RAINFALL AND DRY SPELL ANALYSIS FOR SOUTHERN DISTRICTS OF MARATHWADA REGION

DISSERTATION

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(Agril. Engineering)

IN

SOIL AND WATER CONSERVATION ENGINEERING

By

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CERTIFICATE-I

This is to certify that the dissertation entitled **"Rainfall and Dry Spell analysis for Southern Districts of Marathwada Region"** submitted to Marathwada Agricultural University, Parbhani in partial fulfillment of the requirement for the award of the degree of **Master of Technology (Agril. Engineering)** in **Soil and Water Conservation Engineering** embodied the results of the bonafied study carried by **Mr. PUJARI MANIK SHANKAR** under my guidance and supervision. I also certify that the dissertation has not previously submitted by him for the award of Degree or Diploma of any University or Institute.

Place : Parbhani.
Date : /06 /2005

Dr. A.S. Kadale
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CERTIFICATE-II

This is to certify that the dissertation entitled **"Rainfall and Dry Spell analysis for Southern Districts of Marathwada Region"** submitted by **Mr. Pujari Manik Shankar** to the Marathwada Agricultural University, Parbhani in partial fulfillment of the requirement for the degree of **MASTER OF TECHNOLOGY (Agril. Engg.)** in the subject of **Soil and Water Conservation Engineering** has been approved by the students advisory committee after oral examination in collaboration with external examiner.

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CANDIDATE'S DECLARATION

I, Hereby Declare that the dissertation

or part there of has not been submitted

by me to any other University or

institution for a degree

or diploma.

Place : Parbhani

Date : 24 / 06 /2005

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DEDICATED TO,

My

FATHER,

MOTHER & SISTER

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Place : Parbhani. ***(Pujari M.S.)***

Date : / 06 /2005

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LIST OF ABBREVIATIONS

Abbreviations		Description
Agric.	:	Agriculture
Agril.	:	Agricultural
Agril. Engg.	:	Agricultural Engineering
CDS	:	Critical dry spell / spells.
CO.	:	Company
Conserv.	:	Conservation
Cv	:	Coefficient of variation
e	:	Evaporation
E	:	East
Ed.	:	edition
ET.	:	Evapotranspiration
et al.	:	and all others
etc.	:	etcetera
fig	:	figure
Geophy	:	Geophysics
GMI	:	Generalised Monsoon Index.
hr.	:	Hour
Hydro	:	Hydrology
IARI	:	Indian Agricultural Research Institute
i.e.	:	that is
Ind.	:	Indian
ISAE	:	Indian Society of Agricultural Engineers.
j	:	Journal
Ltd.	:	Limited

List of Abbreviations continued.

Mah.	:	Maharashtra
mm	:	Milimeter.
Met.	:	Meteorology.
MSL	:	Mean sea level
N	:	North
No.	:	Number.
OEM	:	Onset of Effective Monsoon.
Res.	:	Research.
S.D.	:	Standard deviation
Uni.	:	University.
Viz.	:	Namely.
WTC	:	Water Technology Centre.

Introduction

CHAPTER-I

INTRODUCTION

The major source of water available either for agriculture or for human consumption is obtained from the rain. South-West monsoon, North-East monsoon, cyclonic depressions and local storms contribute to rainfall in different degrees in various rainfall regions of the country. Due to high temperatures of summer, the moisture-laden south-west monsoon originates from the vast expanse of the Indian ocean and enters the Indian sub-continent from the south-west. These south-west monsoonic winds increases from June to July and begins to weaken in September, specially in North India. By the first week of July the monsoon is established all over the country, The withdrawal of the monsoon starts in September in North India and there is a rapid decrease of rainfall towards the end of the month. The dates of onset of monsoon and withdrawal are different at different parts of the country. The crucial months for agriculture are July and August and the fate of rainfed kharif crop largely depends upon the amount and distribution of rain especially during these two months.

Rainfall is one of the most important natural inputs in many hydrologic processes. The planning and design of irrigation and drainage systems are influenced by the rainfall characteristics of the area. Analysis of such meteorological data helps to develop and modify the management practices to increase the agricultural production. In order to stabilize the crop production in the rainfed eco-system at certain level, it is essential to plan agriculture by making the best use of rainfall potential of an area. Since rainfall is quite erratic both in time and space, probability study offers better scope for predicting the minimum assured rainfall. Since annual and monthly rainfall data is inadequate to evaluate the deficiencies of soil moisture that may occur during crop development stages, it is essential to analyse the short period rainfall like pentads or weeks for planning rainfed agriculture.

The important characteristics of rainfall influencing production from agriculture in rainfed farming are the dates onset of effective monsoon (OEM), the duration of rainy spells, the dates of occurrence and duration of intervening dry spells and distribution of the rainfall during crop growing period. The occurrence of certain amounts of rainfall at crucial times can determine the success or failure of a crop. Drying of crops, germination of seeds, disease control during crop growing periods, applying irrigations, fertilizers, pesticides are some important agricultural activities for which probability of various sequences of wet and dry days may be useful to determine the possible economic gains and losses.

The farmers had learn to live with the limitations of their local climatic conditions through trial and error over generations is no more wholly true. No doubt past experiences provide them with very broad information on rainfall, flood and droughts , yet for modern agriculture this is not enough. It is very clear that for deriving the maximum benefit from dry land agriculture, one must have a proper knowledge of short period rainfall distribution on both in time and space. Rainfall during the monsoon period is not uniform. Breaks in monsoon are common phenomena during the monsoon period. A break continues from a few days to several weeks. A knowledge of the distribution of dry spells during the monsoon period is very much essential for successful management of agriculture. Short period rainfall probability analysis brings out the numbers of years of crop success and duration of crop growing period so that suitable crops may be chosen to get optimum yield. Runs of wet and dry spells help to identify the duration of stress period. (Biswas, 1981).

The average annual rainfall over plains of India is 119.4 cm and the average for all the lands of the world put together is only 70 cm per year. Though India has 1.7 times the average annual rainfall of whole world, its agricultural production is at low level. Main reason behind this is that half of the total amount of rainfall falls in 15 to 20 hours distributed within 35 to 45 days. Being of high intensity, 3 to 5 cm per hour, this half amount of total rainfall runs off the ground as runoff. So there is a great need to store this water received from short period rainfall and to utilize the same when dry spells occur during important growth phases of crops grown particularly during kharif seasons. Hence, knowledge of dry spell analysis plays an important role in proper utilization of the available resources.

The average annual rainfall of Maharashtra is 1200 mm whereas rainfall of Marathwada varies between minimum 550 mm to 1100 mm with an average of 774 mm. Out of eight districts of Marathwada region, Beed, Latur and Osmanabad districts lie in moderately drought prone area of Maharashtra. Precipitation is very uncertain in this region and some times suffers from severe droughts. Beed, Latur and Osmanabad districts receive average annual rainfall of 716 712 and 708 mm, respectively. Majority of population living in these three districts depend on the rainfed agriculture. Annual rainfall is comparatively low and its distribution is not uniform. Under such circumstances for increasing crop productivity, better crop planning for carrying out the different agricultural activities at proper time could be beneficial. For better crop planning information related to the date of onset of effective monsoon, wet spells, dry spells during the different developmental stages of the crops plays an important role.

Keeping in view, the present investigation has been planned with the following specific objectives.

1. To analyse the daily rainfall data for Beed, Latur and Osmanabad districts of Marathwada region.
2. To find out probable dates of onset of effective monsoon, critical dry spells, its length and duration of wet spells.
3. To find out probability of occurrence of dry spells during crop developmental stages.

Review of Literature

CHAPTER-II

REVIEW OF LITERATURE

This chapter deals with research work done in the past by various investigators on the rainfall analysis, dry-spell analysis and determination of onset of effective monsoon and its withdrawal. The work most pertinent to the present study has been reviewed and presented in this chapter under following headings.

1. Rainfall analysis.
2. Onset of effective monsoon.
3. Dry spell analysis.

2.1 Rainfall analysis :

Rainfall analysis on specific area basis could be useful for crop planning, water management planning, designing soil and water conservation structures. Some of the research reviews on rainfall analysis are presented here.

Kundu (1973) analysed the annual maximum daily total rainfall data of 48 years (1925-1972) for the station, Ludhiana, Punjab. The frequency curves of annual maximum rainfall data were plotted using three different theoretical probability distributions e.g. log pearson type-III distribution, log-normal distribution and Gumbel distribution. The theoretical frequency curves were in close agreement with the observed data points, except at the highest rainfall for all the three distributions. For the data analysed in this paper, the lognormal probability distribution seems to give the closest fit to the observed data though the difference among the three was negligible.

Vanjari *et al.* (1978) analysed the rainfall data of 30 years for Pune, 20 years for Nagpur, 35 years for Bombay and 18 yeas for Vengurla. From this data the rainfall intensity, duration, frequency relationship for these four stations in Mahrashtra state were worked out by analyzing the self-recording rain guage charts of these stations. The annual maximum values for intensities for various durations were selected for analysis. The frequency analysis was done by using Fisher and Tippett (1928) I-extreme value distribution method.

Dhar *et al.* (1985) analysed the rainfall data of the Saurshtra-Kutch region of Gujrat for the 90 year period from 1891 to 1980 at all stations. Examination of annual and seasonal rainfall data of the region showed that the during this period, there has no increasing or decreasing trend in the occurrence of excess (+ 20% of more) or deficit (-20% or less) rainfall over the region. The highest observed point rainfall at stations in the Saurashtra region during this period for 1, 2 and 3-day durations were found to be 50 cm, 66 cm and 77 cm, respectively. However, the magnitudes of 1-day, 2-day and 3-day rainfall values had substantially been altered during June 1983, when severe storm over Saurashtra region occured. The probable maximum rainfall at this region varies from 40 cm to 106 cm. The rainfall of the region as a whole is normally distributed with no trends or persistence.

Chakraborty and Chakraborty (1990) used data on daily rainfall during 1976-85 for estimating assured rainfall pattern, conditional probability analysis and water balance analysis for the Berhampore region in the Murshidabad district. The use of the information obtained from these analysis for crop planning in the region is discussed.

Maliwal and Chatrola (1992) analysed the monthly rainfall pattern of different stations of Bhal and coastal agro-climatic zones. The year to year variability and variability in rainfall occurring during monsoon season alongwith other statistical parameters were worked out. Using simple probability percentage, the weekly probability of getting different amount of rainfall for Arnej were computed for monsoon period. The study revealed that the rainfall of the zone varies from 545 to 755 mm. The probability of recurring 20 mm or more rain after 42^{nd} week was found to be zero.

Tiwari *et al.* (1992) from rainfall data analysis of Daita (M.P.) (1968-1986) revealed that the average rainfall is 861 mm spread over 37.5 rainy days (rainfall > 2.5 mm). Ninety per cent of rainfall is received in the monsoon period with an average of 68,292, 294 and 115 mm for June, July, August and September respectively. Yearly, monthly and weekly rainfall variability indicated that the weekly rainfall of 20 mm is expected from 27^{th} to 33^{rd} standard meterological weeks.

Verma *et al.* (1994) analysed the rainfall records for 1973-1992 for Palampur, Kangra district. Study revealed that the probability of getting adequate rain for a good Kharif crop of maize is very high in July and August when excess rainwater can be stored in the soil profiles and tanks. Analysis of the lowest assured weekly rainfall at different probability levels using the incomplete Gamma distribution was found suitable for planning rainfed crops and related rain water conservation measures for hilly regions of Himachal Pradesh.

Gaikwad *et al.* (1995) analysed 30 years rainfall data recorded at Dry Farming Research Station, Solapur for annual seasonal, monthly and weekly periods and weekly rainfall probabilities (>=20 mm rainfall/week) were worked out. The mean annual rainfall was 723 mm, out of this 76 per cent is received during southwest monsoon and 15 per cent from northeast monsoon. Trend values were around the mean. There is 40 per cent chance of getting more than normal rainfall. The water availability period total 140 days. Medium to long dry spells are of common occurrence during kharif season.

Mishra and *et al.* (1996) collected rainfall data from meteorological observatory located in the Chotanagpur plateau, Bihar during 1967-92. The range, mean standard deviation and co-efficient of variation for weekly, monthly, seasonal and annual rainfall were calculated as per standard statistical procedures and probability of rainfall was calculated. June-September received 78.4-85.5% of annual rainfall. Variation in monthly rainfall followed the sequence as October> June> September > August > July. During June-September at least 826 mm rainfall was predicted at 80%

probability level and it is suggested that this assures the success of an upland paddy crop. The analysis of rainfall data indicated that the sowing of varieties with a maturity period of 80-95 days should be completed in June, while varieties with shorter maturity periods (75-80 days) may be chosen for sowing later in the year.

Subudhi *et al.* (1996) computed the monthly rainfall data of the Aidal area of Orissa, India at 40, 50, 60 and 70% probability levels. Variation of mean annual rainfall, coefficient of variation and standard error were calculated. Rainfall probability at 60% and 70% may assist crop planning and irrigation planning, respectively.

Subudhi (1996) analysed precipitation data for 14 years for the Kanjo sub-watershed of the Upper Damodar valley for randomness and the probability of distribution. The monthly precipitation at probabilities of 20-80% are tabulated for June, July, August, September and October. The maximum precipitation expected during July.

Sahane and Jadhav (1997) analysed 27 years rainfall data recorded at Agricultural Research Station, Vadgaon (Maval). Majority of weeks recorded more than 50 per cent probability receiving more than 25 mm rainfall. Out of 52 weeks, 12 weeks recorded more than 50 per cent initial probabilities for 25 mm rainfall, followed by 8,2 and 1 weeks for more than 50, 70 and 100 mm rainfall respectively.

Subagio (1997) analysed 15-days rainfall data over 43 years at Pasuruan and 30 years of Probolinggo, Indonesia, for determining the best land treatment and planting time.

Data analysis using Markov Chain Probability Analysis showed that the best time for land treatment in Pasuruan and Probolinggo was second half of October. Cane planting is best in the first half of November in which the rainfall is high.

Ethan and Bababe (1998) performed the probability analysis of rainfall in Maiduguri by Markov chain model using daily rainfall and decade rainfall values for a period of 20 years (1977-1996). Planning of millet in this region is possible by the first decade of July for a variety of 90 day growth period. The probability of occurrence of two consecutive dry decades in July and August is between 0 to 14%. Excessive rainfall of more than 300 mm may be expected in one out of ten years in month of August.

Rana and Thakur (1998) analysed rainfall data of 23 years for crop planning in Kullu valley, Himachal Pradesh. The weekly rainfall data meteorological week-wise were collected and analysed employing Weibull's method for computation of weekly rainfall amounts of 20, 50 and 80 per cent probability levels. They concluded that the value of weekly rainfall so predicted at different probability levels were of very low magnitudes and indicates that the expected rainfall was either equal or greater than the actual value.

Deka *et al.* (1999) analysed the daily rainfall data of 25 years (1974-98) recorded at the Assam Agricultural University, Jorhat, India, for annual, seasonal and monthly periods. The overall mean total annual rainfall was 1930.2 mm, which was distributed as 1232.2 mm, 478.6 mm and 219.4 mm in monsoon, summer and winter seasons, respectively. Among the season, the lowest co-efficient of variation was recorded in the monsoon indicating most reliable of rainfall. Approximately 63.84% of the total rainfall was recorded between June-September. At the 75% probability level, Jorhat is expected to receive 1785.4 mm of rainfall annually which is distributed as 1073.8 mm, 345.9 mm and 161.2 m in monsoon, summer and winter seasons, respectively.

Gare *et al.* (1999) analysed the daily rainfall data for 28 years recorded at Agril. Research Station, Gadhainglaj, Kolhapur for annual, seasonal, monthly and weekly periods and weekly rainfall probability were worked out. The mean annual rainfall was 931.1 mm, out of this 75 per cent is received during southwest monsoon and 14 per cent from Northeast monsoon. Study indicated that there is 39 per cent chance of getting more rainfall than the normal rainfall.

Panigrani *et al.* (2001) analysed rainfall of 30 years (1969-1998) at IIT Kharagpur and probability of occurrence of rainfall in various weeks has been estimated. The study revealed that probable values of 1-day maximum rainfall are predicted by power transformation and the values are seen to be decreased from 144.7 to 48.1 mm as probability of exceedance increased from 5 to 95 per cent.

Maniyar and Kulkarni (2002) analysed 30 years rainfall data of Marathwada talukawise. The annual varition in rainfall ranges from 550 mm at Vaijapur of Aurangabad district to 1200 mm at Billoli of Nanded district. Broadly the region is divided into 3 main Agro-climatic zones as under.

1) Scaricity zone receives 500 to 700 mm annual rainfall.

2) Assured rainfall zone getting annual precipitation ranging between 700 to 900 mm.

3) Moderate to moderately high rainfall zone where 900 to 1200 mm rainfall occurs.

On the basis of taluka-wise observations of past 30 years, the Deptt. of Agricultural Meteorology., M.A.U., Parbhani has further classified these zones in following six classes.

Sr. No.	Agro-climatic zone	Mean annual rainfall (mm)
1.	Heavy rainfall zone	> 1020
2.	Assured rainfall zone	895 to 1020
3.	Moderately assured rainfall zone	775 to 895
4.	Moderately drought prone rainfall zone	650 to 775
5.	High drought prone rainfall zone	530 to 650
6.	Severe drought prone rainfall zone.	< 530

Mishra (2002) analysed the weekly rainfall data for a period of 39 years (1947-1985) at Sehore and 35 years (1950-1984) at Jabalpur and the average of weekly rainfall (AWR), standard deviation(s) and co-efficient of variation (CV) were calculated. The co-efficient of variation in general decreased for weeks having large amount of rainfall and increased for the weeks receiving scanty rainfall. It was concluded that if the weekly rainfall is received with Cv values less than 169.29 and 100 percent respectively at Sehore and Jabalpur, the crops would not experience water stress in the area.

Pravendra kumar *et al.* (2002) analysed the daily weather data of meteorological observatory, Pantnagar for a period of 31 years (1970-2000) on weekly and annual basis to see variation in distribution pattern of weather parameters. The different statistical parameters such as mean, standard deviation and co-efficient of variation was worked out for the weekly and monthly data series. The mean monthly rainfall was worked out as 112.5 mm with co-efficient of variation of 129.0 per cent. The highest monthly rainfall (420.8 mm) was received in the month of July while the highest number of rainy days were observed in the month August.

Upadhyaya *et al.* (2002) collected the daily rainfall data for 27 years (1974-2000) from Department of Statistics and Evaluation, Govt. of Bihar at three rain gauge stations (Daudnagar, Pauliganj and Naubatpur). Various probability distribution models were tried to fit weekly, monthly and annual rainfall at these rain gauge stations. Out of various models, the only one model i.e. two parameter Gamma probability distribution model was found fitting well in weekly, monthly and annual rainfall of these three rain gauge stations. Employing this model, probable weekly, monthly and annual rainfall values at probability levels of 0.50 to 0.95 were computed.

Chand *et al.* (2003) analysed the rainfall data of Kanpur, U.P., India for 30 years (1968-97) at different probability levels (10-90%). Analysis revealed that the climate of Kanpur is highly variable with respect to rainfall, with Cv ranging from 56.6% in August to 238.6% in November. Rainy months accounts for approximately 88% of yearly rains. June, July, August and September have on average of 5.4, 14.1, 13.5 and 8.6 rainy days, respectively. The weekly rainfall at 50% probability can be expected only from 27th week to the 40th week, ranging from 7.3 to 57.7 mm .The 27th week falls on the onset of the S-W monsoon.

Pardha et al. (2003) analysed the daily rainfall data for determination of 2,3,4,5 and 6 days rainfall totals in scarcity region, studied the probability distribution of extended days rainfall totals for scaricity region. For this purpose the daily rainfall data of Rahuri and Solapur was used. The probability analysis was carried out using Weibull's formula. By this formula the probability and return periods were estimated. The probability relationships, regression analysis was done in MS-Excel. The analysis was carried out for maximum values of rainfall of extended days.

Jadhav (2004) analysed the daily rainfall data of 25 years (1977-2002) obtained from department of agricultural meteorology, M.A.U., Parbhani. The annual variation of rainfall for Parbhani was worked out. Maximum and minimum weekly rainfall was found to be 260 mm and 1.7 mm, respectively. The AWR during June to September was found to be higher than other seasons varying from 10.215 to 17.25 mm. The average annual rainfall at 50, 60 and 70 per cent probability level were estimated.

2.2 Onset of effective monsoon and its withdrawal :

Agricultural operations start with the onset of South-west monsoon in rainfed areas. The commencement of effective monsoon is crucial for 'kharif' sowing in these areas. A slight delay in sowing of rainfed crops leads to reduction of grain yield and may adversely affect to the next crop too. An advance information about onset, breaks and withdrawal of monsoon and its activity during any particular period is helpful to the farmer.

Onset of effective monsoon (OEM) in rainfed areas should be precisely defined in terms of soil moisture storage in seeding zones after meeting evaporation losses and should be based on the characteristics of the soils and the crops grown. There should be some minimum amount of rainfall sufficient to permit sowing operations. Thus the relevant work which gives the different criteria to identify these effective monsoons is reviewed.

Raman (1974) analysed the daily rainfall data of the black cotton soil area of Maharashtra and identified the 'commencement of sowing rains'. He drew up a criterion to identify the spells of rain at beginning of the south-west monsoon, which would provide sufficient moisture reserve in the soil, adequate for the commencement of sowing. Raman called the commencement of a 7-days spell with a total rainfall of 25 mm with not less than five days of one mm or more rain each day as the 'commencement of sowing rain'. Using this criteria, from daily rainfall data of 231 stations over about 40 to 70 years, he found mean and median dates of commencement of sowing rains which disper's from 2nd June to 6th July and from 4th June to 2nd July, respectively.

Ashok Raj (1979) defined the onset of effective monsoon (OEM) based on the following three criteria.

1. The first day's rain in the 7 days spell is not less than e mm, where e is the average daily evaporation.
2. The total rain during the 7 days spell is not less than (5e + 10) mm.
3. At least four out of these seven days are rainy days with not less than 2.5 mm of rain each day.

The significance of the first criteria is obvious. Using above three criteria, the daily rainfall data from five districts of India were analysed to find mean date of OEM, standard deviation, median date of OEM and earliest and latest probable dates of OEM. It was observed that mean date of OEM ranges from 3rd July to 13th July for Banswara ,19th May to 24th May for Cannanore, 29th May to 24th June for Chandrapur, 6th April to 26th April for Gara Hills and 17th June to 17th July for Mahbubnagar district.

Reddy (1985) modified the above approach for studying the monsoon characteristics of Punjab by proposing following criteria for onset of effective monsoon:

i) The first days rain in 7 days rainy spell is not less than 'e' where 'e' is the average daily evaporation of June and July months.

ii) The total rain during the 7 days rainy spell is not less than the amount of rain which brings the top 30 cm soil layer to the field capacity.

iii) At least 3 out of 7 days must be rainy days with not less than 2.5 mm of rain on each day.

Verma and Samra (1990) studied the monsoon rainfall of a typical rainfed belt of Northern India, namely 'Kandi' belt of northern Punjab for a period of 27 years (1960-1986) to develop criteria of OEM for sowing of rainfed crops, namely maize and sunhemp in sandy loam and loamy sand soils, respectively.

On the basis of logic of above criteria, the following criteria were proposed for the onset of effective monsoon in the case study area.

i) The first day's rain in a seven days spell should not be less than 'e' where 'e' is average daily pan evaporation of the season.

ii) The total rain during the 7 days spell should not be less than EOR, where EOR is "effective onset rainfall" and can be expressed as.

$$EOR = 0.75\ (FC-WP)\ \mathbf{BD'} * d + 5\ e + RO$$

Where,

FC = Moisture content at field capacity (on weight basis)

WP = Moisturc content at wilting point. (on weight basis)

BD' = Relative bulk density of soil w.r.t. water.

d = Effective seeding zone depth or ploughing depth whichever is more cm , and,

RO = Runoff, mm.

iii) At least three out of 7 days are rainy days (having a minimum of 2.5 mm of rain per day).

iv) If above three criteria are satisfied in a week of the first fortnight of June, but followed by a prolonged dry spell then it should be considered as pre monsoon spell and not OEM.

By using above criteria the dates of onset of effective monsoon for maize and sunhemp crops in sandy loam and loamy sand soils were worked out.

Dani (1991) analysed daily rainfall data of Parbhani for the period of 30 years from 1961 to 1990 to find out the dates of onset of effective monsoon (OEM) and the end of monsoon by using the criteria stated by Ashok Raj (1979). It was found that mean date of OEM for Parbhani is June 25 with standard deviation of 20 days. Earliest and latest probable dates of OEM were found to be June 5 and July 15 respectively.

Taksale (1992) analysed daily rainfall data of seven stations of Marathwada region for a period of 20 years (1967-1986) to find out the dates of onset and end of effective monsoon by using criteria developed by Ashok Raj (1979). It was found that the mean date of onset of effective monsoon was July 1 and mean date of end of monsoon was October 15. The earliest probable date and latest probable date of OEM was June 10 and July 22, respectively with standard deviation of 21 days.

Talekar and Parghane (2002) collected the daily rainfall data for Hingoli, Maharashtra for a period of 25 years (1975-2000) and analysed to find out onset of effective monsoon. By using the criteria developed by Ashok Raj (1979), they found earliest and latest probable date of OEM as June 4 and 6th July, respectively. The mean date of OEM was 20th July with standard deviation of 16 days. The effective monsoon ends on 24th September.

Sharma and Kumar (2003) investigated the rainfall of past 20 years of Nagaur district in the arid region of Rajasthan (India) to suggest the probable date of onset of monsoon using criteria given by Raj (1979) and Markov chain model. In the regions where rainfall is erratic and frequent dry periods are expected within the monsoon season, it is essential to determine the most probable dates of onset of effective monsoon to plan agricultural operations. The study revealed that the earliest and latest dates of onset of effective monsoon are on the 16th June and 15th August, respectively. Similarly, the earliest and latest probable dates of withdrawal of effective monsoon are observed on the 4th August and 9th September.

Subhash and Das (2004) studied onset of effective monsoon and its withdrawal using daily rainfall data of 42 years (1960-2001) recorded at the Agricultural Research Institute, Patna, Bihar, India. The annual rain is 1130 mm, of which highest rain (340 mm) contributing to 30% of the annual rain is received in July followed by August (260 mm). Rain starts increasing from standard meteorological week 24 (June 11-17) and is highest during the week 28. As per the present study the mean effective onset of monsoon is 28th June, with standard deviation of 11 days.

2.3 Dry spell analysis :

The presence or absence of certain amount of rainfall at crucial times determine the success or failure of rainfed agricultural crop. In rainfed areas, for successful crop planning, the knowledge of occurrence of dry and wet spells assumes a vital role. The work done related to this subject is reviewed here.

Ashok Raj (1979) analysed daily rainfall data for various stations of five districts of India. The dry spell was defined as the interval between the end of 7 days spell beginning with the onset of effective monsoon and another rainy day with 5e mm or more of rain, or the commencement of another 7 days spell with 5e mm or more of rain, four out of which are the rainy days of 2.5 mm or more rain each day. If duration of this spell exceeds certain value depending on crop soil complex of the region, this dry spell was called as first critical dry spell. The mean date of commencement of dry spell and mean duration of the dry spell was worked out for each station .

Gupta (1982) analysed the 25 years rainfall data for Karnal station to find out the average number of dry days, consecutive dry spells expected in each of the monsoon months and the continuous dry spells expected taking all the months together. Gumbel distribution and modified Gumbel distribution were used in the analysis. The probability of dry spells computed showed a closer agreement with the predictions made from Gumbel's distribution, the computed and observed probabilities of occurrence of various durations of dry spells are given. It was reported that 25 per cent level of probability can be assumed for agricultural operations.

Mohan *et al.* (1985) studied frequencies of wet and dry spells at eight stations in Nasik district for the south-west monsoon period. The study was based on the daily rainfall data of the stations for 50 years (1921-70). It was seen that the frequencies of rain spells of less than five days are common and high for all stations and there is a general decrease in the frequencies for spells more than five days. The same analogy was noticed in dry spells also. The effect of persistence, the number of runs of different durations expected only on chance were also worked out for both wet and dry spells for all stations.

Kolhe (1988) analysed the daily rainfall data for 9 stations, one in each district of Vidarbha region for the period of 20 to 22 years (1965-1986) to find out the mean dates of commencement of critical dry spells along with their durations. The criteria adopted for analysis was one, which was stated by Ashok Raj (1979). It was observed that the first critical dry spell commences sometimes in between July 6 to July 17 with duration ranging from 11 days to 25 days, the second CDS starts sometimes in between July 6 to July 17 with the mean duration ranging from 11 days to 25 days, third CDS starts sometimes in between August 24 to September 23, with the duration ranging from 15 days to 50 days in the whole Vidarbha region. The cumulative probability nomographs for dry spells during crop developmental stages for various region and for various crop varieties depending upon region were also prepared. Isohydal maps showing dates and duration of first three critical dry spells for Vidarbha region were also plotted.

Dani (1991) analysed the daily rainfall data of Parbhani for the period of 30 years (1961-90) to find out the mean date of commencement of critical dry spells along with their mean duration. The criteria adopted was one which was suggested by Ashok Raj (1979). The mean dates of commencement of critical dry spell observed were July 16 for first, August 14 for second and September 12 for third CDS. The mean durations of these three CDS observed were 20 for first, 27 for second and 35 days for third CDS. Dry spell durations at different probability levels for all the eight fortnights were also determined and plotted.

Shivakumar (1991) used the specific definition of onset of rains in each year as sowing date, the lengths of dry spells were calculated from the historical rainfall data for 150 station in Burkina Faso, Mali, Niger and Senegal. Probability distribution of time to the next wet day and the percentage frequencies of dry spells were computed for successive days after sowing (DAS) a crop. Dry spell analysis showed a pronounced drop in the drought risk for cereal crops from panicle initiation (20 DAS) to flowering (160 DAS). The relationships between mean annual rainfall and average frequency of dry spells for the selected locations in West Africa showed distinct patterns and permitted to prediction of the frequency of dry spells from annual rainfall totals.

Maliwal and Chhatrola (1992) analysed the monthly rainfall pattern of different stations of Bhal and Coastal agroclimatic zones. The year to year variability and variability in rainfall occurring during monsoon season along with other statistical parameters were worked out. Moreover the dry spells of different durations were worked out. The study revealed that drought periods of various duration were computerized from weekly rainfall data showed that ten continuous rainless weeks can be expected to once during the period with probability 12.9%. The analysis further showed that a maximum of four non-continuous rainless weeks can be expected to occur once with the high water holding capacity of medium black soils of Arnej.

Ranade and Gupta (1992) observed from rainfall analysis of 22 years data that 23rd week had maximum frequency of drought while minimum was in case of 27th and 30th week. Thus sowing of the crops should be done in 25th week. Further, period wise maximum frequency of drought was in summer and followed by post-monsoon. Thus irrigation of crops is must during November and December.

Taksale (1992) analysed the daily rainfall data of 20 years for Marathwada regions of Maharashtra. The seven important raingauge stations, one in each district of Marthwada were selected for the study. Dry spell analysis was done by applying criteria stated by Ashok Raj. By considering the critical value for each station, the critical dry spells along with their mean durations were also determined. The curves of dry spell at different probability levels viz. 25, 40, 60 and 80% levels were plotted. The cumulative probability nomograms were developed for important growth phases of different crops selected, for each station Isohydal maps showing the dates of OEM and end of monsoon, number of rainy days and mean dates and mean durations of three critical dry spells were also drawn for Marathwada region.

Mishra *et al.* (1996) analysed the rainfall data obtained from meteorological observatory located in the Chotanagpur plateau, Bihar during 1967-92. From study it was found that dry spells 5-12, 0-10, and 5-23 days were recorded during 11th June- 10th July, 11th July – 14th August and 15th August-14th October, respectively, which coincides with the vegetative growth and reproductive stages of upland rice.

Sharma (1996) predicted the stochastic behaviour of the longest dry and wet spells using theory of runs, Poisson probability density function of the occurrence of spells and Weibull's distribution of total rain over wet spell. The entire analysis was carried out using only five parameters, namely the probability of any day being a dry day, the probability of dry day followed by the previous dry day, the probability of a wet day followed by the previous wet day, the mean and variance of the daily rainfall sequences during a rainy season.

Talekar and Parghane (2002) analysed the daily rainfall data for Hingoli for the period of 25years (1975 to 2000) to find out the dry spells, critical dry spell and its probability during crop development stages, Total 84 dry spells were observed during the period of 26 years. Average number of CDS were 2 and mean date of first CDS was July 5 with mean duration of 20 days and that of second CDS was July 17 with duration of 14 days. Cumulative probability nomograms were developed for Cotton and Sorghum.

Sharma and Kumar (2003) investigated the rainfall of part 20 years of Nagaur district of the arid region of Rajasthan, to suggest the occurrence of dry spells using criteria given by Ashok Raj (1979) and Markov chain model. The study revealed that the expected dates of start of first and second critical dry spell are worked out to be 14^{th} July and 16^{th} August, respectively. The respective duration of first and second critical dry spell has been obtained as 20 and 17 days.

Materials and Methods

CHAPTER-III

MATERIAL AND METHODS

This chapter describes the project area under consideration, length of data collected and the methods employed for analysing data.

3.1 Location :

The present study is confined to three districts of the Marathwada region, namely Beed, Latur and Osamanbad. Marathwada region of Maharashtra state comprises of eight districts and geographically situated between $17^{0}35"$ to 20^{0} 40" (N) latitude and 74^{0} 40' to $78^{0}.16"$ (E) longitude. The altitude ranges from 300 to 900 meters above MSL. Jawar, soybean, cotton etc. are the most important crops, grown on large scale all over Marathwada region.

There are 56 raingauge stations in Marathwada region. Amongst them, three stations, located at district headquarter , were selected for detailed analysis. The names and locations of the rainguage stations selected for analysis are given in Table 3.1

Table 3.1 : Location of the rainguage station which are selected for analysis.

Sr. No.	Raingauge Station	Location	
		Latitude North	Longitude East
1.	Beed	19^{0}	75^{0}
2.	Latur	18^{0}	77^{0}
3.	Osmanabad	18^{0}	76^{0}

3.2 Data collection

The daily rainfall data and evaporation data of the 3 raingauge stations namely Beed, Latur and Osmanabad were obtained for the analysis from the Department of Agricultural Meteorology, M.A.U., Parbhani and India Meteorology Department, Pune. The details of data collected are given below.

1. Beed : Rainfall data for 23 years from 1980 to 2002 were obtained.
2. Latur : Rainfall data of 22 years from 1981 to 2002 were obtained.
3. Osmanabad : Rainfall data of 22 years from 1981 to 2002 were obtained.

3.3 Analysis of rainfall data :

For making the daily rainfall data obtained for various stations to be concise, total of rainfall in the month for each station per year obtained. The number of rainy days for each month for every year were also obtained. From the monthly totals obtained, the normal rainfall for every month, the minimum and maximum rainfall and the average rainy days for each month for all stations were computed.

The daily rainfall data collected for various stations and lumped to form 52 sets of weeks, each corresponding to different weeks of the year. From this the total of the rainfall in the week for each station per year obtained. From the weekly totals obtained, the minimum weekly rainfall, maximum weekly rainfall, average weekly rainfall, standard deviation and coefficient of variation for each week for all the stations were computed.

3.4 Onset of effective monsoon (OEM) :

There is a need for identifying "Effective Monsoon" as 'commencement of sowing rains' distinct from the premonsoon showers. Premonsoon rains cannot be considered as effective monsoon for agricultural operations, particularly because these rains are followed by long dry spells which may affect the germination of seeds resulting in crop failure if sowings are under taken immediately after these showers.

Determination of dates of OEM :

The concept developed by Ashok Raj (1979) on onset of effective monsoon and dry spells was adopted in the present study. Effective monsoon is that monsoon which leaves enough moisture to support agricultural operations. If the average daily evaporation is e mm, and after a prolonged dry spell, if it rains on a particular day an amount of r mm of rain, it is assumed that only (r-e) mm of rain will be available for the soil that day. If it rains on the subsequent days, the evaporation loss will be less than e mm. In the light of this, the rainfall of seven day period that leaves atleast 10 mm of rain after meeting the evaporational demand, is designated as the effective monsoon. Accordingly the date of commencement of a 7 day spell satisfying the following criteria can be defined as the date of onset of effective monsoon.

1. The first day's rain in the seven days spell should be more than average daily evaporation (e) of the place.

2. The total rain during the seven days spell should not be less than (5e+10) mm.

3. Atleast four out of these seven days should be rainy days with not less than 2.5 mm of rain each day. A day is called a rainy day if the rainfall of that day is more than or equal to 2.5mm.

The dates of onset of effective monsoon for every year for each station were determined by applying the above three criteria. After identifying the date of onset of effective monsoon Xi (i=1,2,3........ n) in the i th year for a particular rain gauge station, the mean date m is computed as follows.

$$M = \sum_{i=1}^{n} \frac{xi}{n} \qquad \text{.. 3.1}$$

Where n is the number of years.

The standard deviation of Xi(i=1,2,3.......n) dates of onset of effective monsoon is calculated as follows.

$$6 = \left(\frac{\sum_{i=1}^{n} X_i^2 - \frac{(\sum_{i=1}^{n} X_i)^2}{n}}{n-1} \right) \qquad \text{....................... 3.2}$$

Where,

6 = standard deviation (days)

n = number of years.

3.5 Determination of Dry and Wet Spells :

3.5.1 General :

The dry spells were found out by applying the criteria stated by Ashok Raj (1979).

The interval between the end of the 7-days spell, beginning with the onset of effective monsoon and another rainy day with 5e mm or more of rain or the commencement of another 7-day rainy spell satisfying the third criteria stated in above paragraph, with a total rainfall of 5e mm or more during this spell is called as the first dry spell. Similarly other dry spells are found.

The interval between the OEM and the beginning of the first critical dry spell is called the first wet spell. The subsequent wet spells are defined as the interval between two critical dry spells. Thus the wet spells are spells of prolonged rain with possible intervening dry spells of duration less than the value depending on crop -soil complex of the region, which makes the dry spell critical.

3.5.2 Critical dry spell (CDS) :

If the duration of the dry spell occurred during the monsoon season exceeds a certain period depending on the crop-soil complex of the region, the dry spell is called the first critical dry spell. Duration of 10 days was considered to classify the dry spell as critical during this study (Taksale,1992). There may occur more than one critical dry spell during every year. The critical dry spells were obtained for every year for each station.

The mean dates of starting of critical dry spells were obtained by the same procedure adopted for obtaining the mean dates of OEM.

3.6 Dry Spell with Reference to Crop development stages :

The probability of occurring a dry spell of specific duration during the crop developmental stages is more important from the point of view of agricultural planning.

3.6.1 Crops considered for each district :

Crops grown vary from district to district depending upon environmental conditions of that region. Jowar is grown on large scale all over Marathwada. That's why Jowar was considered for Beed, Latur and Osmanabad dist. Next to Jowar, Cotton is also important crop to this region and therefore considered for these all districts.

3.6.2 Dry spell analysis with reference to crop developmental stages.

From the daily rainfall data for the stations, the dry spells during the particular crop developmental stages were found out. During every year the maximum length of dry spell during the crop stage was considered. The duration of crop developmental stages and the varieties of crop considered are given in Appendix-I. Unlike dry spells in fortnightly analysis, the dry spells are dependent on the duration of the crop developmental stage. If the spell starts in a particular developmental stage but extent in the next stage, then the spell was supposed as if it ends in the same crop stage. The commencement of new spell is considered from the starting of new crop developmental stage. Thus the length of dry spells never exceed the length of crop developmental stage. For each crop at each station the dry spells were found out depending on the crop developmental stage. The dates of sowing at all station were different. The dates of sowing for each station are given in Appendix-II. Date of sowing was considered to be seven days after the mean date of the onset of effective monsoon (OEM) of station supposing the end of first seven days wet spells. Like the exceedance probability was not considered. For plotting the probability nomograms the cumulative probabilities were considered. The cumulative probability is defined as "The probability that the random variate has a value of equal to or less than a certain assigned value" (Varshney 1986). According to the extreme value distribution the cumulative probability Pc has the expression

$$Pc = e^{-e^{-y}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.3$$

in which y is reduced variate and is given as

$$Y = \frac{(d-\bar{d}) + 0.45\ 6}{0.7797\ \ 6} \quad \ldots\ldots\ldots\ldots \quad 3.4$$

Where 6 = Standard deviation

$$6 = \left[\frac{\sum_{i=1}^{n} X_i^2 - \frac{\left(\sum_{i=1}^{n} X_i\right)^2}{n}}{n-1} \right]^{1/2}$$

and d= length of dry spell of which the probability is to be found out.

$$\bar{d} = \text{mean} = \sum_{i=1}^{n} \frac{d_i}{n}$$

These cumulative probabilities so obtained were plotted for all crop developmental stages for each station on a probability paper against the length of dry spell in days, forming the nomogram for each station. This is considered as a representative nomogram for the district.

Results and discussion

CHAPTER-IV

RESULTS AND DISCUSSION

Records of daily rainfall data for 23 years for Beed and 22 years for Latur and Osmanabad districts were obtained from the Deptt. of Agricultural Meteorology, M.A.U., Parbhani. Data were analysed to determine the rainfall characteristics influencing agricultural operations and irrigation management. The characteristics includes mean monthly rainfall, average weekly rainfall (AWR), standard deviation, coefficient of variation and average annual rainfall. Daily rainfall and evaporation data of five years were used for determining the dates of onset of effective monsoon, critical dry spells and wet spells. The data were also analysed for probabilities of occurrence of dry spell during crop developmental stages.

4.1 Analysis for Beed station :

4.1.1 Analysis of Rainfall data :

Although annual, seasonal and monthly rainfall of a region is helpful for design of water harvesting structures but weekly rainfall analysis gives more useful application for crop planning (Tiwari et al., 1992). Daily rainfall data of 23 years from 1980-2002 were analyzed to find out the minimum weekly rainfall, maximum weekly rainfall, average weekly rainfall (AWR), standard deviation, co-efficient of variation, minimum, maximum and average monthly rainfall, average annual rainfall and number of rainy days.

Table 4.1 furnishes values of weekly observed minimum, maximum and average rainfall, standard deviation and coefficient of variation of different weeks.

Table 4.1 : Weekly observed minimum, maximum and average rainfall, standard deviation and coefficient of variation of different weeks.

Rainguage station : Beed.

Week No.	Minimum rainfall,mm	Maximum rainfall,mm	AWR, mm	Std. dev. mm	Cv, %
1.	0.0	0.0	0.0	0.0	0.0
2.	0.0	1.8	0.08	0.4	500
3.	0.0	0.4	0.02	0.08	400
4.	0.0	0.0	0.0	0.0	0.0
5.	0.0	1.4	0.06	0.29	483.34
6.	0.0	0.0	0.0	0.0	0.0
7.	0.0	24.2	1.05	5.05	480.95
8.	0.0	0.0	0.0	0.0	0.0
9.	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0
11.	0.0	0.0	0.0	0.0	0.0
12.	0.0	0.0	0.0	0.0	0.0
13.	0.0	0.0	0.0	0.0	0.0
14.	0.0	0.0	0.0	0.0	0.0
15.	0.0	47.2	2.05	9.84	480
16.	0.0	5.0	0.22	1.04	472.73
17.	0.0	0.0	0.0	0.0	0.0
18.	0.0	30.2	1.31	6.3	480.92
19.	0.0	16.0	0.7	3.34	477.14
20.	0.0	29.2	1.27	6.09	479.53
21.	0.0	71.8	3.12	14.97	479.81
22.	0.0	141.6	11.67	33.18	284.32
23.	0.0	167.8	38.77	43.42	111.99
24.	0.0	260.6	42.95	58.53	136.28
25.	0.0	176.4	31.01	46.56	150.55

Table No. 4.1 Cont.

Week No.	Minimum rainfall,mm	Maximum rainfall,mm	AWR, mm	Std. dev. mm	Cv, %
26.	0.0	144.8	33.03	40.05	121.25
27.	0.0	105.6	26.00	28.33	108.96
28.	0.0	130.6	33.17	43.16	130.15
29.	0.0	125.0	33.17	30.4	91.65
30.	0.0	393.4	47.61	88.4	184.68
31.	0.0	127.0	17.92	27.92	155.80
32.	0.8	128.8	44.7	59.53	133.18
33.	0.0	126.4	30.16	37.49	124.30
34.	0.0	197.4	36.75	48.73	132.60
35.	0.0	150.2	34.13	41.24	120.83
36.	0.0	251.6	46.63	57.76	123.87
37.	0.0	200.2	48.07	62.01	128.99
38.	0.0	147.6	40.47	45.58	112.63
39.	0.0	252.8	51.87	60.15	115.96
40.	0.0	155.4	27.93	39.55	141.60
41.	0.0	192.2	28.24	52.89	187.29
42.	0.0	101.0	15.13	27.87	184.20
43.	0.0	53.8	10.81	17.76	164.30
44.	0.0	29.1	4.09	9.24	225.92
45.	0.0	31.0	2.78	7.21	259.35
46.	0.0	49.2	3.23	10.49	324.77
47.	0.0	55.4	3.49	11.7	335.24
48.	0.0	86.0	3.74	17.93	479.41
49.	0.0	4.4	0.19	0.92	484.21
50	0.0	12.8	0.56	2.67	476.79
51.	0.0	12.6	0.55	2.63	478.18
52.	0.0	45.8	2.77	9.74	351.62

It is observed from Table 4.1 that the minimum and maximum weekly observed rainfall are found to be ranged between 0 to 0.8 mm and 0.4 to 393.3 mm, respectively. The average weekly rainfall (AWR) at Beed varies from a minimum of 0.02 mm for 3rd week to a maximum of 51.87 mm for 39th week. It can also be seen from table that the AWR varies from a minimum of 38.77 mm for 23rd week to a maximum of 51.87 mm for 39th week of the wet period, while it varies from 0.0mm in 1st, 4th, 6th, 8th to 14th and 17th week to 28.24 mm in 41st week in the dry period. The AWR for 39th week during 23 years period was more i.e. 51.87 mm and thus 39th week is the wettest period with rainfall of 51.87 mm. While no rainfall was received in 1st, 4th, 6th, 8th to 14th and 17th week during 23 years period.

The value of Cv varied from a minimum of 91.65% for 29th week to a maximum of 184.68% for 30th week of the wet period, lying between 23rd to 39th week. However it shows larger variation from 91.65% for 29th week to 500% for 2nd week expect 1st, 4th, 6th, 8th to 14th and 17th weeks (Table 4.1). In general, Cv was less than 184.68% for the wet period. The lesser value of Cv in between 23rd to 39th week is therefore an indications of the wet periods as also indicated by AWR. Thus, Cv is associated with the wetness and dryness of the region indicating that it decreases as AWR increases. The values of standard deviation of weekly rainfall data for different weeks during 23 years of period presented in Table 4.1 indicated that the value of standard deviation of weekly rainfall increases with increase in the AWR.

Minimum, maximum and average monthly rainfall values were determined for Beed from daily rainfall data of 23 years. These values are presented in Table 4.2.

Table 4.2 : Monthly observed minimum, maximum and average rainfall and rainy days. Raingauge station : Beed.

Sr. No.	Month	Average number of rainy days	Rainfall (mm)		
			Minimum rainfall, mm	Maximum rainfall, mm	Average rainfall, mm
1.	January	0.0	0.0	2.2	0.1
2.	February	0.04	0.0	25.6	1.11
3.	March	0.00	0.0	0.0	0.0
4.	April	0.17	0.0	47.2	3.61
5.	May	0.43	0.0	140.8	6.63
6.	June	7.04	23.2	509.4	155.88
7.	July	6.87	3.6	688.2	137.01
8.	August	7.96	11.3	388.2	153.15
9.	September	9.13	29.6	488.6	189.96
10.	October	4.13	0.0	225.2	85.01
11.	November	0.87	0.0	114.7	11.8
12.	December	0.52	0.0	45.8	5.5
	Total	**37.16**			**749.76**

It is seen from Table 4.2 that the minimum monthly rainfall values varies from a minimum of 0 mm in January, February, March, April, May, October, November and December to maximum of 29.6 mm in the month of September during 23 years. Maximum monthly rainfall varied in the range of 2.2 to 688.2 mm. Maximum monthly values for the period June to September are higher than the values observed for the remaining months.

From the Table 4.2, it is observed that the total of average monthly rainfall for the month from June to September is 635.92 mm, which is 84.83% of the annual rainfall. Thus it is concluded that the maximum amount of rainfall is received during the month June to September of the year. It can be also seen from table that average number of rainy days are minimum i.e. 0 days for the month of January and March and maximum in September ie 9.13 days. The total number of rainy days are 37.16 days in period of one year.

Table 4.3 : Variation in annual rainfall and number of rainy days.

Sr. No.	Year	Total rainfall (mm)	Number of rainy days
1.	1980	712.0	37
2.	1981	652.5	39
3.	1982	477.6	32
4.	1983	950.7	50
5.	1984	579.9	30
6.	1985	466.7	29
7.	1986	641.6	30
8.	1987	759.0	42
9.	1988	1170.6	58
10	1989	1228.2	43
11.	1990	1076.3	52
12.	1991	322.9	20
13.	1992	691.0	29
14.	1993	569.6	38
15.	1994	423.8	26
16.	1995	640.5	33
17.	1996	1032.2	50
18.	1997	678.6	40
19.	1998	1158.3	45
20.	1999	498.2	31
21.	2000	1190.4	41
22.	2001	741.4	33
23.	2002	581.8	27
	Average	**749.76**	**37.17**

The variation in annual rainfall and number of rainy days of Beed for 23 years are presented in Table 4.3

Data from Table 4.3 shows that the annual rainfall averaged over 23 years for Beed station is 749.76 mm. The minimum rainfall of 322.9 mm was recorded during 1991 and maximum rainfall of 1228.2 mm was recorded during 1989. The number of rainy days varied from a minimum of 20 days during 1991 to a maximum of 58 days during 1988.

4.1.2 Onset and end of effective monsoon :

As there is large variation in rainfall data of recent 5 years (1998-2002) as compared to previous years (1980-1998), and therefore rainfall data of recent year was taken into account. Daily rainfall and evaporation data of 5 years for Beed Station from 1998 to 2002 were analysed to find out the dates of onset of effective monsoon (OEM) and dates of withdrawal of monsoon during individual years. The criteria stated by Ashok Raj (1979) mentioned in 3.4 was used in the analysis. Results obtained are shown in Table 4.4

Table 4.4: Dates of onset and end of effective monsoon for Beed station.

Year	Effective monsoon	
	Onsets	Ends on
1998	July 21	October 15
1999	June 13	October 11
2000	June 1	September 30
2001	June 6	October 12
2002	July 17	October 16
Mean	June 23	October 10

Mean date of OEM = June 23.
Standard deviation = 24 days.

From the Table 4.4, it is seen that effective monsoon starts from first week of June to third week of July. It can be also seen that mean date of onset of effective monsoon for station is June 23 with standard deviation of 24 days.

From Table 4.4, it is also observed that effective monsoon ends in between last week of September and third week of October. Mean date of withdrawal of monsoon is found to be October 10.

4.1.3 Dry spell analysis :

The dates of commencement and durations of dry spells were determined during every year from the daily rainfall and evaporation data of the Beed station by using the criteria suggested by Ashok Raj (1979).

4.1.3.1 Observed dry spells :

Table 4.5, shows the dates and durations of dry spells determined during every year after the commencement of effective monsoon.

After observing the Table 4.5 it is clear that the short duration dry spells are very less in number. It is due to the criteria for determining the dry spells which states that it is interval between the end of the 7 days spells, beginning with the onset of effective monsoon and another rainy day with 5e mm (e = average daily evaporation) or more of rain or the commencement of another 7-day rainy spell with 5e mm rainfall or more and with atleast 4 rainy days with not less than 2.5 mm of rain each day. Because of this criteria short duration dry spells get merged into 7 days wet spells and a long wet spell occurs.

Table 4.5 : Observed dry spells during 1998-2002 at Beed Station.

Year	DRY SPELLS									
	First		Second		Third		Fourth		Fifth	
	Date	Days	Date	Days	Date	Days	Date	Days	Date	Days
1998	August-27	5	September-12	10	September-29	4	October-04	7	--	--
1999	June-20	4	June-25	11	July-19	12	August-3	35	September-18	5
2000	June - 17	14	July – 14	25	August-13	8	September-1	27	--	--
2001	June - 20	42	August-25	21	September-18	7	--	--	--	--
2002	August-12	11	August-25	6	September-6	40	--	--	--	--

From the table 4.5, it is obvious that there are atleast three dry spells during every year. Three dry spells occurred during 2001 and 2002 and four dry spells occurred during 1998 and 2000 and five dry spells occurred during 1999. Three dry spells of duration 35, 40 and 42 days were observed in the years 1999, 2002 and 2001, respectively. The duration of the remaining dry spells ranged between 4 to 27 days. Total 19 dry spells were observed during the period of five years.

4.1.3.2 Critical dry spells (CDS) and wet spells :

When the duration of dry spell exceeds a certain value depending on crop-soil complex of the region, it is called as critical dry spell. The critical value of duration of dry spell for Beed station was considered as 10 days (Taksale, 1992).

Table 4.6 : Critical dry spells (CDS) during the year for Beed station.

Year	CRITICAL DRY SPELLS (CDS)						
	First		Second		Third		Total
	Date	Days	Date	Days	Date	Days	
1998	September 12	10	--	0	--	0	1
1999	June-25	11	July-19	12	August-3	35	3
2000	June-17	14	July-14	25	September 1	27	3
2001	June-20	42	August-25	21	--	0	2
2002	August-12	11	Septem-Ber 6	40	--	0	2
Mean	July-17	18	August-8	25	August - 17	31	2

Critical dry spell (CDS) : When length of dry spell exceeds 10 days.

Average number of CDS : 2

Average dates of starting of CDS and length

First CDS -- July 17 Length - 18 days

Second CDS -- August 8 Length - 25 days

Third CDS -- August 17 Length - 31 days

Mean dates of wet spells :

First wet spell -- June 23 to July 16.

Second wet spell -- August 4 to August 8

Third wet spell -- September 18 to October 10.

Table 4.6 shows the observed critical dry spells and their mean durations during every year. It is seen from table that mean number of critical dry spell is two. Critical dry spells ranged from one to three during every year. It is also observed that only one CDS occurred during 1998 and maximum three CDS occurred during 1999 and 2000.

Data in Table also presents the mean dates of commencement of CDS and their mean durations. Average dates of commencement and end of wet spells are also given at the bottom of the Table 4.6.

4.1.4 Dry spell probability nomograms during crop developmental stages:

The allotment of dry spell duration during the crop developmental stages was done as described in previous chapter. The maximum length of dry spell is equal to the duration of the crop developmental stage. The dry spell is considered to end in the same crop developmental stage. The crops considered for Beed station are Jowar and Cotton. The probabilities of occurrence of dry spell of different durations during each crop developmental stages were determined by Gumbel's method. The probabilities found are cumulative probabilities hence it increases as dry spell duration increases.

4.1.4.1 Jowar :

There are five stages of which the dry spell probabilities are plotted. The dry spell probabilities were determined for different developmental stages of Jowar crop for Beed station. The method of finding dry spell probability in a particular crop

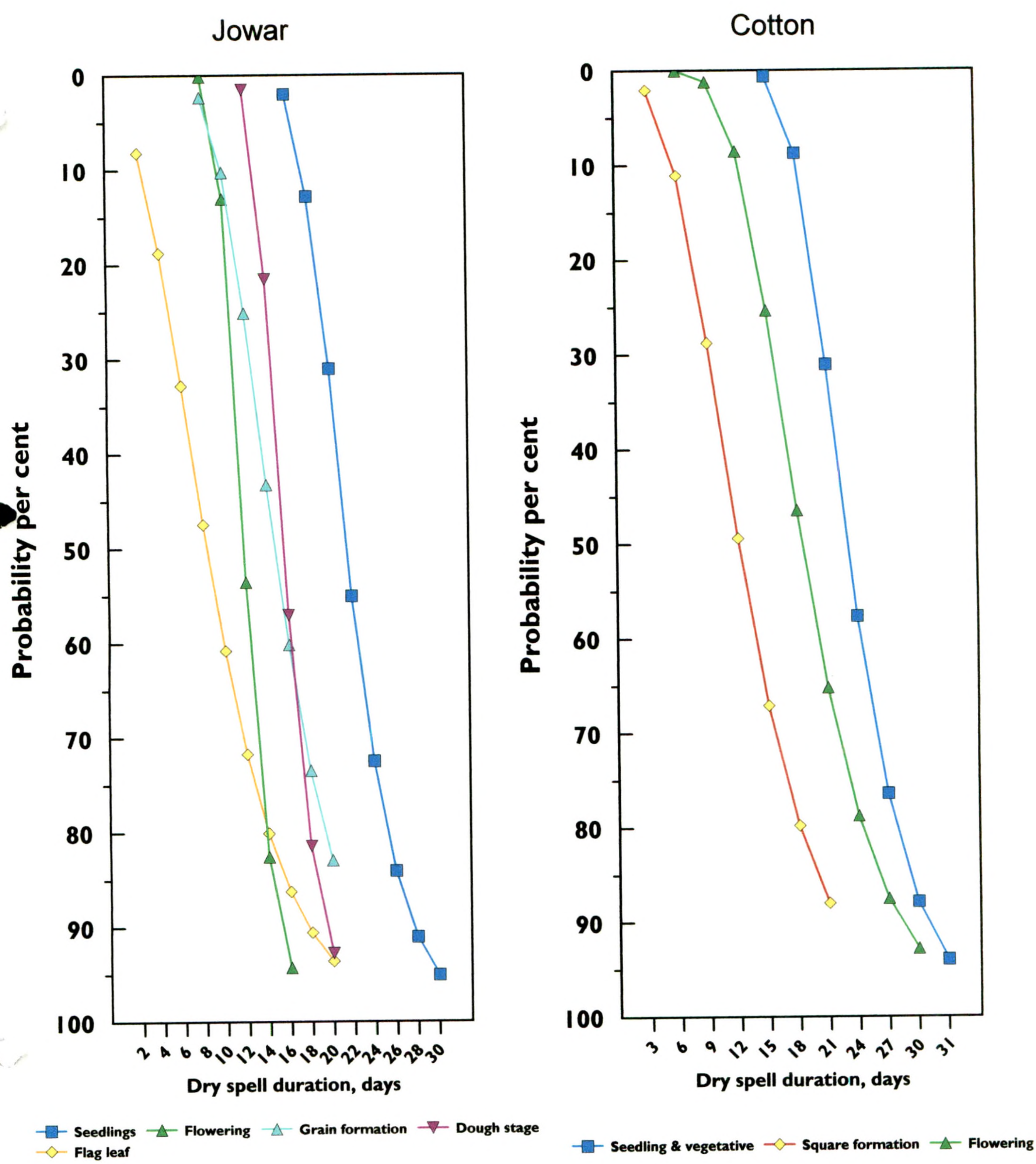

Fig. 4.1: (A, B) Probability nomograms for occurrence of dry spell during developmental stages for Beed station

developmental stage is explained in Appendix III. Using dry spell duration and probability values, dry spell probability nomogram was developed which is depicted in Fig. 4.1 (A). This nomogram could be used to determine dry spell duration at different values of probability. The values of dry spell durations at different probability levels are obtained from nomogram and presented in Appendix-V. It is reported that 25 per cent probability level is considered for agricultural purposes (Taksale, 1992). At 25 per cent probability, the number of dry days were found to be 19.27 days for seedling stage, 4.93 days for flag leaf stage, 5.27 days for flowering stage, 5.98 days for grain formation stage and 6.20 days for dough stage, respectively.

4.1.4.2 Cotton :

There are three stages of which the dry spell probabilities are plotted. The boll formation and boll bursting stages are not considered as these lasts after the end of monsoon season. The dry spell probabilities were determined for different developmental stages of cotton for Beed station. The method finding of dry spell probability in a particular crop development stage is explained in Appendix-III. Using dry spell durations and probabilities values, dry spell probability nomogram was developed which is depicted in Fig. 4.3 (B). This nomogram could be used to determine dry spell duration of different values of probability. The values of dry spell durations at different probability level are obtained from nomogram and presented in Appendix-V. At 25 percent probability, the number dry days were found to be 19.31 days for seedling and vegetative stage, 8.44 days for square formation and 14.95 days for flowering stage, respectively.

4.2 Analysis for Latur station :

4.2.1 Analysis of Rainfall data :

Daily rainfall data of 22 years from 1981-2002 were analysed to find out the minimum weekly rainfall, maximum weekly rainfall, average weekly rainfall (AWR), standard deviation, co-efficient of variation, minimum, maximum and average monthly rainfall, average annual rainfall and number of rainy days.

Values of weekly observed minimum, maximum and average rainfall, standard deviation and coefficient of variation of different weeks are given in table 4.7

Table 4.7 : Weekly observed minimum, maximum and average rainfall , standard deviation and coefficient of variation of different weeks.

Raingauge station : Latur.

Week No.	Minimum rainfall,mm	Maximum rainfall,mm	AWR, mm	Std. dev. mm	Cv, %
1.	0.0	0.0	0.0	0.0	0.0
2.	0.0	21.0	1.36	4.79	352.21
3.	0.0	6.0	0.27	1.28	474.07
4.	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0
6.	0.0	9.0	0.41	1.92	468.29
7.	0.0	24.2	1.1	5.16	469.10
8.	0.0	16.3	0.74	3.48	470.27
9.	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0
11.	0.0	0.0	0.0	0.0	0.0
12.	0.0	0.0	0.0	0.0	0.0
13.	0.0	0.0	0.0	0.0	0.0
14.	0.0	0.0	0.0	0.0	0.0
15.	0.0	0.0	0.0	0.0	0.0

Table 4.7 Cont.

Week No.	Minimum rainfall,mm	Maximum rainfall,mm	AWR, mm	S.D., Mm	Cv, %
16.	0.0	0.0	0.0	0.0	0.0
17.	0.0	0.0	0.0	0.0	0.0
18.	0.0	0.0	0.0	0.0	0.0
19.	0.0	0.0	0.0	0.0	0.0
20.	0.0	0.0	0.0	0.0	0.0
21.	0.0	0.0	0.0	0.0	0.0
22.	0.0	60.0	4.29	12.92	301.17
23.	0.0	120.4	27.2	29.19	109.15
24.	0.0	123.2	36.75	33.65	91.56
25.	0.0	109.8	26.14	31.84	86.6
26.	0.0	110.4	33.65	34.66	103.0
27.	0.0	142.2	23.55	32.57	138.30
28.	0.0	149.0	41.56	42.03	101.37
29.	0.0	118.2	25.2	26.44	105.76
30.	4.0	170.2	56.52	43.87	77.63
31.	0.0	78.0	25.22	21.47	85.20
32.	0.2	201.0	45.87	52.7	114.89
33.	0.0	252.8	33.84	55.76	164.82
34.	0.0	278.0	40.83	60.81	148.94
35.	0.0	177.4	38.96	54.21	139.21
36.	0.0	221.5	47.88	60.69	126.75
37.	0.0	155.0	47.11	46.2	98.32
38.	0.0	156.4	36.99	49.23	133.16
39.	0.0	161.3	38.21	48.73	127.53
40.	0.0	253.0	45.4	58.76	129.43
41.	0.0	143.0	23.9	33.05	138.29
42.	0.0	107.0	20.18	33.51	166.14
43.	0.0	71.2	9.35	17.87	181.12
44.	0.0	54.0	5.87	14.64	251.11
45.	0.0	28.2	3.16	6.96	220.25
46.	0.0	26.0	2.66	7.08	266.17
47.	0.0	40.0	2.67	8.81	332.45
48.	0.0	0.0	0.0	0.0	0.0
49.	0.0	49.0	3.61	11.87	328.81
50	0.0	8.0	0.36	1.71	475.6
51.	0.0	1.0	0.05	0.21	420.0
52.	0.0	55.0	2.5	11.73	469.2

It is observed from Table 4.7 that minimum and maximum weekly observed rainfall are found to be ranged between 0 to 4 mm and 1 to 278 mm, respectively. The average weekly rainfall (AWR) at Latur varies from a minimum of 0.05 mm for 51st week to a maximum of 56.52 mm for 30th week. It can be also seen from table that the AWR varies from a minimum of 23.55 mm for 27th week to a maximum of 56.52 mm for 30th week of the wet period, while it varies from 0.0 mm in 1st, 4th, 5th, 9th to 21st and 48th week to 45.4 mm in 40th week in the dry period. The AWR for 30th week during 22 years period was more i.e. 56.52 mm and thus 30th week is the wettest period with rainfall of 56.52 mm. While no rainfall was received in 1st, 4th, 5th, 9th to 21st and 48th week during 22 years period.

The value of Cv varied from a minimum of 77.63% for 30th week to a maximum of 164.82% for 33rd week of the wet period, lying between 23rd to 39th week. However it shows larger variation from 77.63% for 30th week to 475% for 50th week expect 1st, 4th, 5th, 9th to 21st and 48th weeks (Table 4.7). In general, Cv was less than 164.82% for the wet period. The lesser value of Cv in between 23rd to 39th week is therefore an indications of the wet periods as also indicated by AWR. Thus, Cv is associated with the wetness and dryness of the region indicating that it decreases as AWR increases. The values of standard deviation of weekly rainfall data for different weeks during 22 years of period presented in Table 4.7 indicated that the value of standard deviation of weekly rainfall increases with increase in the AWR.

Minimum, maximum and average monthly rainfall values were determined for Latur from daily rainfall data of 22 years. These values are presented in Table 4.8.

Table 4.8 : Monthly observed minimum, maximum and average rainfall and rainy days. Raingauge station : Latur.

Sr. No.	Month	Average number of rainy days	Rainfall (mm)		
			Minimum rainfall, mm	Maximum rainfall, mm	Average rainfall, mm
1.	January	0.14	0.0	21.0	1.64
2.	February	0.14	0.0	33.2	2.25
3.	March	0.00	0.0	0.0	0.0
4.	April	0.0	0.0	0.0	0.0
5.	May	0.0	0.0	0.0	0.0
6.	June	7.84	35.0	267.6	125.6
7.	July	9.57	41.5	273.6	153.9
8.	August	9.76	17.8	429.8	170.16
9.	September	8.96	11.9	507.6	179.88
10.	October	4.92	1.0	289.0	104.25
11.	November	0.73	0.0	78.1	8.88
12.	December	0.33	0.0	56.5	6.8
	Total	**42.39**			**753.36**

It is seen from Table 4.8 that the minimum monthly rainfall values varies from a minimum of 0 mm in January, February, March, April, May, November and December to maximum of 41.5 mm in the month of July during 22 years. Maximum monthly rainfall varied in the range of 21.0 to 507.6 mm. Maximum monthly values for the period June to September are higher than the values observed for the remaining months.

From the Table 4.8, it is observed that the total of average monthly rainfall for the month from June to September is 629.54 mm, which is 83.56% of the annual rainfall. Thus it is concluded that the maximum amount of rainfall is received during the month June to September of the year. It is also seen from data that average number of rainy days are minimum i.e. 0 days for the month of March, April and May and maximum in August ie 9.76 days. The total number of rainy days are 42.39 days in period of one year.

Table 4.9 : Variation in annual rainfall and number of rainy days.

Sr. No.	Year	Total rainfall (mm)	Number of rainy days
1.	1981	806.2	44
2.	1982	599.5	38
3.	1983	1302.8	55
4.	1984	488.7	30
5.	1985	539.4	36
6.	1986	311.9	31
7.	1987	706.0	45
8.	1988	1102.1	52
9.	1989	981.9	51
10	1990	1077.1	44
11.	1991	551.5	34
12.	1992	849.2	36
13.	1993	749.9	49
14.	1994	345.7	33
15.	1995	758.0	39
16.	1996	981.8	45
17.	1997	577.7	46
18.	1998	1223.3	59
19.	1999	697.4	42
20.	2000	929.0	44
21.	2001	553.1	44
22.	2002	442.0	36
	Average	**753.37**	**42.40**

The variation in annual rainfall and number of rainy days of Latur for 22 years are presented in Table 4.9

It is seen from Table 4.9 that annual rainfall averaged over 22 years for Latur Station is 753.37 mm. The minimum rainfall of 311.9 mm was recorded during 1986 while maximum rainfall of 1302.8 mm was recorded during 1983. The number of rainy days varied from a minimum of 30 days during 1984 to a maximum of 59 days during 1998.

4.2.2 Onset and end of effective monsoon :

Daily rainfall and evaporation data of 5 years for Latur Station from 1998 to 2002 were analysed to find out the dates of onset of effective monsoon (OEM) and dates of withdrawal of monsoon during individual years. The criteria stated by Ashok Raj (1979) mentioned in 3.4 was used in the analysis. Results obtained are shown in Table 4. 10

Table 4.10 : Dates of onset and end of effective monsoon for Latur station.

Year	Effective monsoon	
	Onsets	Ends on
1998	June 15	October 16
1999	June 13	October 04
2000	June 2	September 30
2001	June 8	October 1
2002	June 24	September 6
Mean	June 12	September 29

Mean date of OEM = June 12.

Standard deviation = 8 days.

From the Table 4.10, it is seen that effective monsoon starts in between first week of June and last week of June. It can be also seen that mean date of onset of effective monsoon for station is June 12 with standard deviation of 8 days.

From Table 4.10, it is also seen that effective monsoon ends in between first week of September and third week of October. Mean date of withdrawal of monsoon is September 29.

4.2.3 Dry spell analysis :

The dates of commencement and durations of dry spells were determined during every year from the daily rainfall data and evaporation data of the station by using the criteria suggested by Ashok Raj (1979).

4.2.3.1 Observed dry spells :

Table 4.11 shows the dates and durations of dry spells determined during every year after the commencement of effective monsoon.

After observing the Table 4.11 it is clear that the short duration dry spells are very less in number. It is due to the criteria for determining the dry spells which states that it is interval between the end of the 7 days spells, beginning with the onset of effective monsoon and another rainy day with 5e mm (e = average daily evaporation) or more of rain or the commencement of another 7-day rainy spell with 5e mm rainfall or more and with atleast 4 rainy days with not less than 2.5 mm of rain each day. Because of this criteria short duration dry spells get merged into 7 days wet spells and a long wet spell occurs.

Table 4.11 : Observed dry spells during 1998-2002 at Latur Station.

Year	DRY SPELLS							
	First		Second		Third		Fourth	
	Date	Days	Date	Days	Date	Days	Date	Days
1998	July-31	7	September-16	05	October-05	5	--	--
1999	June-21	18	July-23	11	August-11	26	SeptemBer-15	13
2000	June – 13	17	July - 16	24	September-2	26	--	--
2001	June – 16	14	July-7	22	August-25	37	--	--
2002	June-28	17	August-14	9	--	--	-	--

From the table 4.11, it is seen that number of dry spells range from two to four during every year. Four dry spells occurred during 1999 and two dry spells occurred during 2002. The longest duration of dry spell of 37 days is observed during the year 2001. All other dry spells range in between 4 days to 26 days. Total dry spells observed are 15 during the period of five years.

4.2.3.2 Critical dry spells (CDS) and wet spells :

When the duration of dry spell exceeds a certain value depending on crop-soil complex of the region, it is called as critical dry spell. The critical value for Latur station was considered as 10 days (Taksale, 1992).

Table 4.12 : Critical dry spells (CDS) during the year for Latur station.

Year	CRITICAL DRY SPELLS (CDS)						
	First		Second		Third		Total
	Date	Days	Date	Days	Date	Days	
1998	--	--	--	--	--	--	0
1999	June-21	18	July-13	11	August-11	26	4
2000	June-13	17	July-16	24	September 2	26	3
2001	June-16	14	July-7	22	August-25	37	3
2002	June-28	17	--	--	--	--	1
Mean	June 19	17	July-12	19	August – 23	25	3

Critical dry spell (CDS) : When length of dry spell exceeds 10 days.

Average number of CDS : 3

Average dates of starting of CDS and length

First CDS -- June 19 Length - 17 days

Second CDS -- July 12 Length - 19 days

Third CDS -- August 23 Length - 25 days

Mean dates of wet spells :

First wet spell -- June 12 to June 18.

Second wet spell -- July 7 to July 12

Third wet spell -- August 1 to August 23.

Table 4.12 shows the observed critical dry spells and their mean durations during every year. It is seen from table that mean number of critical dry spell is three. Critical dry spells ranged from zero to four during every year. It is also observed that no CDS occurred during 1998 and maximum four CDS occurred during 1999.

Data presented in table also shows the mean dates of commencement of CDS and their mean durations. Average dates of commencement and end of wet spells are also given at the bottom of the Table 4.12.

4.2.4 Dry spell probability nomograms during crop developmental stages:

The allotment of dry spell duration during the crop developmental stages was done as described in previous chapter. The maximum length of dry spell is equal to the duration of the crop developmental stage. The dry spell is considered to end in the same crop developmental stage. The crops considered for Latur station are Jowar and Cotton. The probabilities of occurrence of dry spell of different durations during each crop developmental stages were determined by Gumbel's method. The probabilities found are cumulative probabilities hence it increases as dry spell duration increases.

4.2.4.1 Jowar :

There are six stages of which the dry spell probabilities are plotted. The dry spell probabilities were determined for different crop development stages of Jowar crop for Latur station. The method of finding dry spell probability in a

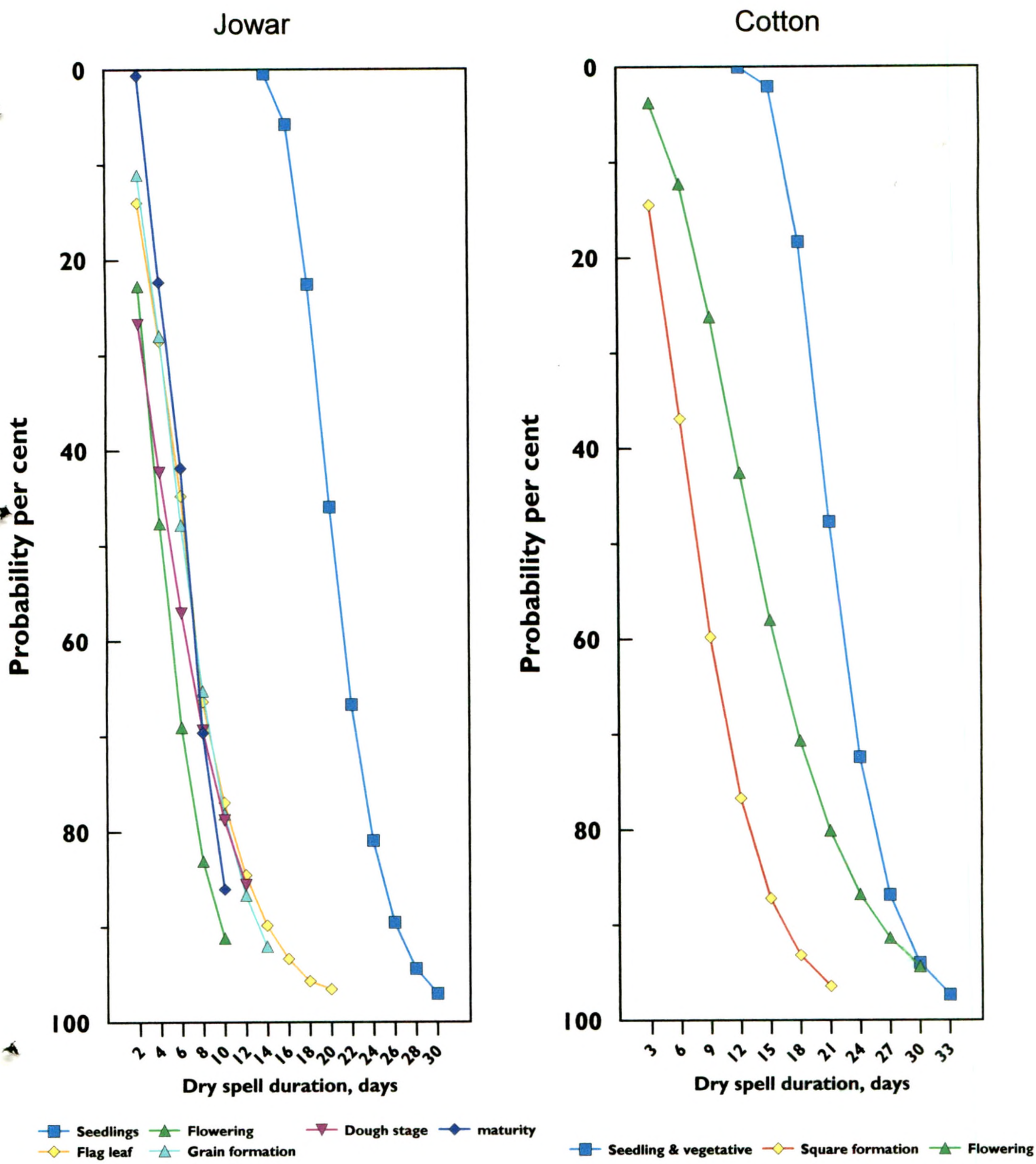

Fig. 4.2: (A, B) Probability nomograms for occurrence of dry spell during developmental stages for Latur station

particular crop developmental stage is explained in Appendix III. Using dry spell duration and probability values, dry spell probability nomogram was developed which is depicted in Fig. 4.2 (A). The values of dry spell durations at different probability levels are obtained from nomogram and presented in Appendix-V. It is reported that 25 per cent probability level is considered for agricultural purposes (Taksale, 1992). At 25 per cent probability, the number of dry days were found to be 18.22 days for seedling stage, 3.56 days for flag leaf stage, 2.19 days for flowering stage, 3.70 days for grain formation stage, 1.77 days for dough stage and 4.94 days for maturity stage, respectively.

4.2.4.2 Cotton:

There are three stages of which the dry spell probabilities are plotted. The boll formation and boll bursting stages are not considered as these lasts after the end of monsoon season. The dry spell probabilities were determined for different crop developmental stage of cotton for Latur station. The method finding of dry spell probability in a particular crop development stage is explained in Appendix-III. Using dry spell durations and probabilities values, dry spell probability nomogram was developed which is depicted in Fig. 4.3 (B). The values of dry spell durations at different probability level are obtained from nomogram and presented in Appendix-V. At 25 percent probability, the number dry days were found to be 18.94 days for seedling and vegetative stage, 4.51 days for square formation and 8.77 days for flowering stage, respectively.

4.3 Analysis for Osmanabad station :

4.3.1 Analysis of Rainfall data :

Daily rainfall data of 22 years from 1981-2002 were analysed to find out the minimum weekly rainfall, maximum weekly rainfall, average weekly rainfall (AWR), standard deviation, co-efficient of variation, minimum, maximum and average monthly rainfall, average annual rainfall and number of rainy days.

Table 4.13 furnishes values of weekly observed minimum, maximum and average rainfall, standard deviation and coefficient of variation of different weeks.

Table 4.13 : Weekly observed minimum, maximum and average rainfall, standard deviation and coefficient of variation of different weeks.

Raingauge station : Osmanabad.

Week No.	Minimum rainfall,mm	Maximum rainfall,mm	AWR, mm	S. D., mm	Cv, %
1.	0.0	0.0	0.0	0.0	0.0
2.	0.0	4.5	0.2	0.96	480
3.	0.0	1.2	0.05	0.26	520
4.	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	0.0	0.0	0.0
6.	0.0	0.0	0.0	0.0	0.0
7.	0.0	0.0	0.0	0.0	0.0
8.	0.0	0.0	0.0	0.0	0.0
9.	0.0	0.0	0.0	0.0	0.0
10.	0.0	0.0	0.0	0.0	0.0
11.	0.0	0.0	0.0	0.0	0.0
12.	0.0	0.0	0.0	0.0	0.0
13.	0.0	15.3	0.7	3.26	465.71
14.	0.0	0.0	0.0	0.0	0.0
15.	0.0	11.4	0.52	2.43	467.31
16.	0.0	9.4	0.41	2.00	384.62
17.	0.0	3.2	0.15	0.68	453.34
18.	0.0	3.2	0.15	0.68	453.34
19.	0.0	124.4	5.62	26.52	469.40

Table 4.13 Cont.

Week No.	Minimum rainfall,mm	Maximum rainfall,mm	AWR, mm	Std. dev. mm	Cv, %
20.	0.0	84.7	3.85	18.06	469.10
21.	0.0	32.5	2.92	8.47	290.10
22.	0.0	116.0	9.64	26.15	270.42
23.	0.0	107.6	37.2	30.86	64.14
24.	1.2	112.1	35.31	32.46	91.82
25.	0.0	82.7	23.82	24.23	101.72
26.	0.0	74.5	19.92	21.23	106.58
27.	0.0	125.3	27.94	33.78	120.82
28.	0.0	85.8	23.4	26.52	113.34
29.	0.0	250.2	41.42	56.72	136.87
30.	3.0	132.2	39.74	38.91	97.84
31.	0.0	136.9	36.73	41.27	112.36
32.	0.0	144.0	41.31	45.78	110.12
33.	0.0	150.0	29.65	34.06	114.80
34.	0.0	186.9	38.13	52.14	136.74
35.	0.0	166.7	30.21	43.75	144.72
36.	0.0	180.3	44.94	42.65	94.90
37.	0.0	124.5	35.84	40.67	113.48
38.	0.0	209.6	52.71	59.34	112.58
39.	0.3	162.7	46.1	43.17	93.64
40.	0.0	111.3	33.2	34.57	102.58
41.	0.0	83.1	18.6	26.2	140.86
42.	0.0	102.3	14.10	25.96	183.85
43.	0.0	79.9	10.16	20.87	205.41
44.	0.0	19.6	1.82	4.65	252.72
45.	0.0	38.0	3.28	8.8	296.30
46.	0.0	35.0	2.94	8.98	302.36
47.	0.0	6.0	0.7	1.79	255.72
48.	0.0	9.7	8.44	2.07	470.45
49.	0.0	24.0	1.92	6.27	326.56
50	0.0	3.8	0.17	0.81	476.47
51.	0.0	0.0	0.0	0.0	0.0
52.	0.0	65.2	3.41	14.96	436.15

It is observed from Table 4.13 that minimum and maximum weekly observed rainfall are found to be ranged between 0 to 3 mm and 1.2 to 250.2 mm, respectively. The average weekly rainfall (AWR) at Osmanabad varies from a minimum of 0.05 mm for 3rd week to a maximum of 52.71 mm for 38th week. It can be also seen from table that the AWR varies from a minimum of 19.92 mm for 26th week to a maximum of 52.71 mm for 38th week of the wet period, while it varies from 0.0 mm in 1st, 4th to 12th, 14th and 51st week to 33.2 mm in 40th week in the dry period. The AWR for 38th week during 22 years period was maximum i.e. 52.71 mm and thus 38th week is the wettest period with rainfall of 52.71 mm. While no rainfall was received in 1st, 4th to 21st, 14th and 51st week during 22 years period.

The value of Cv varied from a minimum of 64.14% for 23rd week to a maximum of 144.72% for 35th week of the wet period, lying between 23rd to 39th week. However it shows larger variation from 64.14% for 23rd week to 520% for 3rd week expect 1st, 4th to 12th, 14th and 51st weeks (Table 4.13). In general, Cv was less than 144.72% for the wet period. The lesser value of Cv in between 23rd to 39th week is therefore an indications of the wet periods as also indicated by AWR. Thus, Cv is associated with the wetness and dryness of the region indicating that it decreases as AWR increases. The values of standard deviation of weekly rainfall data for different weeks during 22 years of period presented in Table 4.13 indicated that the value of standard deviation of weekly rainfall increases with increase in the AWR.

Minimum, maximum and average monthly rainfall values were determined for Osmanabad from daily rainfall data of 22 years. These values are presented in Table 4.14.

Table 4.14: Monthly observed minimum, maximum and average rainfall and rainy days. Raingauge station : Osmanabad.

Sr. No.	Month	Average number of rainy days	Rainfall (mm)		
			Minimum rainfall, mm	Maximum rainfall, mm	Average rainfall, mm
1.	January	0.05	0.0	5.7	0.26
2.	February	0.0	0.0	0.0	0.0
3.	March	0.05	0.0	15.3	0.7
4.	April	0.23	0.0	20.8	1.24
5.	May	0.5	0.0	223.3	12.43
6.	June	7.41	28.9	238.7	125.0
7.	July	8.45	17.1	444.8	142.61
8.	August	8.95	23.0	369.2	152.42
9.	September	8.95	29.3	475.5	193.65
10.	October	4.45	0.0	203.1	78.34
11.	November	0.59	0.0	50.3	7.4
12.	December	0.27	0.0	65.2	5.15
	Total	**39.4**			**719.2**

It is seen from Table 4.14 that the minimum monthly rainfall values varies from a minimum of 0.0 mm in January, February, March, April, May, October, November and December to maximum of 29.3 mm in the month of September during 22 years. Maximum monthly rainfall varied in the range of 5.7 to 475.5 mm. Maximum monthly values for the period June to September are higher than the values observed for the remaining months.

From the Table 4.14, it is observed that the total of average monthly rainfall for the month from June to September is 613.68 mm, which is 85.32% of the annual rainfall. Thus it is concluded that the maximum amount of rainfall is received during the month June to September of the year. It can be also seen from table that average number of rainy days are minimum i.e. 0 days for the month of February and maximum in August and September i.e. 8.95 days. The total number of rainy days are 39.4 days in period of one year.

Table 4.15 : Variation in annual rainfall and number of rainy days.

Sr. No.	Year	Total rainfall (mm)	Number of rainy days
1.	1981	812.8	51
2.	1982	567.5	35
3.	1983	1013.5	49
4.	1984	363.7	25
5.	1985	563.0	33
6.	1986	538.0	33
7.	1987	582.2	44
8.	1988	1263.6	65
9.	1989	1041.4	39
10.	1990	916.4	40
11.	1991	467.1	30
12.	1992	485.7	39
13.	1993	708.6	43
14.	1994	423.6	33
15.	1995	688.4	31
16.	1996	717.8	38
17.	1997	515.7	40
18.	1998	1314.0	59
19.	1999	591.4	32
20.	2000	959.6	37
21.	2001	594.5	41
22.	2002	633.7	29
	Average	**719.19**	**39.4**

The variation in annual rainfall and number of rainy days of Osmanabad for 22 years are presented in Table 4.15.

It is seen from Table 4.15 that the annual rainfall averaged over 22 years for Osmanabad Station is 719.19 mm. The minimum rainfall of 363.7 mm was observed during 1984 and maximum rainfall of 1314 mm was observed during 1988. The number of rainy days varied from a minimum of 25 days during 1984 to a maximum of 65 days during 1988.

4.3.2 Onset and end of effective monsoon :

Daily rainfall and evaporation data of 5 years for Osmanabad Station from 1998 to 2002 were analysed to find out the dates of onset of effective monsoon (OEM) and dates of withdrawal of monsoon during individual years. The criteria stated by Ashok Raj (1979) mentioned in 3.4 was used in the analysis. Results obtained are shown in Table 4.16

Table 4.16 : Dates of onset and end of effective monsoon for Osmanabad station.

Year	Effective monsoon	
	Onsets	Ends on
1998	June 15	November-10
1999	June 13	October 16
2000	May 11	September 20
2001	June 7	October 14
2002	June 10	October 18
Mean	June 8	October 15

Mean date of OEM = June 8.

Standard deviation = 14 days.

From the Table 4.16, it is seen that effective monsoon starts in between third week of May and third week of June. It can be also seen that mean date of onset of effective monsoon for station is June 8 with standard deviation of 14 days.

From Table 4.16, it is also seen that effective monsoon ends in between third week of September and second week of November. Mean date of withdrawal of monsoon is October 15.

4.3.3 Dry spell analysis :

The dates of commencement and durations of dry spells were determined during every year from the five years daily rainfall and evaporation data of the Osmanabad station by using the criteria suggested by Ashok Raj (1979).

4.3.3.1 Observed dry spells :

Table 4.17 shows the dates and durations of dry spells determined during every year after the commencement of effective monsoon.

After observing the Table 4.17 it is clear that the short duration dry spells are very less in number. It is due to the criteria for determining the dry spells which states that it is interval between the end of the 7 days spells, beginning with the onset of effective monsoon and another rainy day with 5e mm (e = average daily evaporation) or more of rain or the commencement of another 7-day rainy spell with 5e mm rainfall or more and with atleast 4 rainy days with not less than 2.5 mm of rain each day. Because of this criteria short duration dry spells get merged into 7 days wet spells and a long wet spell occurs.

Table 4.17 : Observed dry spells during 1998-2002 at Osmanabad Station.

Year	DRY SPELLS									
	First		Second		Third		Fourth		Fifth	
	Date	Days	Date	Days	Date	Days	Date	Days	Date	Days
1998	July-10	11	October-17	22	--	00	--	00	--	00
1999	June-19	5	June-25	15	August-11	27	September-13	13	October-5	7
2000	May-21	17	June-23	22	August-24	13	September-10	8	--	00
2001	June – 16	12	July-4	19	August-22	17	September-9	5	--	00
2002	June-15	9	July-2	15	July-25	7	August-15	9	September-9	16

From the table 4.17, it is seen that number of dry spells range from three to five during every year. Five dry spells occurred during 1999 and 2002, while two dry spells occurred during 1998. The longest duration of dry spell of 27 days is observed during year 1999. All other dry spells range in between 4 days to 27 days. Total dry spells observed are 20 during the period of five years.

4.3.3.2 Critical dry spells (CDS) and wet spells :

When the duration of dry spell exceeds a certain value depending on crop-soil complex of the region, it is called as critical dry spell. The critical value for Osmanabad station was considered as 10 days (Taksale, 1992).

Table 4.18 : Critical dry spells (CDS) during the year for Osmanabad station.

Year	CRITICAL DRY SPELLS (CDS)						
	First		Second		Third		Total
	Date	Days	Date	Days	Date	Days	
1998	July-10	11	October-17	22	--	0	2
1999	June-25	15	August-11	27	September-13	13	3
2000	May-21	17	June-23	22	August-24	13	3
2001	June-16	12	July-23	19	August-22	17	3
2002	July-2	15	September 9	16	--	0	2
Mean	June-24	14	July-11	21	September-3	14	3

Critical dry spell (CDS) : When length of dry spell exceeds 10 days.

Average number of CDS : 3

Average dates of starting of CDS and length

First CDS -- June 24 Length - 14 days

Second CDS -- July 11 Length - 21 days

Third CDS -- September 3 Length - 14 days

Mean dates of wet spells :

First wet spell -- June 8 to June 23.

Second wet spell -- July 8 to July 11

Third wet spell -- August 1 to September 2

Table 4.18 shows the observed critical dry spells and their mean durations during every year. It is seen from table that mean number of critical dry spell is three. Critical dry spells ranged from two to three during every year. It is also observed that two CDS occurred during 1998 and 2002 and maximum three CDS occurred during 1999, 2000 and 2001.

Data also shows the mean dates of commencement of CDS and their mean durations. Average dates of commencement and end of wet spells are also given at the bottom of the Table 4.18.

4.3.4 Dry spell probability nomograms during crop developmental stages:

The allotment of dry spell duration during the crop developmental stages was done as described in previous chapter. The maximum length of dry spell is equal to the duration of the crop developmental stage. The dry spell is considered to end in the same crop developmental stage. The crops considered for Osmanabad station are Jowar and Cotton. The probabilities of occurrence of dry spell of different durations during each crop developmental stages were determined by Gumbel's method. The probabilities found are cumulative probabilities hence it increases as dry spell duration increases.

4.3.4.1 Jowar :

There are six stages of which the dry spell probabilities are plotted. The dry spell probabilities were determined for different crop development stages of Jowar crop for Osmanabad station. The method of finding dry spell probability in a particular crop developmental stage is explained in Appendix III. Using dry spell duration and probability values, dry spell probability nomogram was developed which is depicted in Fig. 4.3 (A). This nomogram could be used to determine dry spell duration at different values of probability. The values of dry spell durations at different probability levels are obtained from nomogram and presented in Appendix-V. It is reported that 25 per cent probability level is considered for agricultural purposes (Taksale, 1992). At 25 per cent probability, the number of dry days were found to be 20.23 days for seedling stage, 7.25 days for flag leaf stage, 0.68 days for flowering stage, 7.83 days for grain formation stage, 4.12 days for dough stage and 5.19 days for maturity stage, respectively.

4.3.4.2 Cotton :

There are three stages of which the dry spell probabilities are plotted. The boll formation and boll bursting stages are not considered as these lasts after the end of monsoon season. The dry spell probabilities were determined for different crop developmental stage of cotton for Osmanabad station. The method finding of dry spell probability in a particular crop development stage is explained in Appendix-III. Using dry spell durations and probabilities values, dry spell probability nomogram was developed which is depicted in Fig. 4.3 (B). This nomogram could be used to determine dry spell duration of different values of probability. The values of dry spell durations at different probability level are obtained from nomogram and presented in Appendix-V. At 25 percent

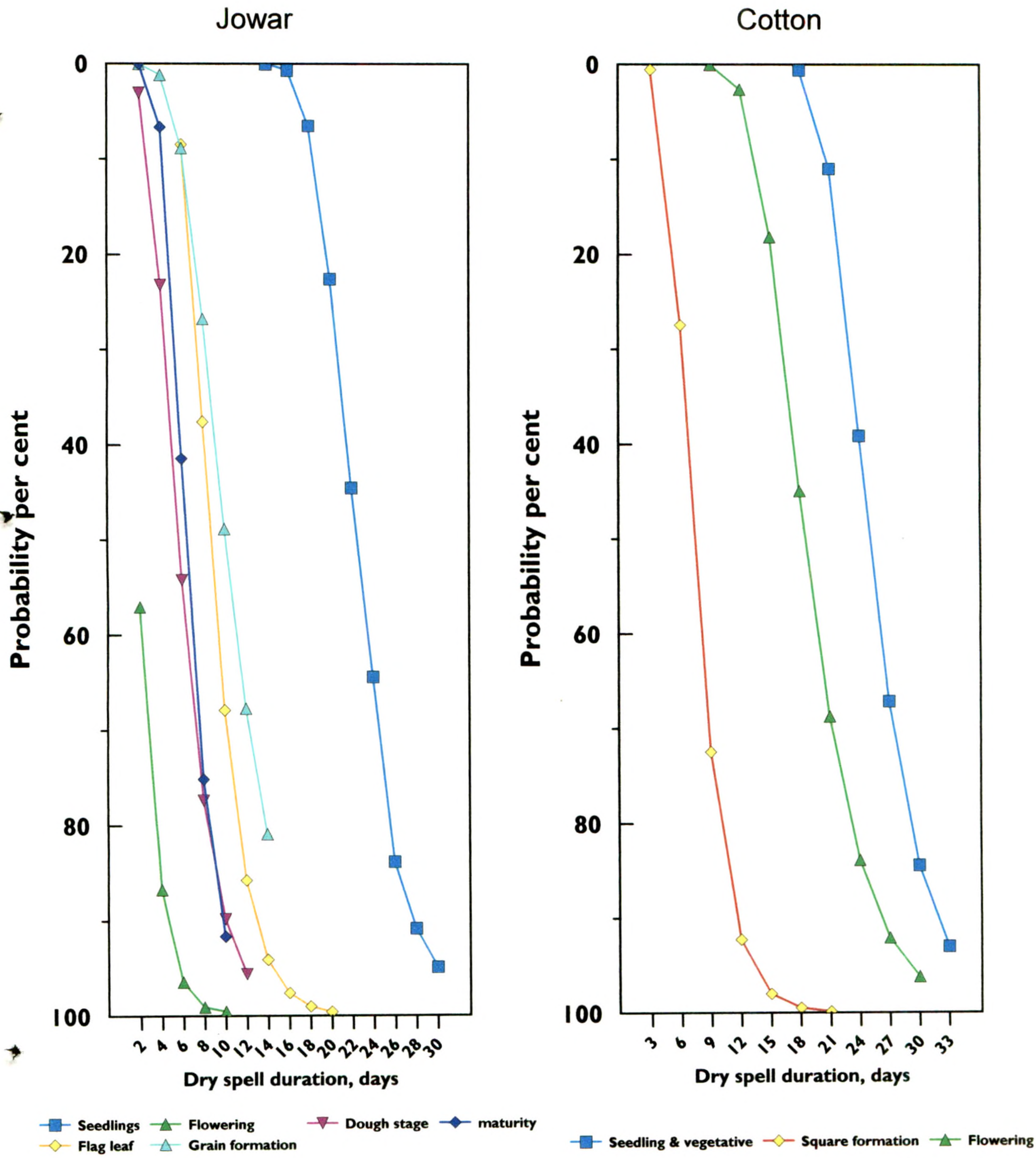

Fig. 4.3: (A, B) Probability nomograms for occurrence of dry spell during developmental stages for Osmanabad station

probability, the number dry days were found to be 22.64 days for seedling and vegetative stage, 5.85 days for square formation and 15.82 days for flowering stage, respectively.

Summary and conclusion

CHAPTER-V

SUMMARY AND CONCLUSION

The daily rainfall and evaporation data of the three raingauge stations namely Beed, Latur and Osmanabad were obtained for the analysis from the Department of Agricultural Meteorology, M.A.U., Parbhani and India Meteorology Department, Pune.

This data was analysed to find the minimum weekly rainfall, maximum weekly rainfall, average weekly rainfall, co-efficient of variation, standard deviation, minimum, maximum and normal monthly rainfall, average annual rainfall and number of rainy days. The dates of onset and end of effective monsoon were determined for individual years by applying the criteria started by Ashok Raj (1979). Also mean dates of OEM and end of monsoon with standard deviation were determined for each station. Dry spell analysis was done by applying criteria stated by Ashok Raj (1979). By considering the critical values for each station, the critical dry spells were found during every year. Mean dates of critical dry spells along with their mean durations were also determined. The average dates of starting and ending of wet spells were also determined for each station. The cumulative probability nomograms were developed for important growth phases of different crops selected, for each station.

Following conclusions are drawn from the present study.

1) The average weekly rainfall for Beed, Latur and Osmanabad varied from 0.02 mm to 51.87 mm, 0.05 mm to 56.52 mm and 0.05 mm to 52.71 mm, respectively.

2) The average monthly rainfall for Beed, Latur and Osmanabad was found to varied from 0.1 mm to 189.96 mm, 1.70 mm to 179.88 mm and 0.26 mm to 193.65 mm, respectively.

3) The average annual rainfall at Beed, Latur and Osmanabad was recorded as 749.46 mm, 753.37 mm and 719.19 mm, respectively.

4) The average number of rainy days were found to be 37.16, 42.40, and 39.4 days for Beed, Latur and Osmanabad district, respectively.

5) The mean dates of OEM were found to be June 23, June 12 and June 8 for Beed, Latur and Osmanabad, respectively.

6) The mean dates of critical dry spells were July 17 with mean duration of 18 days for first, August 8 with in duration of 25 days for second and August 17 of mean duration of 31 days for third CDS, for Beed Station, June 19 with mean duration of 17 days for first, July 12 with mean duration of 19 days for second, August 23 with mean duration of 25 days for third CDS for Latur Station, June 24 with mean duration of 14 days for first, July 11 with mean duration of 21 days for second and September 3 with mean duration of 14

days for third CDS for Osmanabad station, respectively.

7) The probability nomograms were developed for developmental stags of various crops selected for each station. Jowar and cotton considered for all the stations.

Literature Cited

LITERATURE CITED

Ashok Raj, P.C. (1979): Onset of effective monsoon and critical dry spells. A computer based forecasting technique: IARI Bulletin No.II, WTC, IARI, New Delhi.

Biswas, B.G. and S.J. Maske (1981): Rainfall analysis for use in Dryland Agriculture. Indian J. Soil. Conservation, 9(2) : 8-19.

Chakraborty, P.K. and A.K. Chakraborty (1990): Climatic water balance approach and rainfall analysis for crop planning in Murshidabad district of West Bengal. Environment and Ecology : 401-405.

Chand Mukesh, Suraj Bhan and D.C. Keim (2003): Rainfall analysis as an aid for stabilized crop production in rainfed areas of Central Uttar Pradesh. Farm Science Journal, 12 (1) : 11-14.

Dani, S.P. (1991): Dry spell analysis for Parbhani. An unpublished B.Tech. Thesis submitted to College of Agril. Engg., M.A.U., Parbhani.

Deka, R.L., K.K. Nath and R. Huassain (1999): Seasonal and monthly rainfall analysis of Jorhat. J. of the Agril. Sci. Society of North-East India., 12 (2) :244-247.

Dhar, O.N., M.K. Soman, B.N. Mandal, S.S. Mulye (1985): Rainfall characteristics of Sourashtra Region – A brief appraisal. Irrigation and Power , 42(1):83-88.

Ethan, S. and B. Bababe (1998): Rainfall analysis for production of millet in Maiduguri – Nigeria.

Agricultural tropica, Ceska Zemedelska Univ., Vol-31: 37-44.

Gaikwad, C.B., J.D. Patil, M.R. Shewale and S.B. Chavan (1995): Rainfall variability analysis- A case study. J. of Maharashtra Agril. Univ., 21 (3) : 442-445.

Gare, B.N., S.M. More, A.S. Jadhav and A.V. Burli (1999): Rainfall variability analysis at Gadhinglaj. J. of Maharashtra Agric. Univ., 25(2): 198-201.

Gupta, S.K. (1982): Probability analysis of dry days for drainage planning in the Ootachmand Ind. J. soil conservation ; 10(1) : 12-16.

Jadhav, G.N. (2003): Analysis of weekly rainfall for Parbhani. An unpublished B. Tech. thesis submitted to College of Agril. Engg., M.A.U., Parbhani.

Kolhe, N.R. (1988): Dry spell probability analysis and its application to crop developmental stages. An unpublished M.Tech Thesis submitted to P.G.I., P.K.V., Akola.

Kundu, P.S. (1973): Probability analysis of annual rainfall data. J. of Agril. Engg., 10(2) : 21-35.

Maliwal, G.L. and H.N. Chhatrola (1992): Probability study of rainfall for Bhal and Coastal Agro-climatic Zone. Gujarat Agril. University Research J., 17 (2): 4-13.

Maniyar, V.G. and V.K. Kulkarni (2002): Agro-climatic assessment of Marathwada region. Soil resource inventory of Marathwada, Deptt. of ACSS., M.A.U., Parbhani: 17-30.

Mishra, G.N., P.K. Sinha, V.D. Shukla and K. Prasad (1996): Rainfall analysis for planning upland rice crop in Bihar Plateau. Indian J. of Agril. Sciences., 66:7, 393-396.

Mishra, K.K. (2002): Water excess and deficits using co-efficient of variation of weekly rainfall. J. of Agril. Engg. 39 (2) : 44-52.

Mohan, V., P.D. Kulkarni and A.V. Rao (1985): Study of frequency of wet and dry spells over Nasik district. Mausum 36 (4) : 513-518.

Panigrahi, B and S.N. Panda (2001): Analysis of weekly rainfall for crop planning in rainfed region. J. of Agril. Engg. 38 (4) : 47-57.

Pardhe, D.D., M.G. Shinde, N.L. Bote and S.R. Savale (2003): Studies on analysis of one day and extended days rainfall for scarcity zone of Maharashtra. XXXVIII annual convention of ISAE, Dapoli: 206.

Pravendra Kumar, S.Dev and R.K. Singh (2002): Analysis of weather parameters in terai region of Udham Singh Nagar; Uttaranchal, XXXVIII Annual Convention of ISAE, Dapoli 2004 : 198.

Raghunath, N.M. (1985): Hydrology, principle, analysis and design. Wiley Eastern Ltd., New Delhi.

Raman, C.R.V. (1974): Analysis of commencement of monsoon rains over Maharashtra State for agril. planning. Prepublished scientific report No. 216., India Meteorological Department, Poona.

Rana, S.R. and D.R. Thakur (1998): Rainfall analysis for crop planning in Kully Valley, Himachal Pradesh, Indian J. of Soil. Conservation. 26(2) : 144-146.

Ranade, D.H. and Rajesh Gupta (1992): Drought analysis of Borwaha, Indian J. of Soil. Conservation 23 (1) : 83-85.

Sharma Devesh and Virendra kumar (2003): Prediction of onset and withdrawal of effective monsoon dates and subsequent dry spells in an arid region of Rajasthan. Indian J. of Soil Conservation 31 (3) : 223-228.

Sharma, T.C. (1996): Simulations of the Kenyan longest dry and wet spells and the largest rain-sums using a Markov Model. J. of Hydrology- Amsterdam, 178 : 1-4, 55 67.

Sivakumar, M.V.K. (1991): Drought spells and drought frequencies in West Africa. Research Bulletin of ICRISAT, No.13, PP. 181.

Subagio, I. (1997): Determination of land treatment and sugarcane planting time using rainfall analysis for wetlands of Pesuruan, Probolinggo and Sekitarnya. Berita pusat penelitian perkebunan Gula Indonesia, No. 20 : 30-34, 3 ref.

Subash, N. and P.K. Das (2004): Rainfall characteristics and probability analysis for crop planning under rice-wheat system in sub-humid climate. Indian J. of Soil. Conservation, 32 (2) : 124-128.

Subudhi, C.R. (1996): Rainfall analysis for khanjo sub-watershed of Upper Damodar Valley. Environment and Ecology. 14 :2, 276-278, 8 ref.

Subudhi, C.R., P.K. Rouland and A.P. Sahu (1996): Rainfall analysis for Bhadrak and Balasoro districts of Orissa .Environment and Ecology. 14: 1, 21-22; 6 ref.

Telekar, B.M. and P.K. Parghane (2002): Dry spell probability analysis for Hingoli. An unpublished B.Tech. thesis submitted to college of Agril. Engg. M.A.U., Parbhani.

Taksale, B.T. (1992): Drought analysis for Marathwada region. An unpublished M.Tech. thesis submitted to College of Agril. Engg. and Tech., Dr. P.D.K.V. Akola.

Tiwari, A.K., A.K. Sharma and M.M. Shrivastava (1992): Probability analysis of rainfall data of Datia for planning. Indian J. of Soil conservation 20 (3) : 82-88.

Upadhyaya, A., J. Kumar and S.K. Sikka (2002): Rainfall analysis in the command of Patna main canal. XXXVIII annual convention of ISAE, Dapoli: 211.

Vanjari, S.S., D.S. Kharche, G.K. Muzumdar and A.I. Patel (1978): Rainfall intensity-Duration-Frequency studies of different stations in Maharashtra State. J. of M.A.U., 3(3) : 241-247.

Varshney, R.S. (1986): Engineering Hydrology. (3rd Ed.), Nemchand and Bros., Roorkee, U.P.

Verma, H.N. and P.B.S. Samra (1990): Criteria for identifying effective monsoon for sowing in rainfed agriculture. Irrigation and Power : 177-184.

Verma, H.N., A.K. Goel and C.M. Singh (1994): Rainfall analysis for rainfed crop planning in mid-hills of H.P., Himachal J. of Agril. Research, 20: 1-2, 22-27, : 6 ref.

APPENDIX

APPENDIX-I

Duration of crop developmental stages and varieties and crops considered during analysis.

Crop	Crop developmental stages and their duration from date of sowing					
	I	II	III	IV	V	VI
Jowar (CSH-9)	Seedling (7-40)	Flag leaf (41-60)	Flowering (61-70)	Grain formation (71-86)	Dough stage (87-99)	Maturity (100-108)
Cotton (NHS-44)	Seedling and Vegetative (7-49)	Square formation (50-80)	Flowering (73-104)	Boll formation (105-153)	Boll bursting (130-183)	

APPENDIX-II

Dates of sowing considered for the Raingauge stations under study for analysis.

Raingauge	Date of sowing	Mean date of onset of effective monsoon
Beed	June 30	June 23
Latur	June 19	June 12
Osmanabad	June 15	June 8

APPENDIX-III

Sample calculation of findings cumulative dry spell probability during the crop developmental stages.

Raingauge station	:	Beed
Crop	:	Jowar
Variety	:	CSH-9
Date of sowing	:	June 30
Mean date of OEM	:	June 23

Crop developmental stages and their duration from the date of sowing.

1.	Seedling	:	7 to 40
2.	Flag leaf	:	41 to 60
3.	Flowering	:	61 to 70
4.	Grain formation	:	71 to 86
5.	Dough stage	:	87 to 99
6.	Maturity	:	100 to 108

From the daily rainfall data and applying the criteria suggested by Ashok Raj (1979) for finding dry spell, the dry spell during every crop developmental stage and during every year were found out. The maximum length of dry spell during the stage was allotted to that stage. The equation for cumulative probability analysis is given as.

$$Pc = e^{-e^{-y}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{A-1}$$

in which y is reduced variate and is given as

$$Y = \frac{(d-\bar{d}) + 0.45\,\sigma}{0.7797\,\sigma} \quad \ldots\ldots\ldots\ldots \quad \text{A-2}$$

Where σ = Standard deviation

$$\sigma = \left[\frac{\sum_{i=1}^{n} X_i^2 - \frac{\left(\sum_{i=1}^{n} X_i\right)^2}{n}}{n-1} \right]^{1/2} \quad \ldots\ldots\ldots \quad \text{A-3}$$

By using the above equations, the calculation for dry spell during 1998 for seedling stage of Jowar crop is shown below.

Length of duration, d = 19 days.

Mean duration, $\bar{d}$ = 22.2 days.

Standard deviation = 4.15 days.

$$Y = \frac{(19-22.2) + 0.45 \times 4.15}{0.7797 \times 4.15}$$

$$Y = -0.4118$$

Keeping value of Y =-0.4118 in equation A-1, the value of probability comes to be

P = 22.10

Table shows probabilities of dry spells during crop developmental stages for all the years.

APPENDIX-IV

Table D-1 : Sample calculation table for dry spell probabilities during developmental stages of Jowar crop at Beed Station.

Year	Seedling		Flag leaf		Flowering		Grain formation		Dough stage	
	d	P	d	P	d	P	d	P	d	P
1998	19	22.10	3	12.94	5	19.65	6	25.13	6	21.54
1999	25	78.95	19	92.24	10	91.88	3	5.37	6	21.54
2000	23	64.50	8	47.47	5	19.65	15	86.54	7	39.52
2001	27	88.04	5	25.52	8	75.86	10	60.17	9	71.21
2002	17	6.08	12	71.74	6	40.62	14	37.71	12	92.76
D	22.2		9.4		6.8		9.6		8	
σ	4.15		6.35		2.17		5.13		2.55	

Table D-2 : Sample calculation table for dry spell probabilities during developmental stages of Cotton crop at Beed Station.

Year	Seedling and vegetative		Square formation		Flowering	
	d	P	d	P	d	P
1998	19	22.43	9	28.77	12	8.55
1999	28	84.78	22	89.97	14	18.88
2000	25	70.88	8	22.18	27	87.52
2001	27	80.98	8	22.18	20	59.48
2002	4	4.44	9	82.96	25	82.15
$\bar{d}$	23		13.2		19.6	
σ	5.24		6.76		6.6	

Table D-3 : Sample calculation table for dry spell probabilities during developmental stages of Jowar crop at Latur Station.

Year	Seedling		Flag leaf		Flowering		Grain formation		Dough stage		Maturity	
	d	P	d	P	d	P	d	P	d	P	d	P
1998	21	57.04	6	44.78	3	35.07	0	--	0	--	5	25.88
1999	18	22.52	8	59.85	9	87.77	13	89.69	0	--	10	86.04
2000	17	12.69	16	91.79	4	47.67	6	47.80	12	85.58	8	69.63
2001	27	92.35	0	--	0	--	8	57.04	12	85.58	3	3.86
2002	22	66.67	8	59.85	8	83.09	8	57.04	6	57.04	9	79.19
$\bar{d}$	21		7.6		4.8		7		6		7	
σ	3.94		5.73		3.70		4.69		6		2.92	

Table D-4 : Sample calculation table for dry spell probabilities during developmental stages of Cotton crop at Latur Station.

Year	Seedling and vegetative		Square formation		Flowering	
	d	P	d	P	d	P
1998	21	47.70	6	36.91	0	--
1999	18	18.33	12	76.71	19	60.79
2000	18	18.33	15	87.22	15	57.99
2001	29	92.21	0	--	21	80.11
2002	24	72.39	10	66.22	19	60.79
$\bar{d}$	22		8.6		14.8	
σ	4.34		5.81		8.56	

Table D-5 : Sample calculation table for dry spell probabilities during developmental stages of Jowar crop at Osmanabad Station.

Year	Seedling		Flag leaf		Flowering		Grain formation		Dough stage		Maturity	
	d	P	d	P	d	P	d	P	d	P	d	P
1998	18	6.48	8	37.58	0	--	4	1.16	8	77.36	3	0.86
1999	22	44.52	9	54.01	4	86.72	15	85.54	8	77.36	8	75.13
2000	21	33.37	8	37.58	3	75.37	13	75.03	3	10.47	7	60.55
2001	28	87.80	14	94.10	0	--	10	48.85	9	84.67	7	60.55
2002	27	83.83	7	21.12	3	75.37	12	67.74	3	10.47	9	84.97
d	23.2		9.2		2		10.8		6.2		6.8	
σ	4.21		2.77		1.87		4.21		2.95		2.28	

Table D-6 : Sample calculation table for dry spell probabilities during developmental stages of Cotton crop at Osmanabad Station.

Year	Seedling and vegetative		Square formation		Flowering	
	d	P	d	P	d	P
1998	20	5.27	3	0.56	10	0.24
1999	22	18.96	9	72.46	26	89.90
2000	22	18.96	8	59.94	19	53.73
2001	32	90.88	10	81.65	20	61.72
2002	29	79.84	10	81.65	15	18.17
$\bar{d}$	25.8		7.8		19.4	
σ	4.49		2.77		5.08	

APPENDIX V

Table E-1: Dry spell durations for different stages of Jowar at different probability for Beed Station.

Probability, percent	Seedling	Flag leaf	Flowering	Grain formation	Dough
5	16.78	1.11	3.97	2.90	4.67
10	17.63	2.41	4.41	3.96	5.19
15	18.26	3.37	4.74	4.73	5.58
20	18.79	4.19	5.02	5.38	5.91
25	19.27	4.93	5.27	5.98	6.20
30	19.73	5.62	5.51	6.55	6.48
35	20.17	6.30	5.74	7.09	6.76
40	20.61	6.97	5.97	7.64	7.03
45	21.06	7.66	6.20	8.19	7.30
50	21.51	8.36	6.44	8.76	7.58
55	21.99	9.10	6.69	9.35	7.88
60	22.51	9.87	6.96	9.98	8.19
65	23.06	10.71	7.25	10.66	8.53
70	23.67	11.65	7.57	11.42	8.90
75	24.36	12.71	7.93	12.47	9.33
80	25.19	13.97	8.36	13.29	9.83
85	26.21	15.54	8.89	14.55	10.47
90	27.61	17.68	9.63	--	11.33
95	29.94	--	--	--	--

Table E-2 : Dry spell durations for different stages of Cotton at different probability for Beed Station.

Probability, percent	Seedling and vegetative	Square formation	Flowering
5	16.16	4.37	10.98
10	17.23	5.76	12.34
15	18.03	6.78	13.33
20	18.69	7.65	14.18
25	19.31	8.44	14.95
30	19.88	9.18	15.67
35	20.44	9.90	16.38
40	20.99	10.62	17.08
45	21.56	11.34	17.78
50	22.14	12.09	18.52
55	22.74	12.86	19.28
60	23.39	13.69	20.10
65	24.08	14.60	20.96
70	24.85	15.60	21.94
75	25.73	16.72	23.04
80	26.77	18.06	24.35
85	28.06	19.73	25.98
90	29.84	22.02	28.21
95	32.78	--	--

Table E-3 : Dry spell durations for different stages of Jowar at different probability for Latur Station.

Probability, percent	Seedling	Flag leaf	Flowering	Grain formation	Dough	Maturity
5	15.86	0.12	--	0.88	--	3.18
10	16.67	1.30	0.73	1.84	--	3.79
15	17.26	2.16	1.29	2.55	0.30	4.23
20	17.77	2.89	1.76	3.15	1.07	4.60
25	18.22	3.56	2.19	3.70	1.77	4.94
30	18.66	4.19	2.60	4.21	2.43	5.26
35	19.08	4.80	2.99	4.71	3.07	5.57
40	19.50	5.41	3.39	5.21	3.71	5.89
45	19.92	6.03	3.78	5.71	4.35	6.20
50	20.35	6.66	4.19	6.23	5.01	6.52
55	20.81	7.32	4.62	6.78	5.71	6.86
60	21.29	8.02	5.07	7.35	6.44	7.22
65	21.81	8.78	5.56	7.97	7.24	7.60
70	22.39	9.63	6.11	8.66	8.12	8.03
75	23.05	10.58	6.73	9.45	9.13	8.52
80	23.83	11.72	7.46	10.37	10.32	9.10
85	24.81	13.14	8.38	11.53	11.80	9.82
90	26.14	15.08	9.63	13.12	--	--
95	28.35	18.29	--	--	--	--

Table E-4 : Dry spell durations for different stages of Cotton at different probability for Latur Station.

Probability, percent	Seedling and vegetative	Square formation	Flowering
5	16.33	1.02	3.63
10	17.22	2.21	5.38
15	17.88	3.08	6.67
20	18.44	3.83	7.77
25	18.94	4.51	8.77
30	19.42	5.14	9.71
35	19.88	5.77	10.62
40	20.34	6.38	11.53
45	20.81	7.00	12.45
50	21.28	7.65	13.40
55	21.79	8.32	14.38
60	22.32	9.03	15.43
65	22.90	9.80	16.57
70	23.61	10.66	17.83
75	24.26	11.63	19.26
80	25.12	12.78	20.96
85	26.20	14.22	23.07
90	27.66	16.18	25.97
95	30.09	19.44	30.77

Table E-5 : Dry spell durations for different stages of Jowar at different probability for Osmanabad Station.

Probability, percent	Seedling	Flag leaf	Flowering	Grain formation	Dough	Maturity
5	17.70	5.58	--	5.30	2.35	3.82
10	18.57	6.15	--	6.17	2.95	4.29
15	19.20	6.57	0.22	6.80	3.40	4.64
20	19.74	6.93	0.46	7.34	3.78	4.93
25	20.23	7.25	0.68	7.83	4.12	5.19
30	20.69	7.55	0.88	8.30	4.45	5.44
35	21.15	7.85	1.08	8.75	4.76	5.69
40	21.59	8.14	1.29	9.19	5.07	5.92
45	22.04	8.44	1.48	9.64	5.39	6.17
50	22.50	8.75	1.70	10.11	5.72	6.43
55	22.99	9.27	1.90	10.59	6.06	6.69
60	23.51	9.40	2.14	10.11	6.42	6.97
65	24.07	9.77	2.40	11.67	6.80	7.27
70	24.68	10.18	2.66	12.29	7.24	7.61
75	25.40	10.64	2.98	12.99	7.74	7.99
80	26.23	11.19	3.35	13.83	8.32	8.44
85	27.27	11.88	3.81	14.87	9.05	9.00
90	28.69	12.81	4.44	--	10.05	9.77
95	--	14.37	5.49	--	11.70	--

Table E-6 : Dry spell durations for different stages of Cotton at different probability for Osmanabad Station.

Probability, percent	Seedling and vegetative	Square formation	Flowering
5	19.94	4.18	12.77
10	20.86	4.75	13.81
15	21.54	5.17	14.58
20	22.11	5.53	15.23
25	22.64	5.85	15.82
30	23.13	6.15	16.38
35	23.61	6.45	16.92
40	24.08	6.74	17.46
45	24.57	7.04	18.00
50	25.06	7.35	18.57
55	25.58	7.67	19.15
60	26.13	8.00	19.77
65	26.73	8.37	20.45
70	27.39	8.78	21.20
75	28.14	9.24	22.05
80	29.03	9.79	23.06
85	30.14	10.48	24.31
90	33.88	11.41	26.03
95	34.18	12.97	28.88