1949	44.9	13-Jun	91.9	29	2.93
1950	183.8	18-Sep	91.2	30	2.83
1951	46.2	18-Aug	90.8	31	2.74
1952	61.4	31-Jul	90.8	32	2.65
1953	49.5	8-Jul	90	33	2.57
1954	145.4	10-Sep	88.9	34	2.5
1955	59.2	1-Sep	86.4	35	2.42
1956	90.8	14-Jul	86.2	36	2.36
1957	105.4	24-Aug	84.8	37	2.29
1958	70.2	25-Sep	82.2	38	2.23
1959	54.1	23-Jul	80.6	39	2.17
1960	49.2	9-Aug	75.4	40	2.12
1961	65.5	4-Jul	74.4	41	2.07

<b>Year</b>	<b>One day maximum rainfall (mm)</b>	<b>Corresponding dates</b>	<b>Values arranged in descending order</b>	<b>Rank M</b>	<b>Plotting position T (years)</b>
1962	43.6	13-Aug	72.8	42	2.02
1963	94.2	6-Jul	72.6	43	1.97
1964	57.6	7-Jul	70.2	44	1.93
1965	133.5	28-Aug	70.2	45	1.88
1966	55.6	8-Sep	69.8	46	1.84
1967	84.8	25-Mar	69.4	47	1.80
1968	100.8	31-Jul	69.3	48	1.77
1969	50.1	17-Aug	66.5	49	1.74
1970	72.8	23-Aug	65.5	50	1.7
1971	86.2	30-Jul	65.4	51	1.66
1972	42.2	29-Jul	62.4	52	1.63
1973	86.4	1-Sep	62.2	53	1.60
1974	93.6	21-Aug	61.8	54	1.57
1975	47.3	13-Jul	61.4	55	1.54
1976	72.6	26-Aug	61.2	56	1.51
1977	46	19-Jul	60.3	57	1.49
1978	93.6	17-Aug	60.2	58	1.46
1979	119.6	11-Aug	59.2	59	1.44
1980	60.2	9-Jun	59	60	1.41
1981	62.4	6-Aug	57.6	61	1.39
1982	92.9	9-Nov	56.6	62	1.37
1983	262.2	30-Jun	55.6	63	1.34
1984	65.4	4-Jul	54.1	64	1.32
1985	104.1	1-Aug	50.2	65	1.30
1986	62.2	24-Jul	50.1	66	1.28
1987	43.4	15-Aug	49.5	67	1.26
1988	59	5-Aug	49.2	68	1.25
1989	80.6	4-Sep	48.8	69	1.23
1990	61.8	1-Sep	48.5	70	1.21
1991	90.8	12-Aug	47.3	71	1.19
1992	158.2	28-Jul	47.2	72	1.18
1993	69.4	16-Jul	46.5	73	1.16
1994	82.2	20-Aug	46.2	74	1.14
1995	40.2	30-Jul	46	75	1.13
1996	70.2	16-Jul	44.9	76	1.11
1997	91.2	21-Jun	43.6	77	1.10
1998	60.3	12-Sep	43.4	78	1.08
1999	42	21-Jun	42.2	79	1.07
2000	61.2	9-Jun	42.2	80	1.06
2001	90	11-Jul	42	81	1.04
2002	56.6	29-Jun	40.2	82	1.03
2003	69.8	25-Aug	34.6	83	1.02
2004	92	30-Sep	20.7	84	1.01

**Table 4.28: Plotting positions for annual one day maximum rainfall at Kota using Weibull's method**

<b>Year</b>	<b>One day maximum rainfall (mm)</b>	<b>Corresponding dates</b>	<b>Values arranged in descending order</b>	<b>Rank M</b>	<b>Plotting position T (years)</b>
1970	79	30-Jun	252	1	36.00
1971	174	28-Jul	188.5	2	18.00
1972	37.2	10-Aug	174	3	12.00
1973	100.6	22-Jul	171.2	4	9.00
1974	171.2	22-Jul	167.9	5	7.20
1975	92.2	6-Jul	167.4	6	6.00
1976	88.3	16-Aug	167.4	7	5.14
1977	78	29-Jun	124	8	4.50
1978	167.4	31-Aug	123.6	9	4.00
1979	167.4	31-Aug	115.5	10	3.60
1980	124	26-Jun	113.4	11	3.27
1981	56.3	21-Jul	101	12	3.00
1982	99.8	9-Nov	100.6	13	2.77
1983	65.7	12-Aug	99.8	14	2.57
1984	167.9	5-Sep	96.1	15	2.40
1985	68.8	10-Aug	93.7	16	2.25
1986	96.1	27-Jul	92.2	17	2.12
1987	43.4	1-Sep	91.5	18	2.00
1988	75.9	26-Aug	91.4	19	1.89
1989	115.5	27-Aug	88.3	20	1.80
1990	91.5	5-Aug	79	21	1.71
1991	123.6	25-Jul	78	22	1.64
1992	101	16-Aug	75.9	23	1.57
1993	69.9	19-Aug	73.8	24	1.50
1994	91.4	13-Aug	73.6	25	1.44
1995	69.2	13-Aug	69.9	26	1.38
1996	73.8	25-Jul	69.2	27	1.33
1997	113.4	8-Aug	68.8	28	1.29
1998	73.6	11-Jul	65.7	29	1.24
1999	93.7	30-Jul	56.5	30	1.20
2000	188.5	21-Jul	56.3	31	1.16
2001	252	2-Jul	43.4	32	1.13
2002	56.5	11-Feb	40.2	33	1.09
2003	39.4	16-Sep	39.4	34	1.06
2004	40.2	24-Aug	37.2	35	1.03

**Table 4.29: Plotting positions for annual one day maximum rainfall at Bhilwara using Weibull's method**

Year	One day maximum rainfall (mm)	Corresponding dates	Values arranged in descending order	Rank M	Plotting position T (years)
1991	1-Aug	105	262.4	1	15.00
1992	16-Aug	113	140	2	7.50
1993	11-Jul	36.2	133	3	5.00
1994	2-Jul	262.4	113	4	3.75
1995	26-Jul	54.6	105	5	3.00
1996	8-Aug	88.6	102.2	6	2.50
1997	31-Jul	83	88.6	7	2.14
1998	4-Oct	65.2	84	8	1.88
1999	30-Jul	102.2	83	9	1.67
2000	21-Jul	84	82.2	10	1.50
2001	17-Aug	133	65.2	11	1.36
2002	5-Aug	46.8	54.6	12	1.25
2003	16-Jul	82.2	46.8	13	1.15
2004	23-Aug	140	36.2	14	1.07

analysis are presented in Tables 4.24, 4.25 and 4.26, respectively for Udaipur, Kota and Bhilwara. Chi-square test was performed to test the goodness of fit of the probability distributions to the annual one day maximum rainfall series. It is observed from the Tables 4.24, 4.25 and 4.26 that all the probability distribution except normal distribution fits equally well for the annual one day maximum rainfall series of Udaipur, Kota and Bhilwara at 5 percent and 1 percent significance levels. Rainfall depths at given probabilities were estimated are presented in Table 4.24, 4.25 and 4.26 for Udaipur, Kota, and Bhilwara, respectively.

In order to test the goodness of fit of estimated rainfall to the observed rainfall, plotting positions of the observed rainfall were estimated, using Weibull's plotting position method and the results are presented in Table 4.27, 4.28 and 4.29. It is observed that the three distributions Log normal, Log pearson type-III and exreamal type-I (Gumbel) distribution fitted equally well to the observed rainfall. Out of the three distributions extreme type I (Gumbel) distribution seems to be closer to observed rainfall for Udaipur, whereas for Kota and Bhilwara Log normal distributions seems to be closer to the observed rainfall.

It is observed from Table 4.24 for Udaipur the probability of occurrence of annual one day maximum rainfall by using Extreme distribution at 10 and 20 years recurrence interval are respectively 127.18 and 146.73mm. Similarly for Kota from Table 4.25 the probability occurrence of annual one day maximum rainfall by using Log Pearson type III distribution at 10 and 20 years recurrence interval are respectively 164.95 and 194.85mm. For Bhilwara from Table 4.26 the probability occurrence of annual one day maximum rainfall by using Log Pearson type III distribution at 10 and 20 years recurrence interval are respectively 164.97 and 202.26mm, which are useful in the design of soil conservation structures and estimation of drainage coefficients.

### **4.3 ASSESSMENT OF WATER AVAILABILITY**

Rainfall amounts for selected probability (10, 25, 50, 75, and 90 percent) using Gamma probability distribution for each month of the year are presented in Table 4.23 for Udaipur, Kota and Bhilwara. Statistics of weekly rainfall presented in Table 4.13, 4.14 and 4.15 for Udaipur, Kota and Bhilwara, respectively, shows a wide variability as is evident from the coefficient of variation of weekly rainfall. Such data do not give enough information about the dependability of rainfall to meet potential demand. Hence, the moisture availability index (MAI) could be used to assess the adequacy of water requirement. Periods with MAI values greater than or equal to 0.34 are considered to be suitable for the production of dry land crops (Virmani et al., 1982) using this information and the onset of monsoon season, the growing dates could be decided.

MAI value in each month in a year presented in Table 4.30 for Udaipur, Kota and Bhilwara reveal that MAI values in excess of 0.34 will commence from July and continues up to the end of September for Udaipur. For Kota it commence from July and continues up to the end of September, and for Bhilwara it commence from July and continues up to the end of September. Thus Udaipur has a period of approximately 12 consecutive weeks of moisture availability for supporting the crop production. MAI at 75 percent dependable precipitation is maximum for the month of August (1.88), and Kota has a period of approximately 20 consecutive weeks of moisture availability for supporting the crop production. MAI at 75 percent dependable precipitation is maximum for the month of August (1.70), and for Bhilwara this period is approximately 18 consecutive weeks of moisture availability for supporting the crop production. MAI at 75 percent dependable precipitation is maximum for the month of August (2.29).

**Table 4.30: Water availability in different month in a year at Udaipur**

Month	Udaipur					Kota					Bhilwara				
	DP in mm at		PE in mm	MAI at 75 %	MAI at 50 %	DP in mm at		PE in mm	MAI at 75 %	MAI at 50 %	DP in mm at		PE in mm	MAI at 75 %	MAI at 50 %
	75 % prob	50 % prob				75 % prob	50 % prob				75 % prob	50 % prob			
<b>Jan</b>	1	3	102.1	0.01	0.03	1	3	91.4	0.01	0.03	1	4	95.6	0.01	0.04
<b>Feb</b>	1	3	123.8	0.00	0.02	1	3	116.5	0.01	0.02	1	1	118.3	0.01	0.01
<b>Mar</b>	1	3	150.6	0.01	0.01	1	2	135.4	0.01	0.01	1	1	122.7	0.01	0.01
<b>Apr</b>	1	2	168.3	0.01	0.01	1	2	154.2	0.01	0.01	1	2	133.8	0.01	0.01
<b>May</b>	1	4	172.3	0.01	0.03	1	5	147.0	0.01	0.03	1	2	176.7	0.01	0.01
<b>Jun</b>	13	34	154.3	0.00	0.29	1	45	107.3	0.01	0.42	12	34	156.2	0.07	0.22
<b>Jul</b>	86	137	109.2	0.58	1.36	64	148	80.1	0.79	1.84	95	167	104.4	0.91	1.59
<b>Aug</b>	109	179	79.7	1.88	3.06	150	244	88.1	1.70	2.77	220	338	95.8	2.29	3.52
<b>Sep</b>	65	128	88.5	1.31	2.27	116	201	107.4	1.07	1.87	100	170	104.4	0.95	1.62
<b>Oct</b>	17	44	114.5	0.04	0.15	5	17	105.1	0.05	0.16	10	34	109.2	0.09	0.31
<b>Nov</b>	1	5	118.7	0.01	0.06	1	7	93.6	0.01	0.07	1	6	97.5	0.01	0.06
<b>Dec</b>	1	3	95.4	0.01	0.04	1	4	84.3	0.01	0.05	1	3	92.7	0.01	0.03

DP = Dependable precipitation;

PE = Potential Evaporation;

MAI = Moisture Availability Index;

MAI = DP / PE.

Riply (1966) and Sarkar and Biswas (1980) stated that during early stage of crop growth (first 3 to 4 weeks), the actual evapotranspiration is about one quarter of the potential rate owing to small sparse foliage and that the maximum demand may even slightly exceed the potential rate, if the size of the field is not too large and there is considerable advection of sensible heat in to the crop field. It was also stated that a plant can narrow its stomatal openings to restrict transpiration when there is moisture stress and can grow almost normally as long as the moisture supply does not fall below about three quarters of the potential rate. After completion of grain formation, the water demand declines rapidly becoming very small at the ripening stage (Holmes and Robertson, 1963).

In view of the above classification, it can be assumed that a crop will be nearly normal if it gets moisture varying from 0.3 to 0.7 of the potential evapotranspiration, commencing from germination to completion of the grain-formation stage (Sarkar and Biswas, 1980). Also it was found that the dependable precipitation at 50 percent probability satisfies the criterion of moisture availability index values of 0.3 for early and 0.7 for subsequent growth stages of the crop life (Sarkar and Biswas, 1980).

On the basis of the above facts, dependable precipitation at 50 percent was also calculated Table 4.30. MAI values computed at 50 percent probability shows that the values in excess of 0.34 will commence from the period June-July and continues up to September, which is same as that for 75 percent dependable precipitation. Hence, it can be inferred from the assessment that the crop will have altogether 12 consecutive weeks (July to September) of moisture availability for supporting crop production in Udaipur and Kota has a period of approximately 20 consecutive weeks of moisture availability. For supporting the crop production. MAI at 75 percent dependable precipitation is maximum for the month of August, and for Bhilwara this period is approximately 18 consecutive weeks of moisture availability for supporting the crop production. MAI at 75 percent DP is maximum for the month of August.

For Udaipur the month of August will have maximum MAI value (1.88) followed by September (1.31) and July for dependable precipitation at 50 percent. For Kota the month of August will have maximum MAI value (1.70) followed by September (1.07) and August for dependable precipitation at 50 percent, whereas for Bhilwara the maximum value of MAI is seen in August (2.29) and followed by September (0.95) and August (3.52) for dependable precipitation at 50 percent probability.

#### **4.4 RAINFALL PROBABILITY BY MORKOV CHAIN PROCESS**

Initial and conditional probabilities for rainfall amounts 5mm, 10mm and 20mm during 1 to 52 weeks have been estimated using the computer program (Appendix – A). The details of the relationships have been used given in Section 3.6 of this report. The results are given in Tables 4.31, 4.32 and 4.33 for Udaipur, Kota and Bhilwara, respectively. On the basis of probability of occurrence of 10mm of rainfall in two consecutive weeks, the data were divided into dry season (probability < 16), pre-monsoon and post-monsoon season (probabilities 16 to 39) and monsoon season (probabilities  $\geq 40$ ) (Virmani et al., 1982). It is apparent that most dependable period of rainfall amounts of 10mm or more is from 24<sup>th</sup> week for Udaipur (Table 4.31), for Kota the most dependable period of rainfall amount of 10mm or more is from 25<sup>th</sup> week (Table 4.32), and for Bhilwara the most dependable period of rainfall amounts of 10mm or more is from 24<sup>th</sup> week (Table 4.33).

The analysis of initial and conditional probabilities of  $DP/PE \geq 0.34$  as shown in figs. 4.14, 4.15 and 4.16 for Udaipur, Kota and Bhilwara, respectively. It is observed that the rainfall distribution at Udaipur is restricted to about 11 weeks (27 to 37 Std. weeks), for Kota it is restricted to about 10 weeks (26 to 35 Std. weeks), and for Bhilwara is restricted to about 12 weeks (25 to 37 Std. weeks). It is evident that rainfall distribution is highly erratic, as only 8-9 points of conditional probability of wet period followed by wet period [P(W/W)] exceed the 70 percent threshold. Also the conditional probability of wet week preceded by dry week [P(W/D)] prevailed during all the weeks of monsoon period.

#### **4.5 PREDICTION OF WEATHER SPELLS AND WEATHER CYCLES**

##### **4.5.1 Conditional Probabilities**

The conditional probabilities  $\pi(W/W)$ ,  $\pi(D/D)$ ,  $\pi(D/W)$  and  $\pi(W/D)$  which serve as the basic elements in the simulation of weather spells and weather cycles, were estimated for each month June, July, August and September. These estimates along with observed frequencies are given in Table 4.34 for Udaipur, Kota and Bhilwara. Also, the pooled estimates for each of the four conditional probabilities are computed by pooling the corresponding frequencies from June to September.

Table 4.38 shows that conditional probabilities  $\pi(W/W)$  start increasing from June i.e. onset of monsoon and is the highest in the month of August (0.5496) for Udaipur, and in the month of August (0.5802) at Kota and in the month of July (0.5362) at Bhilwara. A similar trend is also seen in case of  $\pi(W/D)$ . Also it can be noticed that the corresponding unconditional probabilities is very marked.

**Table 4.31 : Initial and Conditional probability of rainfall at Udaipur.**

Std week	Rainfall $\geq 5\text{mm}$			Rainfall $\geq 10\text{mm}$			Rainfall $\geq 20\text{mm}$		
	P(W)	P(W/D)	P(W/W)	P(W)	P(W/D)	P(W/W)	P(W)	P(W/D)	P(W/W)
<b>Pre-Monsoon Season</b>									
22	21.43	20.78	28.57	16.67	16.46	20.00	10.71	10.98	0.00
23	27.38	30.30	16.67	22.62	22.86	21.43	17.86	17.33	22.22
<b>Monsoon Season</b>									
24	54.76	54.10	56.52	45.24	43.08	52.63	28.57	30.43	20.00
25	53.57	50.00	56.52	45.24	41.30	50.00	33.33	35.00	29.17
26	61.90	48.72	73.33	52.38	47.83	57.89	45.24	46.43	42.86
27	75.00	71.88	76.92	69.05	65.00	72.73	57.14	54.35	60.53
28	71.43	61.90	74.60	66.67	61.54	68.97	59.52	55.56	62.50
29	78.57	62.50	85.00	69.05	64.29	71.43	60.71	58.82	62.00
30	72.62	38.89	81.82	65.48	50.00	72.41	57.14	51.52	60.78
31	76.19	60.87	81.97	67.86	58.62	72.73	58.33	50.00	64.58
32	77.38	65.00	81.25	70.24	55.56	77.19	58.33	45.71	67.35
33	71.43	57.89	75.38	64.29	56.00	67.80	48.81	40.00	55.10
34	63.10	50.00	68.33	58.33	53.33	61.11	54.76	51.16	58.54
35	72.62	54.84	83.02	69.05	57.14	77.55	59.52	42.11	73.91
36	61.90	26.09	75.41	53.57	23.08	67.24	41.67	23.53	54.00
37	48.81	37.50	55.77	40.48	30.77	48.89	30.95	18.37	48.57
38	59.52	55.81	63.41	48.81	36.00	67.65	32.14	25.86	46.15
39	47.62	35.29	56.00	44.05	39.53	48.78	30.95	31.58	29.63
<b>Post Monsoon Season</b>									
40	20.24	6.82	35.00	15.48	8.51	24.32	5.95	3.45	11.54
41	15.48	8.96	41.18	10.71	5.63	38.46	5.95	2.53	60.00

Cont.

Std week	Rainfall $\geq 5\text{mm}$			Rainfall $\geq 10\text{mm}$			Rainfall $\geq 20\text{mm}$		
	P(W)	P(W/D)	P(W/W)	P(W)	P(W/D)	P(W/W)	P(W)	P(W/D)	P(W/W)
<b>Dry Season</b>									
42	9.52	7.04	23.08	4.76	1.33	33.33	3.57	2.53	20.00
43	5.95	3.95	25.00	5.95	5.00	25.00	2.38	2.47	0.00
44	4.76	5.06	0.00	3.57	3.80	0.00	3.57	3.66	0.00
45	3.57	3.75	0.00	2.38	2.47	0.00	1.19	1.23	0.00
46	5.95	6.17	0.00	4.76	4.88	0.00	2.38	2.41	0.00
47	8.33	6.33	40.00	5.95	5.00	25.00	4.76	3.66	50.00
48	3.57	1.30	28.57	3.57	1.27	40.00	0.00	0.00	0.00
49	3.57	3.70	0.00	1.19	1.23	0.00	1.19	1.19	0.00
50	4.76	3.70	33.33	1.19	1.20	0.00	1.19	1.20	0.00
51	4.76	5.00	0.00	2.38	2.41	0.00	2.38	2.41	0.00
52	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	4.82	4.82	0.00	4.82	4.82	0.00	3.61	3.61	0.00
2	7.14	7.50	0.00	5.95	6.25	0.00	3.57	3.70	0.00
3	3.57	3.85	0.00	2.38	2.53	0.00	1.19	1.23	0.00
4	4.76	3.70	33.33	3.57	2.44	50.00	2.38	2.41	0.00
5	4.76	5.00	0.00	1.19	1.23	0.00	0.00	0.00	0.00
6	7.14	7.5	0.00	2.38	2.41	0.00	1.19	1.19	0.00
7	5.95	5.13	16.67	2.38	2.44	0.00	1.19	1.20	0.00
8	7.14	6.33	20.00	3.57	2.44	50.00	0.00	0.00	0.00
9	4.76	5.13	0.00	3.57	3.70	0.00	1.19	1.19	0.00
10	1.19	1.25	0.00	1.19	1.23	0.00	0.00	0.00	0.00
11	2.38	2.41	0.00	1.19	1.20	0.00	1.19	1.19	0.00
12	4.76	4.88	0.00	3.57	3.61	0.00	2.38	2.41	0.00
13	4.76	2.50	50.00	2.38	1.23	33.33	1.19	0.00	50.00
14	1.19	1.25	0.00	1.19	1.22	0.00	0.00	0.00	0.00
15	2.38	2.41	0.00	1.19	1.20	0.00	1.19	1.19	0.00
16	7.14	7.32	0.00	1.19	1.20	0.00	1.19	1.20	0.00
17	5.95	5.13	16.67	3.57	3.61	0.00	0.00	0.00	0.00
18	5.95	6.33	0.00	3.57	3.70	0.00	0.00	0.00	0.00
19	2.38	2.53	0.00	2.38	2.47	0.00	2.38	2.38	0.00
20	14.29	13.41	50.00	5.95	6.10	0.00	2.38	2.44	0.00
21	8.33	6.94	16.67	5.95	6.33	0.00	2.38	2.44	0.00

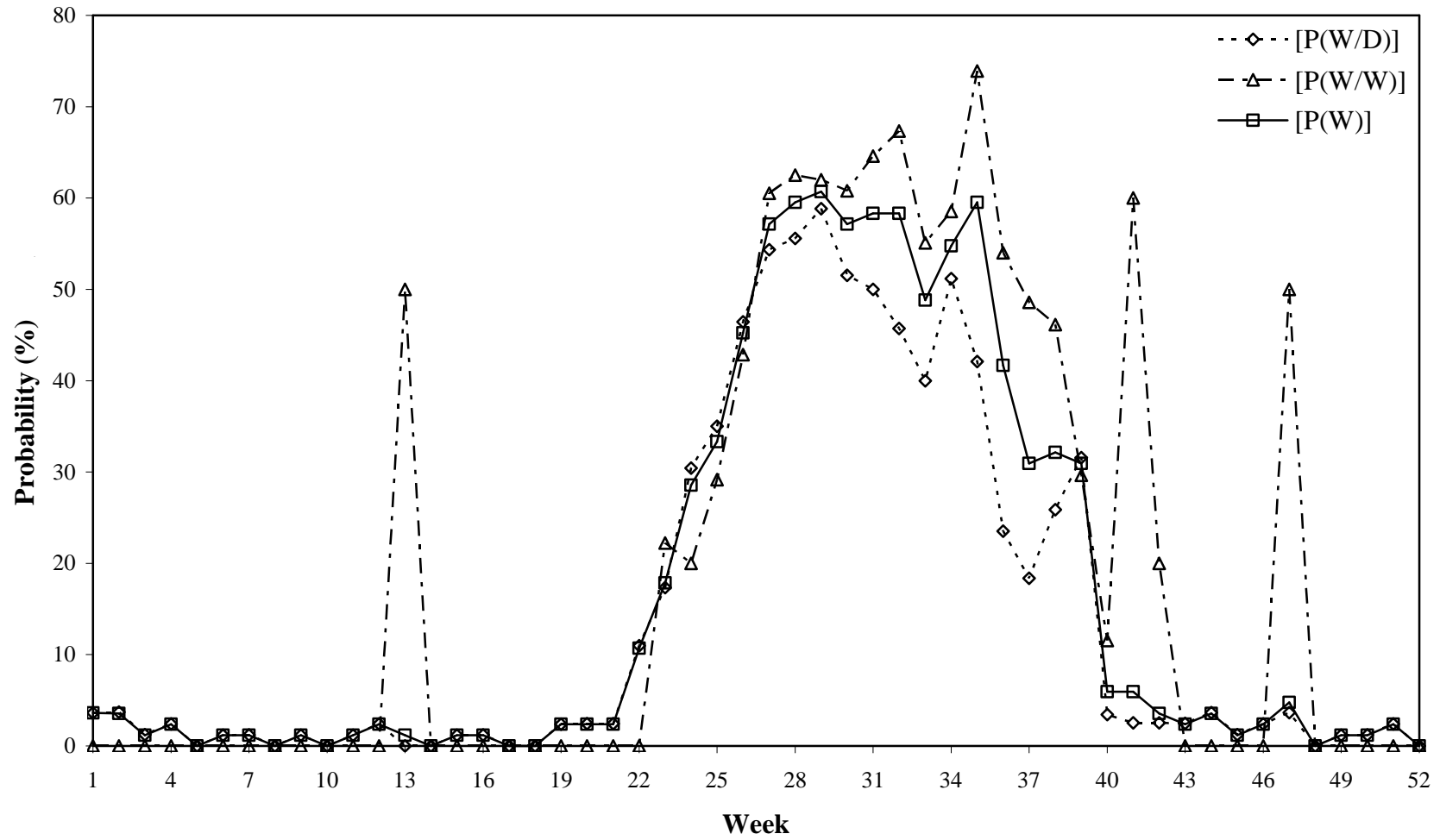


Fig 4.14: Initial and Conditional probabilities of DP/PE > 0.34 at Udaipur

**Table 4.32: Initial and Conditional probabilities (%) of rainfall at Kota**

Std week	Rainfall $\geq$ 5mm			Rainfall $\geq$ 10mm			Rainfall $\geq$ 20mm		
	P(W)	P(W/W)	P(W/D)	P(W)	P(W/W)	P(W/D)	P(W)	P(W/W)	P(W/D)
<b>Pre-Monsoon Season</b>									
22	22.86	16.67	24.14	11.43	0.00	12.90	8.57	0.00	9.38
23	34.29	37.50	33.33	31.43	50.00	29.03	17.14	33.33	15.63
<b>Monsoon Season</b>									
24	54.29	50.00	56.52	45.71	45.45	45.83	11.43	16.67	10.34
25	42.86	47.37	37.50	34.29	37.50	31.58	28.57	50.00	25.81
26	60.00	66.67	55.00	54.29	66.67	47.83	34.29	60.00	24.00
27	65.71	71.43	57.14	65.71	78.95	50.00	57.14	66.67	52.17
28	82.86	82.61	83.33	74.29	73.91	75.00	65.71	60.00	73.33
29	82.86	86.21	66.67	80.00	88.46	55.56	71.43	73.91	66.67
30	74.29	79.31	50.00	68.57	75.00	42.86	60.00	64.00	50.00
31	77.14	84.62	55.56	77.14	83.33	63.64	77.14	85.71	64.29
32	91.43	96.30	75.00	85.71	88.89	75.00	80.00	85.19	62.50
33	88.57	90.63	66.67	74.29	73.33	80.00	71.43	71.43	71.43
34	71.43	70.97	75.00	71.43	69.23	77.78	68.57	68.00	70.00
35	80.00	84.00	70.00	71.43	80.00	50.00	57.14	66.67	36.36
36	62.86	78.57	0.00	57.14	72.00	20.00	54.29	65.00	40.00
37	40.00	50.00	23.08	40.00	50.00	26.67	22.86	26.32	18.75
38	34.29	57.14	19.05	25.71	35.71	19.05	11.43	25.00	7.41
39	17.14	50.00	0.00	14.29	33.33	7.69	11.43	25.00	9.68
<b>Post Monsoon Season</b>									
40	20.00	33.33	17.24	17.14	20.00	16.67	11.43	25.00	9.68
41	11.43	14.29	10.71	11.43	16.67	10.34	11.43	25.00	9.68

Cont.

Std week	Rainfall $\geq$ 5mm			Rainfall $\geq$ 10mm			Rainfall $\geq$ 20mm		
	P(W)	P(W/W)	P(W/D)	P(W)	P(W/W)	P(W/D)	P(W)	P(W/W)	P(W/D)
<b>Dry Season</b>									
42	8.57	0.00	9.68	8.57	0.00	9.68	5.71	0.00	6.45
43	11.43	33.33	9.38	5.71	0.00	6.25	2.86	0.00	3.03
44	2.86	0.00	3.23	2.86	0.00	3.03	2.86	0.00	2.94
45	2.86	0.00	2.94	2.86	0.00	2.94	2.86	0.00	2.94
46	5.71	0.00	5.88	5.71	0.00	5.88	2.86	0.00	2.94
47	2.86	50.00	0.00	2.86	50.00	0.00	2.86	0.00	2.94
48	8.57	0.00	8.82	5.71	0.00	5.88	0.00	0.00	0.00
49	2.86	0.00	3.13	2.86	0.00	3.03	2.86	0.00	2.86
50	5.71	0.00	5.88	5.71	0.00	5.88	5.71	0.00	5.88
51	2.86	0.00	3.03	0.00	0.00	0.00	0.00	0.00	0.00
52	5.71	0.00	5.88	0.00	0.00	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	11.43	0.00	11.43	8.57	0.00	8.57	2.86	0.00	2.86
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4	5.71	0.00	5.71	2.86	0.00	2.86	2.86	0.00	2.86
5	5.71	50.00	3.03	2.86	99.99	0.00	0.00	0.00	0.00
6	8.57	0.00	9.09	2.86	0.00	2.94	2.86	0.00	2.86
7	5.71	0.00	6.25	5.71	0.00	5.88	0.00	0.00	0.00
8	2.86	0.00	3.03	0.00	0.00	0.00	0.00	0.00	0.00
9	11.43	0.00	11.76	2.86	0.00	2.86	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	2.86	0.00	2.86	2.86	0.00	2.86	0.00	0.00	0.00
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	2.86	0.00	2.86	2.86	0.00	2.86	0.00	0.00	0.00
14	5.71	0.00	5.88	0.00	0.00	0.00	0.00	0.00	0.00
15	5.71	0.00	6.06	2.86	0.00	2.86	0.00	0.00	0.00
16	5.71	0.00	6.06	2.86	0.00	2.94	0.00	0.00	0.00
17	5.71	50.00	3.03	5.71	0.00	5.88	5.71	0.00	5.71
18	5.71	0.00	6.06	2.86	0.00	3.03	0.00	0.00	0.00
19	8.57	0.00	9.09	5.71	0.00	5.88	0.00	0.00	0.00
20	11.43	66.67	6.25	11.43	50.00	9.09	11.43	0.00	11.43
21	17.14	0.00	19.35	11.43	0.00	12.90	8.57	0.00	9.68

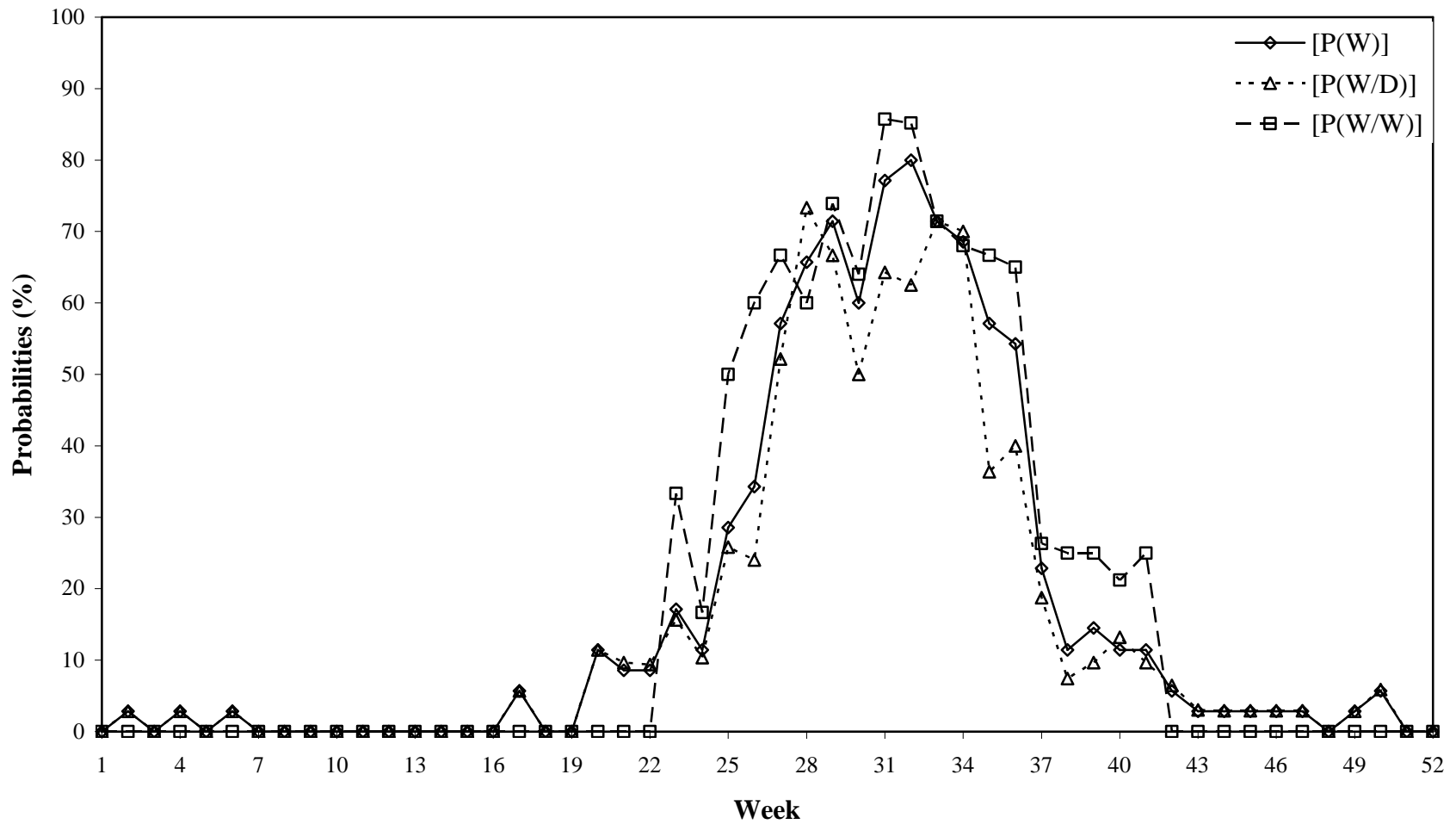


Fig. 4.15: Initial and Conditional probabilities of DP/PE>0.34 at Kota

**Table 4.33: Initial and Conditional probabilities (%) of rainfall at Bhilwara**

Std week	Rainfall $\geq$ 5mm			Rainfall $\geq$ 10mm			Rainfall $\geq$ 20mm		
	P(W)	P(W/W)	P(W/D)	P(W)	P(W/W)	P(W/D)	P(W)	P(W/W)	P(W/D)
<b>Pre-Monsoon Season</b>									
22	5.56	0.00	5.88	5.56	0.00	5.56	5.56	0.00	5.56
23	27.78	0.00	29.41	22.22	0.00	23.53	11.11	0.00	11.76
<b>Monsoon Season</b>									
24	61.11	80.00	53.85	50.00	75.00	42.86	50.00	50.00	50.00
25	55.56	45.45	71.43	50.00	33.33	66.67	33.33	11.11	55.56
26	55.56	40.00	75.00	55.56	33.33	77.78	38.89	16.67	50.00
27	61.11	70.00	50.00	61.11	70.00	50.00	44.44	57.14	36.36
28	77.78	81.82	71.43	61.11	72.73	42.86	61.11	62.50	60.00
29	99.99	99.99	99.99	99.99	99.99	99.99	66.67	63.64	71.43
30	83.33	83.33	0.00	77.78	77.78	0.00	61.11	66.67	50.00
31	77.78	86.67	33.33	77.78	85.71	50.00	72.22	81.82	57.14
32	88.89	85.71	99.99	88.89	85.71	99.99	83.33	84.62	80.00
33	77.78	81.25	50.00	72.22	75.00	50.00	44.44	53.33	0.00
34	77.78	78.57	75.00	66.67	69.23	60.00	55.56	50.00	60.00
35	72.22	85.71	25.00	66.67	75.00	50.00	66.67	70.00	62.50
36	61.11	69.23	40.00	61.11	75.00	33.33	50.00	66.67	16.67
37	44.44	54.55	28.57	44.44	54.55	28.57	33.33	33.33	33.33
38	38.89	37.50	40.00	33.33	25.00	40.00	22.22	16.67	25.00
39	44.44	71.43	27.27	33.33	66.67	16.67	27.78	50.00	21.43
<b>Post Monsoon Season</b>									
40	27.78	37.50	20.00	16.67	0.00	25.00	5.56	0.00	7.69
41	16.67	0.00	23.08	16.67	0.00	20.00	5.56	0.00	5.88

Cont.

Std week	Rainfall $\geq$ 5mm			Rainfall $\geq$ 10mm			Rainfall $\geq$ 20mm		
	P(W)	P(W/W)	P(W/D)	P(W)	P(W/W)	P(W/D)	P(W)	P(W/W)	P(W/D)
<b>Dry Season</b>									
42	5.56	0.00	6.67	5.56	0.00	6.67	5.56	0.00	5.88
43	11.11	0.00	11.76	5.56	0.00	5.88	5.56	0.00	5.88
44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	11.11	0.00	11.11	0.00	0.00	0.00	0.00	0.00	0.00
47	16.67	0.00	18.75	11.11	0.00	11.11	5.56	0.00	5.56
48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49	5.56	0.00	5.56	0.00	0.00	0.00	0.00	0.00	0.00
50	5.56	0.00	5.88	0.00	0.00	0.00	0.00	0.00	0.00
51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	5.56	0.00	5.56	5.56	0.00	5.56	5.56	0.00	5.56
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	11.11	0.00	11.11	11.11	0.00	11.11	5.56	0.00	5.56
3	5.56	0.00	6.25	0.00	0.00	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	5.56	0.00	5.56	0.00	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	5.56	0.00	5.56	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	5.56	0.00	5.56	5.56	0.00	5.56	5.56	0.00	5.56
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	11.11	0.00	11.11	0.00	0.00	0.00	0.00	0.00	0.00
19	5.56	0.00	6.25	5.56	0.00	5.56	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	5.56	0.00	5.56	0.00	0.00	0.00	0.00	0.00	0.00

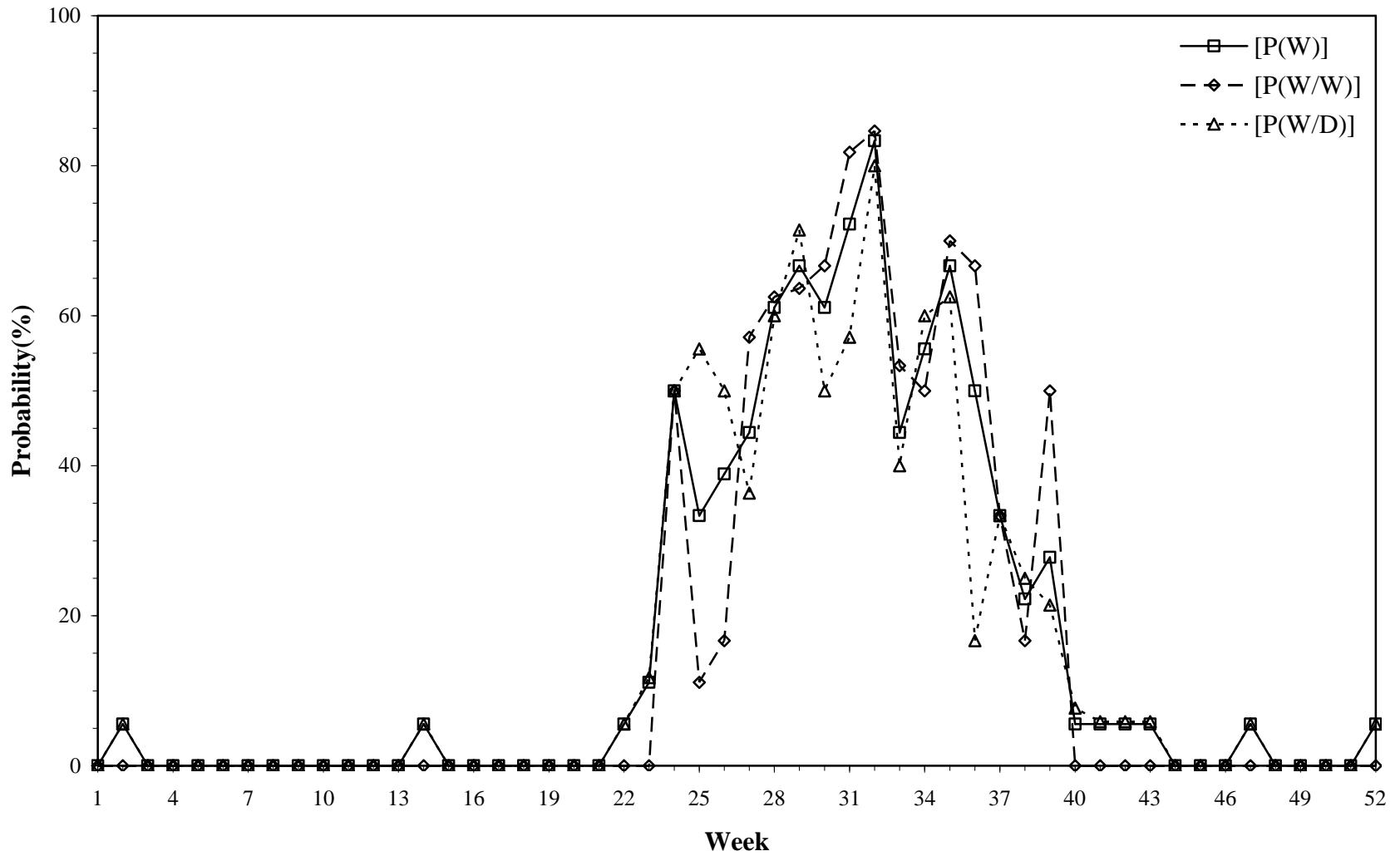


Fig. 4.16: Initial and Conditional probabilities of DP/PE>0.34 at Bhilwara

#### 4.5.2 Wet and Dry Spells

Expected frequencies of wet spells and dry spells were worked out as explained for wet spells and dry spells in Section 3.7 for the months June to September and these compared with the corresponding observed frequencies with the help of Chi-square test. These are presented in Table 4.35 for Udaipur, Table 4.36 for Kota and Tables 4.37 for Bhilwara.

It is seen from Tables 4.35 to 4.37 that the degree of agreement is better in the case of June and August, followed by July and September. The Chi-square values in all the cases are nonsignificant at 5 percent significance level. Wet spells of minimum duration were seen to occur during September followed by June. The highest number of wet spells was occurred during July and August. The totals of observed and expected frequencies in all the four months are observed to be equal. Thus in general, Markov-based geometric model seems to fit well for the prediction of wet spells.

From these Tables (4.35 to 4.37) it is also observed that dry spells unlike wet spells do not seem to confirm to the geometric model as judged from the Chi-square values for each of four months and for the consolidated period, although for the months June, July and August chi-square test statistics is non-significant. In September followed by August, July and June, the corresponding observed frequencies are very high. Also during August the expected frequency of 1 day dry spell is very high as compared to its observed frequency. It is also Observed that the frequencies of higher spell lengths is more during September followed by June.

It is very much interesting to note from Tables 4.35 to 4.37 that observed totals of both wet and dry spells of various lengths are high during July and August. Table 4.38 presents the various observations viz., mean, standard deviation, expected length of wet run, expected length of dry run etc, for the months June to September. It can be seen that the expected length of wet run varies from 1.51 to 2.28 for Udaipur, 1.50 to 2.44 for Kota, and 1.61 to 1.94 for Bhilwara. Whereas for dry run it varies between 4.12 to 6.30 for Udaipur, 3.50 to 6.43 for Kota, and 1.26 to 5.59 for Bhilwara. Thus it can be said that at Udaipur and Kota after every two consecutive wet day a dry day is expected to occur, whereas after 4 to 8 consecutive dry days a wet day is expected to occur. Thus the expected length of a cycle is therefore 6 to 10 days, and for Bhilwara after every two consecutive wet day a dry day is expected to occur, whereas after 3 to 6 dry days a wet day is expected to occur. Thus the expected length of a cycle is therefore 3 to 8 days.

**Table 4.34: Estimation of conditional probabilities of rainfall occurrence from relative frequencies of different months.**

Month	Preceding day	Udaipur				Kota				Bhilwara			
		Actual day		Conditional probability		Actual day		Conditional probability		Actual day		Conditional probability	
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
June	Dry	1908	244	0.8866	0.1134	811	101	0.8893	0.1107	334	33	0.9101	0.0899
	Wet	230	138	0.6250	0.3750	93	45	0.6739	0.3261	31	22	0.5849	0.4151
	Total	2138	382	0.8484	0.1516	904	146	0.8610	0.1390	365	55	0.8690	0.1310
July	Dry	1434	370	0.7949	0.2051	555	165	0.7708	0.2292	232	64	0.7838	0.2162
	Wet	361	439	0.4513	0.5488	166	199	0.4548	0.5452	64	74	0.4638	0.5362
	Total	1795	809	0.6893	0.3107	721	364	0.6645	0.3355	296	138	0.6820	0.3180
August	Dry	1419	368	0.7941	0.2059	506	174	0.7441	0.2559	237	64	0.7874	0.2126
	Wet	368	449	0.4504	0.5496	170	235	0.4198	0.5802	64	69	0.4812	0.5188
	Total	1787	817	0.6863	0.3137	676	409	0.6230	0.3770	301	133	0.6935	0.3065
September	Dry	1722	277	0.8614	0.1386	797	83	0.9057	0.0943	333	31	0.9148	0.0852
	Wet	294	227	0.5643	0.4357	98	72	0.5765	0.4235	34	22	0.6071	0.3929
	Total	2016	504	0.8000	0.2000	895	155	0.8524	0.1476	367	53	0.8738	0.1262
<b>Total</b>		7736	2512	0.7549	0.7549	3196	1074	0.7485	0.2515	1329	379	0.7781	0.2219

It is further apparent from the Table 4.38 that the expected number of dry days during each month varies from 20 to 25 days whereas that of wet days varies from 4 to 11 days. The standard deviation of the distribution is of the order of about 3 days. The period of the days to equilibrium for each month varies from 8 in June and 12 days in September which indicates that the maximum persistency of September to withhold the wet condition the condition is 8 days even through the dry period is almost the same for both June and September it is clear that the initial conditions of June and September are different. The intensity of dry condition before June, decreases as the rainy season advances, especially August experiences a maximum wet condition which results in increasing the persistency of September month to withhold the 'disturbed' condition. This information is useful in preparing the prevailing conditions during its growth period.

#### **4.5.2 Weather Cycles**

Table 4.39, 4.40 and 4.41 give the observed and the expected frequencies for wet-dry (or dry-wet) cycles of various lengths. The dry-wet and wet-dry spell lengths 2 to 15 and more days which are calculated by using the Markov chain model are mostly similar to the observed spells for all the months and there chi square values also mostly in the acceptable range at 1 per cent and 5 per cent significance level. It is evident from the Tables 4.39, 4.40 and 4.41 that the expected frequencies of wet-dry and dry-wet cycles agree well with those of the observed frequencies in all the months except in September as shown by the chi-square test.

In all three months (June-August) the Chi-square values are nonsignificant at 5 percent level except for dry-wet cycle in June month which is nonsignificant at 1 percent level. The observed frequencies of the cycles of longer lengths (say  $\geq 15$ ) are more when compared to those in other months.

Table 4.42 presents the observed and the expected frequencies of wet (or dry) days K days after a wet (or dry) day for two specific values of  $K=2$  and  $K=3$ . As judged by Chi-square values, the agreement between the observed and the expected frequencies is very poor in the case of wet and dry days for the second and third preceding days in all the months. So it may be inferred that the agreement between observed and expected frequencies of wet (or dry) days of K days greater than 1 after a wet (or dry) day will be poor.

**Table 4.35: Expected (E) and Observed (O) frequencies of wet and dry spells of selected lengths at Udaipur**

Length of spell (days)	June				July				Aug				Sep			
	Wet		Dry		Wet		Dry		Wet		Dry		Wet		Dry	
	O	E	O	E	O	E	O	E	O	E	O	E	O	E	O	E
1	223	239	49	43	273	278	162	166	263	265	150	168	275	284	93	89
2	82	90	35	38	106	118	129	132	102	110	129	134	117	124	55	60
3	29	34	31	34	92	111	97	105	60	60	99	106	52	54	43	52
4	6	2	27	30	59	61	76	83	18	33	79	84	23	24	39	45
5	3	5	25	27	31	34	61	66	15	18	16	11	13	10	36	38
6	1	2	21	24	16	18	52	53	10	10	45	53	8	4	25	33
7	-	-	11	21	6	10	38	42	5	11	43	42	1	2	20	29
8	-	-	16	19	3	6	32	33	5	9	31	33	-	-	14	25
9	-	-	15	17	3	3	21	26	-	-	25	27	-	-	19	21
10	-	-	12	12	-	-	11	21	-	-	15	21	-	-	17	18
11	-	-	14	13	-	-	16	17	-	-	15	17	-	-	7	16
12	-	-	14	12	-	-	12	13	-	-	9	13	-	-	9	14
13	-	-	9	10	-	-	9	11	-	-	7	11	-	-	6	12
14	-	-	8	9	-	-	5	8	-	-	6	8	-	-	4	10
15	-	-	11	12	-	-	1	7	-	-	40	47	-	-	81	79
<b>Total</b>	344	370	298	320	589	639	722	783	478	516	709	775	489	502	468	539
<b>Av. length</b>	1.50		5.86		1.94		4.12		2.27		4.72		1.79		6.29	
<b>Chi-square value</b>	14.176		8.36		12.965		14.705		8.085		13.17		4.777		25.197	
<b>DF</b>	5		14		7		14		8		14		6		14	

**Table 4.36: Expected (E) and Observed (O) frequencies of wet and dry spells of selected lengths at Kota**

Length of spell (days)	June				July				Aug				Sep			
	Wet		Dry		Wet		Dry		Wet		Dry		Wet		Dry	
	O	E	O	E	O	E	O	E	O	E	O	E	O	E	O	E
1	71	75	24	26	89	96	81	83	166	172	96	105	84	89	16	19
2	17	19	13	14	63	68	58	59	93	100	72	78	26	38	11	13
3	10	10	11	13	47	49	42	50	56	58	57	58	13	16	10	12
4	1	1	9	11	19	27	37	38	23	34	42	43	3	7	9	11
5	3	3	8	10	15	15	14	19	11	13	12	10	3	5	12	13
6	-	-	7	9	7	8	21	23	7	11	11	12	-	-	7	9
7	-	-	6	8	2	4	15	17	5	7	13	13	-	-	5	8
8	-	-	5	7	1	2	8	13	-	-	11	10	-	-	7	7
9	-	-	4	6	1	1	4	6	-	-	6	7	-	-	6	7
10	-	-	6	6	2	1	7	8	-	-	3	5	-	-	4	6
11	-	-	3	5	-	-	3	3	-	-	3	4	-	-	4	5
12	-	-	7	4	-	-	5	5	-	-	3	4	-	-	27	17
13	-	-	3	4	-	-	3	4	-	-	12	7	-	-	-	-
14	-	-	5	4	-	-	1	3	-	-	-	-	-	-	-	-
15	-	-	2	3	-	-	8	2	-	-	-	-	-	-	-	-
<b>Total</b>	102	109	113	131	246	271	307	333	361	393	341	356	129	155	118	127
<b>Av. length</b>	1.51		5.62		2.44		3.94		2.06		3.49		1.55		6.43	
<b>Chi-square value</b>	0.456		7.437		7.897		22.958		6.298		6.661		7.512		10.144	
<b>DF</b>	4		14		9		14		6		12		4		11	

**Table 4.37: Expected (E) and Observed (O) frequencies of wet and dry spells of selected lengths at Bhilwara**

Length of spell (days)	June				July				Aug				Sep			
	Wet		Dry		Wet		Dry		Wet		Dry		Wet		Dry	
	O	E	O	E	O	E	O	E	O	E	O	E	O	E	O	E
1	25	32	5	5	48	64	29	28	40	64	29	28	21	32	8	5
2	12	13	3	3	28	34	18	20	26	33	21	22	6	13	4	4
3	4	6	2	3	7	18	11	11	12	17	16	18	2	5	4	4
4	2	2	2	2	12	10	10	10	7	9	12	14	3	2	4	3
5	-	-	3	3	-	-	6	7	4	5	12	11	-	-	2	3
6	-	-	3	3	-	-	5	5	-	-	5	6	-	-	21	20
7	-	-	2	3	-	-	5	4	-	-	6	7	-	-	-	-
8	-	-	2	3	-	-	3	3	-	-	1	3	-	-	-	-
9	-	-	3	2	-	-	3	4	-	-	3	2	-	-	-	-
10	-	-	2	2	-	-	2	3	-	-	2	2	-	-	-	-
11	-	-	3	2	-	-	1	1	-	-	2	3	-	-	-	-
12	-	-	2	2	-	-	2	3	-	-	2	2	-	-	-	-
13	-	-	2	2	-	-	2	3	-	-	6	7	-	-	-	-
14	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-
<b>Total</b>	43	53	48	49	95	127	97	102	89	128	117	124	32	52	43	39
<b>Av. length</b>	1.61		4.81		1.82		3.76		1.75		4.09		1.59		1.26	
<b>Chi-square value</b>	2.204		1.769		12.691		1.878		12.655		2.936		9.707		3.218	
<b>DF</b>	3		14		3		12		4		12		3		5	

**Table 4.38: Particulars of different observations for the months June to September**

Particulars	Udaipur				Kota				Bhilwara			
	Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep
<b>Mean</b>	79.29	193.11	189.98	107.04	70.14	254.72	247.04	85.41	61.47	263.42	203.73	48.92
<b>S.D.</b>	60.14	104.08	124.12	98.66	69.86	156.46	96.18	79.36	59.42	135.72	168.30	37.18
<b>C<sub>v</sub></b>	75.86	53.89	65.33	92.17	99.59	61.42	38.93	92.91	96.65	51.52	82.60	76.00
$\pi_1$	0.8667	0.6820	0.6935	0.8769	0.8589	0.6649	0.6212	0.8594	0.8464	0.6874	0.6862	0.8028
$\pi_2$	1.3486	1.1526	1.1349	1.3213	1.1334	1.1269	1.1012	1.3501	1.2007	1.2111	1.2099	1.2254
<b>Expected length of wet run</b>	1.71	2.16	2.08	1.65	1.48	2.19	2.38	1.73	1.6	2.21	2.22	1.77
<b>Expected number of wet days</b>	3.99	9.53	9.19	3.69	4.23	10.05	11.36	4.21	4.60	9.37	9.41	5.91
<b>Expected length of dry run</b>	11.12	4.62	4.70	11.73	9.03	4.36	3.90	10.60	8.81	4.87	4.85	7.21
<b>Expected number of dry days</b>	26.00	20.46	20.80	26.30	25.76	19.94	18.63	25.78	25.39	20.62	20.58	24.08
<b>Expected length of a cycle</b>	12.83	6.78	6.78	13.38	10.51	6.56	6.28	12.33	10.41	7.09	7.07	8.98
<b>No. of days to equilibrium</b>	8	12	11	12	10	11	12	11	10	14	12	12

**Table 4.39: Observed (O) and Calculated (Cal) frequencies of dry-wet and wet dry weather cycles at Udaipur**

Days spell	Jun				Jul				Aug				Sep			
	DRY-WET		WET-DRY		DRY-WET		WET-DRY		DRY-WET		WET-DRY		DRY-WET		WET-DRY	
	O	Cal.	O	Cal.	O	Cal.	O	Cal.	O	Cal.	O	Cal.	O	Cal.	O	Cal.
2	34	22	34	22	28	25	29	25	58	65	69	65	52	58	53	58
3	33	29	32	29	50	61	62	61	61	62	58	62	37	42	35	42
4	30	30	28	30	59	71	63	71	64	72	63	72	15	43	34	43
5	16	28	19	28	60	69	54	69	49	70	45	70	35	41	16	41
6	24	25	21	25	55	62	59	62	51	62	48	62	34	36	33	36
7	14	23	17	23	43	53	46	53	42	53	48	53	28	32	30	32
8	14	20	13	20	39	44	35	44	33	44	38	44	25	28	24	28
9	15	18	14	18	25	36	23	36	39	36	36	36	13	24	11	24
10	15	16	12	16	24	29	22	29	25	29	28	29	13	21	17	21
11	18	14	13	14	19	24	21	24	17	24	16	24	19	18	15	18
12	14	12	14	12	10	19	10	19	16	19	18	19	14	15	18	15
13	11	11	13	11	12	15	11	15	13	15	11	15	10	13	8	13
14	4	10	6	10	9	12	9	12	8	12	11	12	7	11	9	11
15	7	9	12	9	7	10	8	10	9	10	8	10	6	10	7	10
>15	57	56	52	56	30	32	33	32	43	44	45	44	80	78	81	78
<b>TOTAL</b>	306	323	317	323	475	562	474	562	519	617	537	617	404	470	398	470
<b>CHI-SQUARE</b>	23.702		20.080		20.694		20.999		19.983		19.335		33.268		31.877	
<b>DF</b>	14		14		14		14		14		14		14		14	

**Table 4.40: Observed (O) and Calculated (Cal) frequencies of dry-wet and wet dry weather cycles at Kota**

Days spell	June				July				Aug				Sep			
	DRY-WET		WET-DRY		DRY-WET		WET-DRY		DRY-WET		WET-DRY		DRY-WET		WET-DRY	
	O	Cal.	O	Cal.	O	Cal.	O	Cal.	O	Cal.	O	Cal.	O	Cal.	O	Cal.
2	24	18	21	18	28	29	27	29	31	27	33	27	24	17	23	17
3	20	12	19	12	29	27	28	27	24	20	23	20	20	10	19	10
4	18	11	18	11	34	32	33	32	28	30	25	30	12	10	14	10
5	17	11	12	11	28	31	29	31	26	31	28	31	15	10	7	10
6	15	9	14	9	25	27	26	27	31	28	29	28	7	9	12	9
7	4	8	7	8	21	23	22	23	19	24	17	24	6	9	7	9
8	7	8	6	8	14	19	15	19	14	19	14	19	5	8	3	8
9	10	7	2	7	5	15	7	15	7	15	8	15	7	7	3	7
10	6	6	6	6	7	12	2	12	8	12	5	12	3	6	4	6
11	5	5	6	5	2	9	4	9	6	9	7	9	3	6	3	6
12	6	5	6	5	6	7	6	7	2	7	2	7	4	5	4	5
13	5	4	6	4	5	6	4	6	4	5	6	5	37	23	38	23
14	5	4	2	4	3	4	5	4	14	7	13	7	-	-	-	-
15	4	3	4	3	2	3	1	3	-	-	-	-	-	-	-	-
>15	25	22	21	22	9	12	11	12	-	-	-	-	-	-	-	-
<b>Total</b>	150	133	146	133	211	256	212	256	216	234	199	234	116	121	111	121
<b>Chi-square</b>	23.913		18.881		18.073		19.111		22.382		23.008		30.073		31.722	
<b>DF</b>	14		14		14		14		12		12		11		11	

**Table 4.41: Observed (O) and Calculated (Cal) frequencies of dry-wet and wet dry weather cycles at Bhilwara**

Days spell	June				July				Aug				Sep			
	DRY-WET		WET-DRY		DRY-WET		WET-DRY		DRY-WET		WET-DRY		DRY-WET		WET-DRY	
	O	Cal.	O	Cal.	O	Cal.	O	Cal.	O	Cal.	O	Cal.	O	Cal.	O	Cal.
2	8	2	7	2	13	14	10	14	9	5	8	5	8	2	9	2
3	2	3	5	3	8	11	13	11	14	11	15	11	5	3	2	3
4	4	4	6	4	9	12	11	12	10	12	11	12	4	3	4	3
5	5	3	4	3	10	12	6	12	11	12	10	12	5	3	3	3
6	4	3	2	3	7	10	6	10	9	10	8	10	4	3	2	3
7	2	3	5	3	6	9	7	9	7	9	5	9	2	3	2	3
8	1	2	2	2	6	7	4	7	3	7	4	7	1	3	1	3
9	2	2	1	2	3	6	3	6	1	6	2	6	21	15	19	15
10	4	2	3	2	2	5	3	5	4	5	3	5	-	-	-	-
11	3	2	4	2	2	4	3	4	1	4	4	4	-	-	-	-
12	4	2	5	2	2	3	2	3	11	7	12	7	-	-	-	-
13	3	2	4	2	1	2	3	2	-	-	-	-	-	-	-	-
14	18	20	18	20	5	2	5	2	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
>15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>TOTAL</b>	60	50	66	50	74	97	76	97	80	88	82	88	50	35	42	35
<b>CHI-SQUARE</b>	26.033		26.533		13.649		15.803		16.167		14.172		25.400		28.233	
<b>DF</b>	12		12		12		12		10		10		7		7	

**Table 4.42: Observed and Expected frequencies and chi-square values for each row for K=2 and K=3**

Month	Preceding days	K=2						K=3					
		Observed		Expected		Chi-square (DF=1)	Observed		Expected		Chi-square (DF=1)		
		Wet	Dry	Wet	Dry		Wet	Dry	Wet	Dry			
Udaipur	Jun	Wet	84	913	81	1119	38.034	76	955	64	1180	45.152	
		Dry	54	1469	55	1265	32.916	92	1397	58	1218	46.237	
	Jul	Wet	275	1245	319	1088	28.724	290	835	275	1006	29.884	
		Dry	228	856	223	974	14.407	210	1269	243	1079	37.938	
	Aug	Wet	345	769	323	922	26.887	301	811	279	1003	38.488	
		Dry	172	1318	226	1133	43.110	216	1276	246	1075	41.240	
Sep	Wet	149	817	135	1058	56.348	132	1319	110	1130	36.011		
	Dry	152	1402	91	1236	63.184	89	980	97	1183	35.494		
Kota	Jun	Wet	36	326	26	481	53.794	38	302	22	499	89.409	
		Dry	32	656	20	523	41.022	30	680	20	508	63.236	
	Jul	Wet	157	312	146	449	42.630	154	219	130	407	91.271	
		Dry	108	508	110	379	43.944	211	501	118	430	85.019	
	Aug	Wet	161	264	182	346	21.856	146	260	164	374	36.724	
		Dry	224	436	139	417	52.844	259	420	150	397	80.539	
Sep	Wet	44	294	36	449	55.285	31	298	27	485	72.693		
	Dry	26	686	19	546	38.476	39	682	21	517	68.088		
Bhilwara	Jun	Wet	9	82	12	181	54.899	13	79	9	195	70.782	
		Dry	13	316	7	220	47.033	10	318	7	208	59.458	
	Jul	Wet	48	91	54	181	45.418	48	91	47	167	34.608	
		Dry	90	205	39	160	79.348	90	205	42	177	59.286	
	Aug	Wet	77	77	49	160	59.056	50	83	49	160	37.076	
		Dry	56	224	37	188	16.650	83	218	37	188	61.976	
Sep	Wet	11	68	11	184	73.130	10	70	8	197	82.373		
	Dry	12	329	6	219	61.251	9	331	6	208	74.235		

#### **4.6 Agricultural potential of southern Rajasthan in relation to rainfall**

In sub humid areas such as southern Rajasthan, rainfall is an important factor that determines the success or failure of a crop. The fluctuation of rainfall during crop growing season effects the cultivation of required crops. Therefore, quantification of rainfall through appropriate methodologies would be of immense use in crop planning. Here attempts are made to provide the description of agriculture environment of southern Rajasthan through proper analysis of rainfall.

##### **4.6.1 General Description of Agricultural Environment of Southern Rajasthan**

Climatic description of southern Rajasthan is dealt with in section 3.1.2. the variation in annual rainfall for 84 years (1921-2004) at Udaipur, for Kota 35 years (1970-2004) and for Bhilwara 14 years (1991-2004) are represented in Figs. 4.5, 4.6 and 4.7 in which 40 years have recorded above normal and 44 years below normal rainfall at Udaipur, at Kota 16 years have recorded above normal and 19 years below normal rainfall and for Bhilwara 7 years have recorded above normal and 7 years recorded below normal rainfall. The rainfall patterns of semi-arid tropic of Rajasthan shows frequent drought conditions, even during rainy season (Singh and Singh, 1987).

##### **4.6.2 Variation of Rainfall in Time and Onset and Withdrawal of Monsoon**

The distribution of rainfall is uneven over the year and has a wide variability between years to year. Nearly 79 percent of the annual rainfall is received during the period of 16<sup>th</sup> June to 15<sup>th</sup> September (South-West monsoon). Table 4.43 present the analysis of onset, withdrawal and duration of south-west monsoon of the study area.

The delayed onset of monsoon and breaks in rainfall are the two major constraints for the dry farming. From Table 4.43, it is observed that the normal date of onset of monsoon can be as ealy as 7<sup>th</sup> June and as delayed as 12 August at Udaipur, for Kota it is observed that the normal date of onset of monsoon can be as early as 6<sup>th</sup> June and as delayed as 17<sup>th</sup> August and for Bhilwara it is observed that the normal date of onset of monsoon can be as early as 15<sup>th</sup> June and as delayed as 12<sup>th</sup> August. The late onset of monsoon reduces the growing season. Under the delayed monsoon conditions, maize, soybean and pigeon-pea can be sown around mid July. In case of early onset either bleck gram, green gram or early varieties of maize can be successfully harvested.

**Table 4.43: Onset and withdrawal of south-west monsoon**

Particulars		Udaipur		Kota		Bhilwara	
		Onset	Withdrawal	Onset	Withdrawal	Onset	Withdrawal
<b>Median date</b>		2-Jul	28-Sep	6-Jun	4-Oct	14-Jul	15-Sep
<b>Earliest date</b>		7-Jun	18-Aug	6-Jun	17-Aug	15-Jun	12-Aug
<b>Latest date</b>		10-Sep	24-Nov	25-Aug	8-Dec	20-Jul	10-Dec
<b>Mean</b>	<b>Week</b>	26	41	27	40	27	41
	<b>Date</b>	4-Jul	8-Oct	7-Jul	9-Oct	8-Jul	23-Sep
<b>Std. dev.</b>	<b>Week</b>	2.19	3.92	2.10	4.82	2.35	4.83
	<b>Date</b>	15.28	27.81	14.19	34.09	11.37	29.31
<b>C<sub>v</sub></b>	<b>Week</b>	8.22	9.84	7.74	11.92	8.65	11.60
	<b>Date</b>	57	67	55	83	59	81

During kharif seasons one or two dry spells are generally experienced. Short duration breaks may not be of serious concern, however the long duration spells create water stress for crop production.

The analysis of weather spells and weather cycles is done and the results are presented under section 4.5. From Tables 4.39, 4.40 and 4.41 it is observed that the dry spells of larger lengths occurred during September followed by June. Even during mid monsoon dry spells to the extent of 13 days or more prevailed. It is observed that breaks in rainfall to the extent of 4-6 days at Udaipur, 3-6 days at Kota and 2-7 days at Bhilwara. It means that after 4 to 8 consecutive dry days a wet day is expected to occur.

The spells and breaks create more concern if they prevail during the critical stages of crop growth. In such cases the production may fail. Therefore, the crop planning may be done in such a way that the probable periods of dry spells do not coincide with such critical stages of crop.

If the break in the rainfall occurs within 10 days after sowing, it is better to re-sow with subsequent rains, rather than allowing inadequate plant population leading to poor harvest. On the other hand if the crop is in the advanced stage then rationing or thinning operation may be adopted.

**Table 4.44: Weekly Probability of onset and termination of rainfall**

Probability	Udaipur		Kota		Bhilwara	
	Onset	Withdrawal	Onset	Withdrawal	Onset	Withdrawal
>10	24	47	25	48	24	48
>20	25	44	25	45	25	47
>30	26	41	26	43	26	43
>40	26	40	27	41	26	42
>50	27	39	27	40	26	41
>60	27	39	28	38	27	40
>70	27	38	28	37	28	39
>80	28	38	29	36	29	38
>90	29	37	30	35	30	36

In the Table 4.44 the onset and withdrawal of south-west monsoon on various probabilities is presented. From the Table 4.44 it can be seen that mostly in the range of 50 to 70 per cent probability the monsoon commences in 27<sup>th</sup> week and withdrawals in 39<sup>th</sup> week at Udaipur, at Kota generally the monsoon comes in 27<sup>th</sup> or 28<sup>th</sup> week and withdrawals in the 40<sup>th</sup> to 37<sup>th</sup> week and in case of Bhilwara the effective monsoon comes in 26<sup>th</sup> to 28<sup>th</sup> week and withdrawals in 41<sup>st</sup> to 39<sup>th</sup> week. Therefore it may be concluded for this region that the generally onset of monsoon may be considered in the 27 week and the withdrawal of the monsoon may be considered in the 40<sup>th</sup> week.

## V – SUMMARY AND CONCLUSIONS

An attempt has been made to analyse rainfall at Southern Rajasthan statistically, which were latter used in planning various agricultural operations.

The statistical analysis was carried out using 84 years (1921-2004) for Udaipur, 35 years for Kota and for Bhilwara 14 years daily rainfall data. Statistical parameters like mean, standard deviation, coefficient of variation ( $C_v$ ), skewness coefficient ( $C_s$ ) and coefficient of Kurtosis ( $C_k$ ) were estimated for daily rainfall series for months June to September, weekly rainfall and annual rainfall series.

Daily rainfall distribution both in time and quality was found to be very erratic during June as compared to, July to September months. It was also observed that the rainfall pattern to be more consistent during months of July and August from the rest of monsoon months (June and September). And the analysis of  $C_s$  and  $C_k$  revealed that, the daily rainfall during months June to September was positively skewed and highly peaked than normal.

The statistical analysis of rainfall on weekly basis revealed that, about 88 percent of annual total rainfall has occurred during weeks 24 to 34. It was also observed that the Rainfall variation about mean was less during monsoon season (from standard weeks 23 to 39) from the rest of period.

A cycle of 5 to 6 years of regular recurrence of similar amounts of rainfall was observed in the annual rainfall distribution.

The probability of observed rainfall during weeks 23<sup>rd</sup> to 41<sup>st</sup> was carried out by Weibull's plotting method. It was observed that rainfall at 70 percent probability level is available during 24<sup>th</sup> to 35<sup>th</sup> standard weeks.

Probability analysis for each month in a year was carried out by gamma probability distribution and its goodness of fit was tested by Chi-square. These tests were found to be fitted well the gamma probability distribution. Rainfall at some selected probability levels were estimated for each month.

Probability analysis of annual one day maximum rainfall series was carried out by employing six probability distributions namely Normal, Log Normal, Pearson type-III, Log Pearson type-III, Gamma and Gumbel distributions. Goodness of fit of these distributions was tested by Chi- square test and Weibull's plotting position method. It was observed from the six distributions three distributions viz., Log Normal, Pearson type-III and Extremal type-I (Gumbel) fit equally well for annual one day maximum rainfall at Southern Rajasthan. However, the Gumbel distribution was found to be better fit by Weibull's method and could be used to predict one day maximum rainfall at Southern Rajasthan.

To assess the suitability of study area for dry land farming moisture availability index (MAI) was estimated for each of 4-standard week period for a dependable rainfall at 50 percent and 75 percent probability. MAI > 0.34 were observed to be available continuously for 12 weeks (18<sup>th</sup> June 9<sup>th</sup> September). On the basis of this, the study area is found to be suitable for dry land farming.

Weekly initial and conditional wet probabilities of 5mm, 10mm and 20mm rainfall were estimated by using Markov Chain process. The continuity of wet condition was observed to be restricted to about 10 weeks (from standard weeks 27 to 36). It was also observed that, the condition, wet period preceded by dry period prevails much during all the weeks of monsoon period.

Weather spells and weather cycles were analysed and predicted by Markov based model, during months June to September.

It was observed from predicted values of weather spells that, the Markov model seemed to fit well for the prediction of wet spells. Further, even through the Chi-square values were nonsignificant in case of dry spells during all the months except September, dry spells did not seem to confirm to the Markov model. The results of wet and dry run revealed that after every two consecutive wet days, a dry day is expected and after 4 to 8 consecutive dry a wet expected to occur.

The results of predicted values of weather cycles revealed that the expected frequencies of wet-dry and dry-wet cycles agree well with the observed frequencies in all months except during September.

The expected frequencies of wet (or dry) days, K days after a wet (or dry) day for K=2 and K=3 were also estimated by the same model. The agreement between the observed and expected frequencies was observed to be very poor.

Considering onset, withdrawal and duration of South-west monsoon and the effect of variation of rainfall in quantity and time on the agricultural potential of Southern Rajasthan were analysed and suggestions have been made for carrying out various agricultural operations.

## **CONCLUSIONS**

Based on the results of the present study, the following major conclusions could be drawn.

1. The daily rainfall pattern was found to be more consistent during months of July and August from the rest of monsoon months (June and September). There was no considerable variation in weekly rainfall pattern both in time and quantity during 24<sup>th</sup> to 39<sup>th</sup> weeks during the study period.

2. The variation in the annual rainfall pattern was very less and there existed a 5 to 6 years of regular recurrence of similar amounts of annual rainfall during study period.
3. Dependable rainfall (at 70 percent probability) was observed to be available from 24<sup>th</sup> to 35<sup>th</sup> weeks. Considering rainfall at 50, 60 and 70 percent probability a total of 16 weeks (24<sup>th</sup> to 39<sup>th</sup> weeks) are available for kharif crops under rainfed conditions.
4. The extremal type-I (Gumbel) probability distribution was maximum rainfall. At 10 and 20 years recurrence interval, annual day maximum rainfall was found to be 127.1mm and 106.8mm for Udaipur, 164.5mm and 136.1mm for Kota and for Bhilwara 169.8mm and 138.3mm respectively.
5. Moisture availability indices (MAI) of values greater than or equal to 0.34 were found to be during 18<sup>th</sup> June to 9<sup>th</sup> September and the crop will have 12 consecutive weeks of moisture availability for supporting crop production at the study area.
6. The initial and conditional probability of 10mm rainfall revealed that, the weeks preceded by dry weeks, prevailed during all the weeks of monsoon period (23<sup>th</sup> to 39<sup>th</sup> weeks) and that the rainfall distribution was found to be restricted to 27<sup>th</sup> to 36<sup>th</sup> weeks.
7. The Markov based geometric model was found to be better fit for prediction of wet spells for the study period (June to September).
8. From the Markov based geometric model it was found that after every two consecutive wet days a dry and after 4 to 8 consecutive dry days a wet day is expected to occur. The expected length of this cycle was found to be 6 to 10 days.
9. The persistency of September month to withhold the wet condition is more (8 days) as compared to June month (7 days).
10. The expected frequencies of wet-dry and dry-wet cycles from Markov based geometric model were to agree well with those of observed frequencies in all the months of the study period (June to September) expect during September.

## REFERENCES

- Agarwal, A., R.V. Singh and H.S Chauhan. 1984. Probability of sequences of wet and dry days in Nainital Tarai region. *J. Agril. Engineering. ISAE*. 21(4):61-70.
- Anil Kumar. 2000. Prediction of annual maximum daily rainfall of Ranichauri (Tehri Garhwal) based on probability analysis. *Indian J. Soil Cons.* **28**(2):178-180.
- Anil Kumar. 2000. Probability analysis of rainfall for crop planning in Garhwal Himalayan region. . *Indian J. Soil Cons.***28**(3): 245-246.
- Agnihotri. 1993. A study on occurrence of wet/dry spells and weather cycles at Chandigarh using Markov chain model. *Indian J. Soil Cons.* **21**(1):71-79.
- Ali, S., U.S. Pathak and C. Prakash. 2002. Frequency analysis of one day and consecutive days maximum rainfall of Eastern Ghats high land (EGHL) zone of Orissa for Marshy watershed management planning, *J. Institute of Engineers (India)- AG*, Vol. 83: 33-36.
- Basu, A. N. 1971. Fitting of a Markov Chain model for daily rainfall data at Calcutta, *Indian J. Meteorology and Geophysics*, 22: 67-74.
- Bernard Bobbe. 1975. The log Pearson type III distribution and its application in hydrology. *Water Resources Research*: 681-689.
- Bhargava,P.N., P.Narain, K.G. Aneja and Asha Pradhan. 1973. A study of occurrence of rainfall in Raipur district with the help of Markov chain model. *Indian Society of Agricultural Statistics*. 25(2):197-204.
- Bhatt,V.K., A. K. Tiwari and A. K Sharma. 1996. Probability models for prediction of annual maximum daily rainfall for Datia. *Indian J. Soil Cons.*, **24**(1):25-27.
- Bhattacharya,A.K and T.K.Sarkar 1982. Analysis of rainfall data for agricultural land drainage design. *J. Agril. Engineering., ISAE* .19(1):15-26.
- Chow, V. T. 1951. A general formula for hydrological frequency analysis. *Tans. Am. Geophysical Union*, **32**(2):231-237.
- Chow,V.T 1953. Design charts for finding rainfall intensity frequency and sewage works, 86-88.
- Chow,V.T 1954. Hand Book of Applied Hydrology. *Mc-Graw Hill book Co. New york*.
- Dabral, P. P. and K. A. Rao. 1995. Forecasting of rainfall for Mohurgong and Gulma Tea Estates. *J. Res.(BAU)*, **7**(1):39-42.

- Dash, M. K. and P. C. Senapati. 1992. Forecasting of dry and wet spell at Bhubaneswar for agricultural planning. *Indian J. Soil Cons.* 20(1&2):75-82.
- Devendra Kumar, Raj Kumar and Sanjay Kumar. 1998. Monthly rainfall probability analysis of Aonla( Bareilly) Rohilkhand region. *Indian J. Soil Cons.*,26(2):156-161.
- Devendra Kumar, Yatish Chandola and Amit Rastogi. 2000. Comparison of probability distributions for analysis of data. *Indian J. Soil Cons.*28(2): 110-116.
- Feyershman,A.M and L.D.Bark. 1967. Statistical methods for persistent precipitation patterns. *J. Applied Meteorology* 4:320-328.
- Feyersherm, A.M. and L. Dean Bark. 1967. Goodness of fit of Markov chain model for sequences of wet and dry days. *J. Applied Meteorology.* 6: 770-773.
- Fitzpatrick and A. Krishnan. 1967. A first order Markov model for assessing rainfall discontinuity in Central Australia. *Archiv furmeteorologie, Geophvsik and Bioklimatologie.*15(3):242-259.
- Gabriel,K.R and J.Neuman. 1957. On a distribution of weather cycles by length. *Quart. J. Royal Meteor. Soc.* 83 : 375-380.
- Gabriel, ICR and Neuman. 1962. A Markov chain model for daily rainfall occurrence at Tel Aviv, *Quart.J, Royal Meteor.Soc.* 88: 90-95.
- Gouranga Kar and Ravender Singh. 2002. Prediction of monsoon and post monsoon rainfall and soil charcterization for sustainable crop planning in upland rainfed rice ecosystem. *Indian J. Soil Cons.*,30(1):8-15.
- Gupta,S.K., S.D.Dalal and Ram Babu. 1968. Analysis of point rainfall data of Dehradun. *Irrigation and Power J.*25(3) : 291-300.
- Hargreaves, G.S 1971. Precipitation, dependability and potential for agricultural production in North East Brazil. *EMBRAPA and Utah State University Publication No.* 74-D159 :123.
- HariPriya Rath, G. N. Jena and P. C. Senapati. 1996. Forecasting of dry and wet spells at Boudh for agricultural planning. *Indian J. Soil Cons.*24(1): 28-36.
- Hershfield, David.M. 1971. Parameter estimation for wet and dry sequences. *Water Resources Bulletin.* 7(3) : 441-446.
- Holems, R.M and G.W. Robertson. 1963. Application of the relationship between actual and potential evapotranspiration in dry land agriculture.*Transactions of ASAE.* 6: 65-67.
- Hooda, B. K. and B. C. Thakur. 1998. Probability analysis of rainfall at Nauni, Himachal Pradesh. *Indian J. Soil Cons.*,26(2):153-155.

- Karija t., A.T. Oo and K. Fujiki. 2005. Data generation of daily rainfall time series for Myanmar's water resources planning. *International Agricultural Engineering J.* 2005, 14(I):29-34.
- Khandelwal, M.K (1988). Determination of agricultural land drainage coefficient through rainfall analysis. *Journ. Agril. Engineering., ISAE.* 25(4) : 42-47.
- Kulkarni, B.S., B.V Patil and G. Ramakrishna Rao. 1976. Two state Markovian model as applied to rainfall distribution. *Proceedings of the Indian Institute of Tropical Metrology. Symposium on Tropical Monsoon held at Pune.*
- Kumar Sonthosh and Devendra Kumar. 1989. Frequency of seasonal antecedent rainfall conditions. *J. Soil Conservation.* 17(1):25-29.
- Kundu, P.S. 1973. Probability analysis of annual rainfall data. *Journ. Agril. Engineering., ISAE.* 10(2) :21-36.
- Manohar, N. 1983. Agroclimatic analysis of a semi-arid region- Raichur for a better crop planning, *Unpublished Ph.D thesis submitted to Gulberga University, Gulberga (India).*
- Manohar, N. and Siddappa. 1984. A study of weather spells and weather cycles at Raichur using Markov chain model. *Indian J. Agrii. Science.* 54(1) :55-60.
- May, I.L.C., M.V.K. Sivakumar, and S.M. Viramani. 1982. Agricultural potential of Magarini in relation to climate and soils. *Agroclimatology Progress Report 6, ICRISAT, Pattancheru, India.*
- Metalas, C. Nicholas. 1963. Probability distributions of low flows. *Geological Survey Professional Paper 434-A, U.S. Govt. printing office, Washington.*
- Mishra, A. K., T. K. Sarkar and A. K. Bhattacharya. 1999. Stochastic rainfall firecasting for weekly water resource assessment in Lower Assam. *Indian J. Soil Cons.,* 27(2): 99-111.
- Mishra, K. 1992. Theoretical probability distribution of annual consecutive daily extreme rainfall events at Sehore-A basis for drainage design. *Indian J. Agril. Engineering.* 2(2) :223-225.
- Misra, K.K, S.K Mittal and S.H. Agrawal. 2004. An easy approach towards frequency analysis in vindhyan plateau of Madhya Pradesh. *IE(I) J.-AG:*26-32
- Mishra, N.K and T. Satyariarvana. 1987. Effects of extreme events on statistical parameters of rainfall at Khargpur, *West Bengal. J. Agril. Engineering., ISAE.* 24(1) 74-86.

- Mockus v. 1960. Selecting a flood- frequency method. *ASAE Trans.* 3,48-51,54.
- Mohan Singh and A. R. Bhandari. 1998. Wet and dry spells analysis using Markov Chain model for mid hill region of Himachal Pradesh. *Indian J. Soil Cons.* **26**(2):147-152.
- Mooley, D.A. 1974. Suitable tables for application of gamma probability model. *Research Report RR.-018. Indian Institute of Tropical Meteorology, Pune.*
- Pandarath, N. 1991. Markov chain model probability of dry and wet weeks during monsoon period over Andhra Pradesh, *Mausum*,42(4):393-400.
- Panigrahi, B. 1998. Probability analysis of short duration rainfall for crop planning in coastal Orissa. *Indian J. Soil Cons.*,**26**(2):162-165.
- Panigrahi, B. and S. N. Panda. 2002. Dry spell probability by markov chain model and its application to crop planning in Kharagpur. *Indian J. Soil Cons.*, **30**(1): 95-100.
- Prasad, B.N., A.K. Sinha and R.K. Rai. 2000. Analysis of rainfall for planning rainfed crops. *Journal of Research(BAU)*. **12**(2): 143 – 148.
- Rana, R. S. and D. R. Thakur. 1998. Rainfall analysis for crop planning in Kullu valley, Himachal Pradesh. *Indian J. Soil Cons.*,**26**(2): 144-146.
- Ray, C.R., S.K. Behra, P.C. Senapati and R. Lal. 1985. Rainfall distribution pattern and surface drainage coefficient through rainfall analysis. *J. Agril. Engineering., ISAE*.25(4): 66-72.
- Ray, C.R., Sengopal and R. Lal. 1980. Rainfall analysis for crop planning at Gopalpur (Orissa). *J. Agril. Engineering., ISAE*. 17(3,4):1-8.
- Ripley. 1966. The use of water by crops, Proceedings of ICID special session on new and promising developments in the field of Irrigation, drainage and flood control. *January 1966, New Delhi, International Commission on Irrigation and Drainage.*
- Rizvi, R. H., Ramesh Singh, R. S. Yadav, R. K. Tewari,, K. S. Dadhwal, and K. R. Solnki. 2001. *Indian J. Soil Cons.*,**29**(3):259-262.
- Sarkar, R.P and B.C. Biswas. 1980. Agroclimatic classification for assessment of crop potential and its application to dry farming tracts of India, Consultants Meeting on Climatic Classification. *14-16 April 1980, ICRISAT, Patancheru, India*,89-107.
- Sethy B.K., S. Ali and S.N. Prasad. 2005. Frequency analysis for one day to five consecutive days maximum rainfall for south-eastern Rajasthan. *Indian J. of Soil Conservation*. 2005. 33(1):22-26
- Sharma,K.D. and D.N. Bohra. 1990. Rainfall analysis for rain water management in a drought prone area. *Annals of Arid Zone*.29(3) :165-169.

- Shih,S.F. 1988. Variation of daily rainfall distribution in South Florida. *Trans.ASAE.* 31(1):149-153.
- Shirahatti, M.S. 1994. Integrated Planning for Rain Water Resources Utilization and Management of Micro Watershed of Udaipur Region. *Unpublished M.E(Ag. ) thesis RAU, Bikaner.*
- Singh, R. K. 2001. Probability analysis for prediction of annual maximum daily rainfall of eastern Himalaya (Sikkim mid Hills). *Indian J. Soil Cons.*, **29**(3):263-265.
- Shrivastava, S.K., S. K. Mishra, A. K. Sahu, M. Ahmed and S. Borah. 1998. Probability analysis of rainfall for crop planning at North Lakhimpur, Assam. *Indian J. Soil Cons.*,**26**(2):162-165.
- Singh, K.A., Rai,R.N. and R.C. Solanki. 1989. Crop planning in relation to rainfall pattern -A case study at Gangtok (Sikkim). *Indian J. Soil conservation.* 17(3):51-54.
- Singh,R.P. and S.P. Singh (1987). Break through in agricultural productivity and production through research on different aspects of dry land agriculture. *Proceedings of 23 annual convention,ISAE held on March 9-11,1987*, pp 20-29.
- Subudhi, C. R., P. C Pradhan and P. C. Senapati. 1998. Rainfall analysis of Baliguda, Kandhamal, Orissa. *Indian J. Soil Cons.*, **26**(2):173-174.
- Sundarraaj,N and S. Ramachandra. 1975. Markov depending geometric models for weather spells and weather cycles-A study. *Indian Journ.Meteorology,Hydrology and Geophysics.* 26(2):222-226.
- Suresh Ram and A.K. Thakur. 1992. A note on analysis of rainfall for crop planning at Pusa, Bihar. *Indian J. Soil Conservation.*20(3) :23-27.
- Suresh Ram and A.K.Thakur. 1993. Statistical evaluation of extreme event and their effects on rainfall parameter at Pusa, Samastipur. *J. Indian Water Resources Society.*13(1&2):78-81.
- Tambile, R.H., U.G. Deshmukh, H.S. Acharva, A.R. Mantri, and B.P.Sawant. 1991. Probability analysis of annual rainfall data at Parabhani (Maharashtra) for crop planning. *J. Indain Water Resources Society.*11(2):33-35.
- Tomar, A. S. and D. H. Rande. 2001. Predicting rainfall probability for irrigation scheduling in black clay soil Indore region of Madhya Pradesh. *Indian J. Soil Cons.*,**29**(1):82-83.
- Victor, U.S. and P.S.N. Sastri. 1979. Dry spell probability by Markov chain model and its application to crop development stages. *Indian Journal of Meteorology, Hydrology and Geophysics.* 30(4):479-489.

- Viramani, S.M., M. Sivakumar and S.J. Reddy 1982. Rainfall probability estimates for selected locations of semi arid India. *Research Bulletin No. 1, 2 Edition, ICRISAT, Patancheru, India.*
- Vishwakarma, S. K., D. H. Rande, L. K. Jain and A. S. Tomar. 1999. Probability analysis of rainfall at Chhindwara (M. P.). *Journal of Agricultural Engineering*, **36**(4):59-60.
- Weiss, L.L 1964. Sequences of wet and dry days described by a Markov probability model. *Monthly Weather Review*.92:169-176.
- Yarnell, D.L 1936. Rainfall intensity frequency data. *U.S. Dept.Agr.Misc. Publ.*204.
- W.M.O (1982). **Technical note. No. 179:149-158.**

## APPENDIX – A

Computer programme to estimate weekly initial and conditional probability of rainfall  
at Southern Rajasthan.

```
c      MARKOV CHAIN -WEEKLY
      DIMENSION PPT(100, 52), ALIM(10)
      CHARACTER FILE1*12, NAME*13
      WRITE (*, '(A\)') ' PPT FILENAME: '
      READ (*, 306)FILE1
306    FORMAT (A12)
c      WRITE (*, '(A\)') ' CENTRE NAME: '
c      READ (*, 13)NAME
c 13   FORMAT (A13)
      WRITE (*, '(A\)') ' NY, NL, NSW, NEW, LBY, LEY: '
      READ (*, *)NY, NL, NSW, NEW, LBY, LEY
      WRITE (*, '(A\)') ' LIMIT: '
      READ (*, *) (ALIM(JJ), JJ=1, NL)
      OPEN(5, FILE=FILE1, STATUS=' OLD' )
      OPEN(6, FILE=' OUT2. MKV' , STATUS=' NEW' )
      READ(5, '(A13)')NAME
      DO 61 NYS=1, NY
      READ (5, *)LYR
      DO 64 NWK=1, 52
      READ (5, *)APPT
      PPT(NYS, NWK)=APPT
64    CONTINUE
61    CONTINUE
      CLOSE(5)
      DO 60 M=1, NL
      WRITE (6, 14)NAME
14    FORMAT(5X, ' INITIAL AND CONDITIONAL PROBABILITIES
      10F RAINFALL AT ', 1X, A13/)
      WRITE (6, 62)ALIM(M), LBY, LEY
62    FORMAT (10X, ' LIMIT=', F7. 1, 1X, ' mm', 22X, ' DATABASE: ',
1     15, ' -', 15)
      WRITE (6, 38)
      WRITE (6, 35)
35    FORMAT (15X, ' INITIAL', 24X, ' CONDITIONAL' /12X, ' PROBABILITIES',
1     20X, ' PROBABILITIES' /11X, 14(1H-), 6X, 40(1H-))
      WRITE (6, 36)
36    FORMAT (1X, ' WEEK', 6X, ' P(W)', 6X, ' P(D)', 7X, ' P(W/W)', 5X, ' P(D/W)',
1     5X, ' P(D/D)', 5X, ' P(W/D)')
      WRITE (6, 38)
      DO 81 I=NSW, NEW
      J=I-1
      IF (J.EQ.0)J=52
```

```

NDD=0
NWD=0
NWW=0
NDW=0
IF (J. EQ. 52)GOTO 53
DO 101 K=1, NY
IF (PPT(K, I)-ALIM(M))21, 22, 22
21 IF (PPT(K, J)-ALIM(M))23, 24, 24
23 NDD=NDD+1
GOTO 101
24 NDW=NDW+1
GOTO 101
22 IF (PPT(K, J)-ALIM(M))25, 26, 26
25 NWD=NWD+1
GOTO 101
26 NWW=NWW+1
101 CONTINUE
GOTO 54
53 DO 102 KL=1, NY
KK=KL+1
IF (KK. GT. NY)GOTO 54
IF (PPT(KK, I)-ALIM(M))41, 42, 42
41 IF (PPT(KL, J)-ALIM(M))43, 44, 44
43 NDD=NDD+1
GOTO 102
44 NDW=NDW+1
GOTO 102
42 IF (PPT(KL, J)-ALIM(M))45, 46, 46
45 NWD=NWD+1
GOTO 102
46 NWW=NWW+1
102 CONTINUE
54 CONTINUE
WD=NWD
DW=NDW
WW=NWW
DD=NDD
TW=WW+DW
TD=WD+DD
PW=(WW+WD)/(TW+TD)
PD=1.0-PW
IF (TW. EQ. 0.0)GOTO 300
IF (TD. EQ. 0.0)GOTO 301
PWD=WD/TD
PWW=WW/TW
PDD=1.0-PWD
PDW=1.0-PWW
GOTO 302
301 PDD=0.0
PWD=0.0
PWW=WW/TW
PDW=1.0-PWW

```

```
GOTO 302
300  PWW=0.0
      PDW=0.0
      PWD=WD/TD
      PDD=1.0-PWD
302  WRITE (6,37)I, PW, PD, PWW, PDW, PDD, PWD
37   FORMAT (1X, I4, 6F11.4)
81   CONTINUE
      WRITE (6,38)
38   FORMAT (1X, 70(1H-))
      WRITE (6,40)
40   FORMAT (1H1)
60   CONTINUE
      CLOSE(6)
      STOP
      END
```

## APPENDIX- B

Computer programme for Gamma distribution.

```

      DIMENSION P(100, 13)
      CHARACTER ST*10, WTH*20, OUT*20
      WRITE(*, '(A/)' ) ' ENTER THE WEATHER FILE'
      READ(*, '(A)' ) WTH
      OPEN(10, FILE=WTH, ACCESS=' SEQUENTIAL', STATUS=' OLD' )
      WRITE(*, '(A/)' ) ' ENTER THE OUTPUT FILE'
      READ(*, '(A)' ) OUT
      OPEN(6, FILE=OUT, ACCESS=' SEQUENTIAL', STATUS=' NEW' )
      WRITE(5, 789)
789  FORMAT(' ENTER NUMBER OF YEARS' )
      READ(*, *)N
      WRITE(*, *)' ENTER THE STATION NAME'
      READ(*, '(A)' ) ST
      DO 102 I=1, N
      READ(10, *)II, P(I, 1), P(I, 2), P(I, 3), P(I, 4), P(I, 5), P(I, 6)
      1, P(I, 7), P(I, 8), P(I, 9), P(I, 10), P(I, 11), P(I, 12)
C103  FORMAT(I4, 12F6. 1)
      P(I, 13)= 0. 0
      102  CONTINUE
      CALL GAMMA(P, N, ST)
C      WRITE(*, *)'                OUTPUT FILE NAME ----> GAMMAM. OUT'
      STOP
      END
      SUBROUTINE GAMMA(P, N, ST)
      DIMENSION P(100, 13)
      DIMENSION ZZ(6), PP(13), S6(14), S7(14)
      DIMENSION R(14, 53), P2(53), G(53), R2(53), R3(53)
      DIMENSION R8(103, 14), AB(8)
      CHARACTER ST*10
      DATA PP/5. , 10. , 20. , 25. , 30. , 40. , 50. , 60. , 70.
      1, 75. , 80. , 90. , 95. /
      DATA ZZ/1. 64485, 1. 28155, . 84162, . 67448, . 53440, . 25300/
      DATA AB/- . 577191652, . 988205891, -. 897056937, . 918206857,
      1-. 756704073, . 482189394, -. 193527818, . 035868343/
      N1=13
      N5=6
      G88=0
      D9=N
      DO 110 IU=1, N
      DO 112 JU=1, 12
      R8(IU, JU)= P(IU, JU)
      R8(IU, 13)= R8(IU, 13)+P(IU, JU)
      112  CONTINUE
      110  CONTINUE
```

```

G8=1
AL7=1.0
D9=N
DO 410 M=1, N
S1=0
DO 420 J=1, 13
E9=R8(M, J)
P2(J)=P2(J)+E9
420 S1=S1+E9
R8(M, 14)=S1
410 P2(14)=P2(14)+S1
DO 430 J=1, 13
430 P2(J)=P2(J)/D9
N1=13
DO 120 J=1, 13
AIJ=P2(J)+AL7
R9=R8(1, J)
S2=(R9 - AIJ)*(R9 - AIJ)
A2=LOG(R9+AL7)
DO 130 I = 2, N
R9=R8(I, J)
S2=S2+(R9 - AIJ)*(R9 - AIJ)
130 A2=A2+LOG(R9+AL7)
A3=LOG(P2(J)+AL7)
A3=A3 - A2/D9
IF (A3.EQ.0)A3=0.1*AL7
P5=1./(4*A3)*(1+SQRT(1+4*A3/3))
IF(AIJ.EQ.0)AIJ=AL7
A1IJ=P5/AIJ
P6=P5 -1
T9= SQRT(S2/(D9 -1))
S6(J)=T9
S7(J)=S6(J)/AIJ*100
IF (J.LT.6)GOTO 860
IF (J.GT.8)GOTO 860
GOTO 1120
860 IF (P5.GE.85)GOTO 1120
C=.43429482
IF (ABS(P5).LT.33) GOTO 1420
H=(P5 -.5)*C*LOG(ABS(P5))- C*P5+.39908995+C*LOG(1+1/
1(12*P5)+1/(288*P5*P5)-138/(51840*P5*P5*P5))
1411 GOTO 910
1420 F1=1
F2=P5 -1
IF (F2.LT.0) GOTO 1450
1430 IF (F2.LT.1) GOTO 1480
F1=F1*F2
F2=F2 -1
GOTO 1430
1450 F2=F2+1
F1=F1*F2
IF (F2.LT.0)GOTO 1450

```

```

      IF (F2.EQ.0)GOTO 900
      F1=1/F1
1480 H=0
      J9=9
      D0 310 I = 1, 8
      J9=J9 -2
      M=I +J9
310 H=(H+AB(M))*F2
      H=(1+H)*F1
      G(J)=H
      G(J)=LOG(G(J))
      GOTO 920
900 GOTO 1160
910 G(J)=2.302585*G(J)
920 G6=G(J)
      D0 210 I7 = 1,13
      T2=0
      T3=.0001
      T5=.0004
      X0=P6
      IF (P5.LT.1)GOTO 960
      IF (X0.LE.0)GOTO 970
      GOTO 980
960 X0=.0001
      GOTO 980
970 X0=.01
980 Z1=2
      T2=T2+1
      T1=X0/(P6+Z1)
      S=T1+1
      D0 235 L1=1,100
      Z1=Z1+1
      T1=(T1*X0)/(P6+Z1)
      S=S+T1
      IF (T1.LE.T3) GOTO 1030
235 CONTINUE
1030 D6=PP(I7)/100
      IF(D6.LT.0) GOTO 1100
      R7=X0
      IF (X0.GT.86)GOTO 1120
      R7=EXP(G6 -(P6*LOG(R7)))
      X1=X0 -(X0/P5)*S+(D6*R7*EXP(X0))
      D7=X1 - X0
      X0=X1
      IF (X0.LT.0) GOTO 1100
      IF (X0.EQ.0) GOTO 1110
      IF (ABS(D7).LE.T5)GOTO 1110
      IF (T2.LE.100) GOTO 980
1100 X1=0
1110 R3(I7)=X1/A11J
210 CONTINUE
      GOTO 1160

```

```

1120 DO 320 I = 1, N5
      F1=T9*ZZ(I)
      R3(I)=AI J- F1
      R3(14 - I)=AI J+F1
      IF (R3(I).LT.0)R3(I) =0
320  IF (R3(14+1).LT.0)R3(14+1)=0
      R3(N5+1)=P2(J)
1160 DO 330 I1 = 1, 13
330  R(I 1, J)=R3(I 1)
120  CONTINUE
      WRITE(6, 891)ST, N
891  FORMAT(1X, ' GAMMA DISTRIBUTION FOR ', A10, ' DATA BASE : ', I3, '
1 YEARS' )
      WRITE(6, 892)
      WRITE(6, 893)
      WRITE(6, 894)
      WRITE(6, 895)
892  FORMAT(1X, ' -----
1-----' )
893  FORMAT(1X, ' MONTH PRECIPITATION (mm) FOR THE PROBABILITIES' )
894  FORMAT(1X, ' ----- M
1EAN' )
895  FORMAT(1X, '          90          75          50          25          10
1(mm)' )
      WRITE(6, 892)
      DO 340 J=1, 12
340  WRITE(6, 2910)J, R(2, J), R(4, J), R(7, J), R(10, J), R(12, J), P2(J)
2910 FORMAT(1X, I4, 6F9.0)
      J=13
      WRITE(6, 892)
      WRITE(6, 2913)R(2, J), R(4, J), R(7, J), R(10, J), R(12, J), P2(J)
2913 FORMAT(1X, ' ANN ', 6F9.0)
      WRITE(6, 892)
      RETURN
      END

```

## APPENDIX – C

Computer programme for onset and termination of the south-west monsoon at  
Southern Rajasthan.

```

C=====
C***** PROGRAM FOR ONSET AND TERMINATION OF THE MONSOON *****
C=====
C***** INPUT OF DATA *****
      DIMENSION P(366), OS(100), TR(100), YR(100), OST(10, 100)
      INTEGER D, E, F, G, J, N, M, YR, OS, TR, OST
      CHARACTER ST*10, WTH*20, OUT*20
      WRITE(*, '(A/)' )' ENTER THE WEATHER FILE'
      READ(*, '(A)' ) WTH
      OPEN(10, FILE=WTH, ACCESS=' SEQUENTIAL', STATUS=' OLD' )
      WRITE(*, '(A/)' )' ENTER THE OUTPUT FILE'
      READ(*, '(A)' ) OUT
      OPEN(6, FILE=OUT, ACCESS=' SEQUENTIAL', STATUS=' NEW' )
      WRITE(*, '(A/)' )' ENTER NUMBER OF YEARS'
      READ(*, *)N
      WRITE(*, '(A/)' )' ENTER THE STATION NAME'
      READ(*, '(A)' ) ST
      WRITE(6, *)' RESULTS FOR THE STATION      ', ST
      DO 5 I=1, N
        READ(10, *) YR(I)
        READ(10, *) (P(J), J=1, 366)
C***** CALCULATION FOR ONSET *****
        A=0
        DO 10 J=149, 366
          IF(A.LT. 75) THEN
            A=A+P(J)
          ELSE
            OS(I)=J
            OST(1, I)=J
            GOTO 15
          ENDIF
        10 CONTINUE
C***** CALCULATION FOR TERMINATION *****
        15 D=366
          F=0
          DO 20 J=0, 148
            M=D-J
            IF(F.LT. 10) THEN
              F=F+P(M)
            ELSE
              M=M+2
              TR(I)=M
              OST(2, I)=M
              GOTO 25
            ENDIF
          20
        ENDIF

```

```

20    CONTINUE
C*****          OUTPUT IN DAYS *****
25    WRITE(6, *) YR(I), OS(I), TR(I)
5     CONTINUE
      DO 26 I=1, N
        WRITE(6, *) YR(I)
        E=I
        G=1
        CALL DATE(OST, N, E, G)
26    CONTINUE
      CALL MEAN(OS, TR, N)
      CALL MEDIAN(OST, N)
      STOP
      END
      SUBROUTINE MEAN(OS, TR, N)
      DIMENSION OS(100), TR(100), OST(10, 100)
      INTEGER N, E, G, TO, TT, OS, TR, OST
      TO=0
      TT=0
      DO 30 I=1, N
        TO=TO+OS(I)
        TT=TT+TR(I)
30    CONTINUE
      MO=TO/N
      MT=TT/N
      WRITE(6, *) ' '
      WRITE(6, *) 'MEAN ONSET AND TERMINATION', MO, MT
      OST(3, 1)=MO
      OST(4, 1)=MT
      E=1
      G=3
      CALL DATE(OST, N, E, G)
      RETURN
      END
      SUBROUTINE MEDIAN(OST, N)
      DIMENSION OST(10, 100)
      INTEGER K, N, M, E, G, OST
      M=N/2
      DO 35 K=1, 2
        NN=N-1
        DO 40 J=1, NN
          L=J
          JJ=J+1
          DO 45 I=JJ, N
            IF(OST(K, L).LT.OST(K, I)) GOTO 45
            L=I
45    CONTINUE
          T=OST(K, L)
          OST(K, L)=OST(K, J)
          OST(K, J)=T
40    CONTINUE
35    CONTINUE

```

```

WRITE(6, *) ' '
WRITE(6, *) ' MEDIAN OF ONSET AND TERMINATION'
1, OST(1, M), OST(2, M)
G=1
E=M
CALL DATE(OST, N, E, G)
WRITE(6, *) ' '
WRITE(6, *) ' EARLIEST ONSET AND TERMINATION'
1, OST(1, 1), OST(2, 1)
G=1
E=1
CALL DATE(OST, N, E, G)
WRITE(6, *) ' '
WRITE(6, *) ' LATEST ONSET AND TERMINATION'
1, OST(1, N), OST(2, N)
G=1
E=N
CALL DATE(OST, N, E, G)
RETURN
END
SUBROUTINE DATE(OST, N, E, G)
DIMENSION OST(10, 100)
INTEGER N, B, C, E, J, K, G, OST
DO 50 K=1, 2
IF(K.EQ. 1) THEN
WRITE(6, *) ' ONSET'
ELSE
WRITE(6, *) ' TERMINATION'
G=G+1
ENDIF
B=OST(G, E)
IF(B.LT. 153) THEN
C=B-121
WRITE(6, *) ' . . . MAY-', C
GOTO 50
ELSEIF(B.LT. 183) THEN
C=B-152
WRITE(6, *) ' . . . JUN-', C
GOTO 50
ELSEIF(B.LT. 214) THEN
C=B-182
WRITE(6, *) ' . . . JUL-', C
GOTO 50
ELSEIF(B.LT. 245) THEN
C=B-213
WRITE(6, *) ' . . . AUG-', C
GOTO 50
ELSEIF(B.LT. 275) THEN
C=B-244
WRITE(6, *) ' . . . SEP-', C
GOTO 50
ELSEIF(B.LT. 306) THEN

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      C=B-274
      WRITE(6,*) ' . . .                OCT-', C
      GOTO 50
    ELSEIF(B.LT.336) THEN
      C=B-305
      WRITE(6,*) ' . . .                NOV-', C
      GOTO 50
    ELSEIF(B.LT.367) THEN
      C=B-335
      WRITE(6,*) ' . . .                DEC-', C
      GOTO 50
    ENDF
50    CONTINUE
      RETURN
      END
```