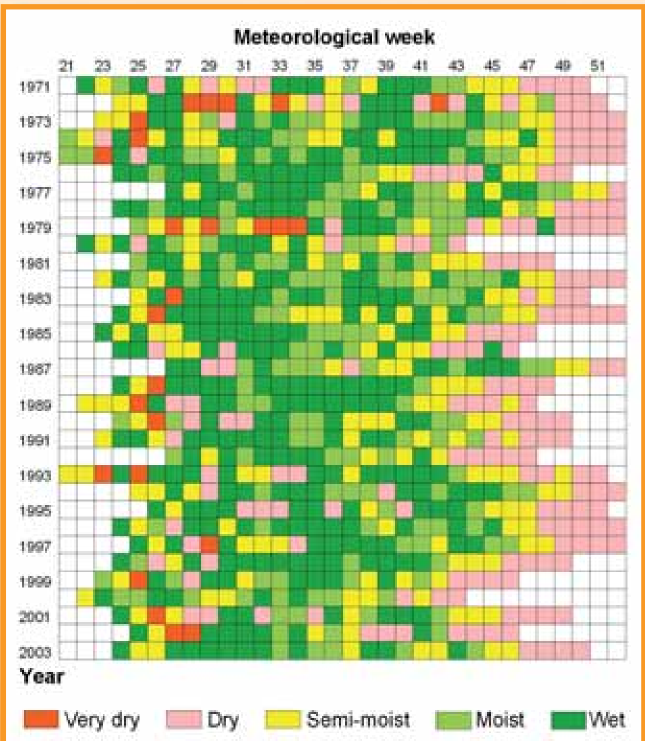
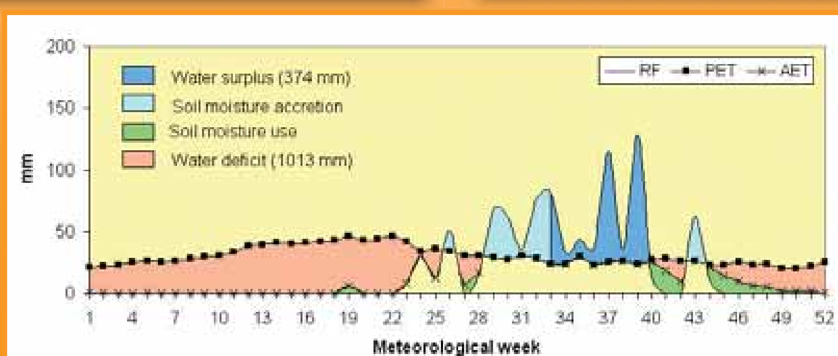
Global Theme on Agroecosystems
Report no. 30

Agroclimatic Characterization of APRLP-ICRISAT Nucleus Watersheds in Nalgonda, Mahabubnagar and Kurnool Districts





International Crops Research Institute for the Semi-Arid Tropics

Citation: Kesava Rao AVR, Wani SP, Singh Piara, Irshad Ahmed M and Srinivas K. 2006. Agroclimatic characterization of APRLP-ICRISAT nucleus watersheds in Nalgonda, Mahabubnagar and Kurnool districts. Global Theme on Agroecosystems Report no. 30. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). 52 pp.

Abstract

Knowledge on agroclimatology of a region is a valuable tool in crop planning. Agroclimatic analysis of the APRLP nucleus watersheds in three target districts (Nalgonda, Mahabubnagar and Kurnool) has been carried out on the basis of agromet data for the period 1971–2003. During the southwest monsoon season, more than 1000 mm rainfall was received at Nemmikal and Appayapally, while it was as low as 143 mm at Nandavaram. More than 85% of the annual rainy days occur during the five-month period – June to October.

Though all the locations have a semi-arid type of climate, there is a tendency for the climate to temporarily shift towards the drier side. About 45% of the study period now shows an arid type of climate. Among the watersheds, Malleboinpally has the most stable climate with 85% of the total years in its normal semi-arid climate. At Nemmikal, there appears to be a slight trend towards dryness in the past 25 years, after 1978, as the climate was never the dry sub-humid type, and it has slowly been tending towards the arid type. Analysis of water balances in extreme rainfall years indicated that many locations recorded water surplus even in dry years. Between the wet and dry years, variation in the water surplus is much higher compared to the water deficit. Nemmikal (medium-deep Vertisol) and Nandavaram (deep Vertisol) watersheds provide greater opportunity for double cropping. Appayapally, Thirumalapuram and parts of Nemmikal watersheds with medium-deep Alfisols, provide opportunity for double cropping with relatively short duration crops, but are more suitable for intercropping with medium-duration crops such as pigeonpea and castor. Watersheds in Kacharam, Mentapally, Sripuram, Malleboinpally and Karivemula have medium-deep Alfisols and provide greater potential for sole cropping during rainy season with crops of 120–130 days duration, and intercropping with short to medium-duration crops to make better use of soil water availability. Early season drought occurs at Karivemula and Thirumalapuram and early and mid-season droughts occur at Nandavaram. These sites would require crop/varieties tolerant to early or mid-season droughts depending upon the location.It is also observed that Mentapally, Malleboinpally, Nemmikal and Appayapally have greater potential for water harvesting.

Assured rainfed crop-growing season is about 165 to 175 days for the Vertisols areas and about 130 to 150 days for the Alfisols areas. There is variation in both the beginning and ending of the season; however, the end is more variable compared to the start. No definite relationship exists between the beginning and length of the growing season.

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2006

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Acknowledgments

The help of the reviewers, Dr GGSN Rao, Project Coordinator (Agromet), CRIDA, Hyderabad; and Dr LS Rathore, Head, Application Division, NCMRWF, Noida, UP, is gratefully acknowledged. The authors would like to thank all the partners of the consortium, ANGRAU, Government Departments – Drought Prone Area Project of Andhra Pradesh, Andhra Pradesh Rural Livelihoods Program, Directorate of Economics and Statistics, MV Foundation (NGO), farmers and self-help groups, for their help and cooperation. The financial support provided by the APRLP-DFID is gratefully acknowledged. The help of Dr Meera Reddy for editing is appreciated.

Contents

Introduction

With the ever-increasing need for food, shelter and energy, maximizing the agricultural production from rainfed areas in a sustainable manner has become the most important aspect of agricultural research. The saying that "farmers learn to live with the limitations of their local climatic conditions through trial and error over generations" is no more wholly true. Past experience provides them with diverse information on rainfall, floods, droughts, etc. Yet, for modern agriculture this is not enough. It is now very clear that to derive maximum and sustained agricultural yield from watersheds, farmers should have access to proper knowledge of the prevailing agroclimatic conditions.

Weather, the day-to-day state of atmosphere, consists of short-term variation of energy and mass exchanges within the atmosphere and between the earth and the atmosphere. It results from processes attempting to equalize differences in the distribution of net radiant energy from the sun. Acting over an extended period of time, these exchange processes accumulate to become C*limate*. In simple terms, climate is the synthesis of weather at a given location over a period of about 30 years. Climate, therefore, refers to the characteristic condition of the atmosphere deduced from repeated observations over a long period. More than a statistical average, climate is an aggregate of environmental conditions involving heat, moisture and air motion. Any study of climate must consider extremes in addition to means, trends, fluctuations, probabilities and their variations in time and space.

Agroclimatology

The full potential of climate as an agricultural resource has not been used or ever realized. As a result, several crops are grown traditionally in areas without any knowledge of the suitability of climate. Thus, on the one hand, poor yields of crops are obtained and on the other, much of the production potential of this vast resource is left unutilized. It is impossible to tame the weather on a large scale, or even be in complete harmony with it. However, it is inevitable to make adjustment with the weather or harness the maximum benefit from this resource. In this context, knowledge on agroclimatology of a region is a valuable tool in crop planning.

The importance of climate assumes greater importance in rainfed regions where moisture regime during the cropping season is highly variable and is strongly dependent on the quantum and distribution of rainfall *vis-à-vis* the soil water holding capacity (WHC) and water release characteristics. Even in irrigated agriculture, where manipulation of moisture regime alone is possible, the thermal and radiation regimes influence the choice of crops, cropping patterns and the optimum dates of sowing for achieving better crop yields. In addition, weather abnormalities such as cyclones, floods, droughts, hailstorms, frost, high winds and extreme temperatures will lead to natural disasters affecting agricultural productivity. A thorough understanding of the climatic conditions will help in devising suitable management practices for taking advantage of the favourable weather conditions and avoiding or minimizing risks due to adverse weather conditions.

Agroclimatological methods can be used in efficient land use planning, determining suitable crops for a region, risk analysis of climatic hazards, profit calculations in farming, production or harvest forecasts, adopting of farming methods or choice of farm machinery.

Study area

Nalgonda, Mahabubnagar, Kurnool, Prakasam and Anantapur are the most drought-prone districts of Andhra Pradesh and are characterized with low and highly erratic rainfall. Land degradation, improper soil and water management practices, lack of improved crop cultivars, pest and disease problems, rural communities unable to meet minimum health and nutrition standards, and many such problems trigger a vicious circle of rural poverty. The Andhra Pradesh Rural Livelihood Project (APRLP) was conceived to meet these challenges with a mission to help reduce poverty by protecting fragile environments, promoting inclusiveness through participatory and convergence approach and creating diversified opportunities to the rural poor.

The APRLP chose watershed as a logical unit for efficient and sustainable management of natural resources thereby sustaining rural livelihoods with a focus on the scope and development of rural people. In the three target districts (Nalgonda, Mahabubnagar and Kurnool), fifty watersheds (10 nucleus and 40 satellites) were selected (Figure 1) as the test sites for implementing the APRLP-ICRISAT Project – *Improving Livelihood Opportunities through Watersheds*. Agroclimatic analysis of these three districts and the ten nucleus watersheds has been carried out and presented in the report.

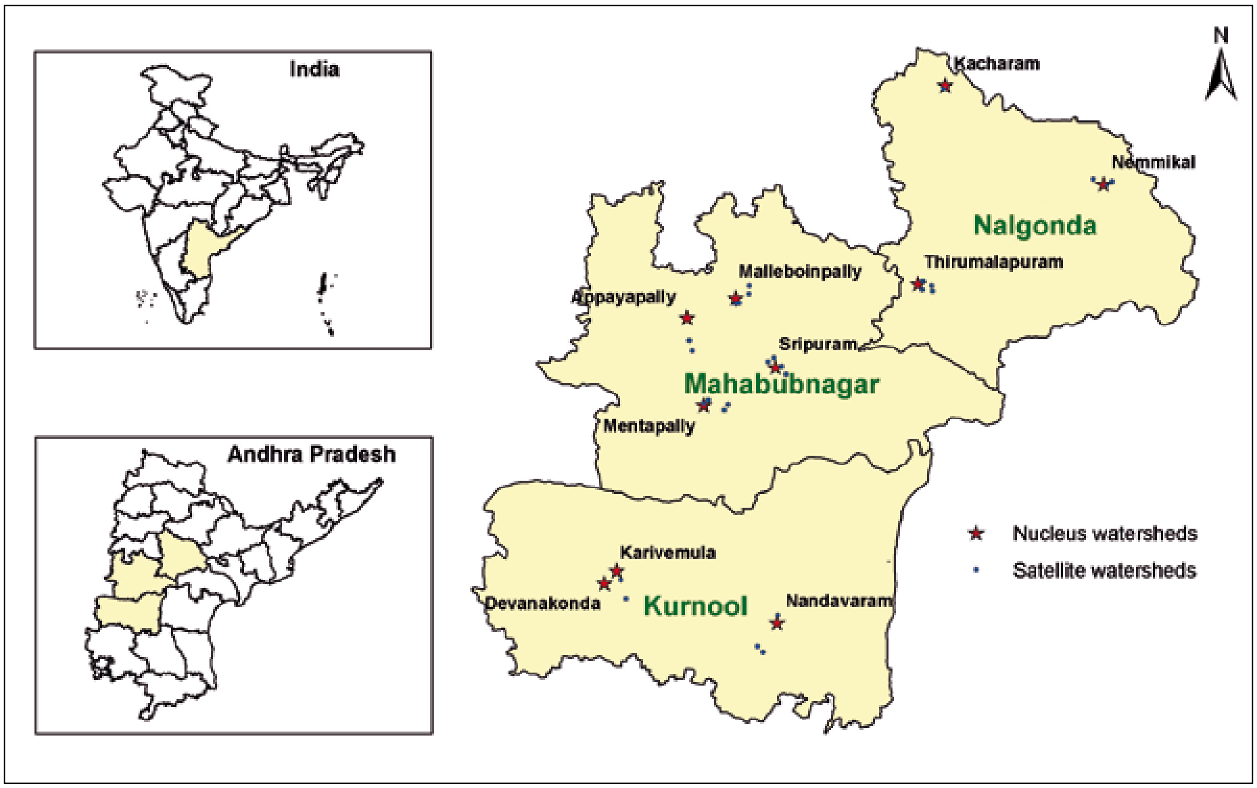


Figure 1. Location of APRLP-ICRISAT nucleus and satellite watersheds.

Data and methods

The districts in Andhra Pradesh (AP) are administratively divided into mandals. There are 59 mandals in Nalgonda, 64 mandals in Mahabubnagar and 54 mandals in Kurnool district. Daily rainfall data of all the 177 mandals for the period 1971–2003 (33 years) was collected from the Directorate of Economics and Statistics, Government of Andhra Pradesh. Daily/weekly agromet data on maximum and minimum temperatures, relative humidity (both morning and afternoon), wind speed and sunshine hours for four stations, viz, Patancheru (ICRISAT), Hayatnagar (CRIDA), Palem and Nandyal (ANGRAU) were collected for estimating the potential evapotranspiration. Soil information published by NBSS&LUP (2000) was used.

Agroclimatic characterization of the watersheds was carried out following well-known and popular methods. Rainfall variability was studied following the method of India Meteorological Department (IMD). Incomplete gamma and Markov-chain methods were used for studying rainfall probabilities. Modified FAO-Penman-Monteith method (Allen 1998) was used to estimate potential evapotranspiration. Plant extractable water was estimated from soil characteristics. Modified Thornthwaite and Mather method (1955) was used to compute water balances. Length of growing period (LGP), dry and wet spells during the crop growth period are calculated based on Index of Moisture Adequacy (IMA).

General description of the study area

The three districts represent the typical semi-arid rainfed conditions of the Deccan Plateau in South India and are characterized by hot summers with relatively pleasant winters. Rice, sorghum, maize, pearl millet, pigeonpea, cotton, castor, groundnut and vegetables are the important crops of the region. Deep loamy and clayey mixed red and black soils dominate the districts. General features of the districts are presented in Table 1. Though the southwest monsoon sets over the region almost at the same time, the withdrawal is extended by about 10 days in some parts of Kurnool district. Among the three districts, Kurnool receives low annual rainfall of about 660 mm in which about

Table 1. General features of the three target districts.

	District		
Feature	Nalgonda	Mahabubnagar	Kurnool
Physiography	North Telangana plateau	North Telangana Plateau	South Telangana plateau (Rayalaseema) and eastern Ghats
Soils and Available Water Capacity (AWC mm/m)	Deep loamy and clayey mixed Red and Black soils with medium to high AWC (100–200)	Deep loamy and clayey mixed Red and Black soils with medium to high AWC (100–200)	Deep loamy to clayey mixed Red and Black soils with medium AWC (100–150)
Agroecological Sub Region (AESR)	Hot Moist Semi-Arid ESR	Hot Moist Semi-Arid ESR	Hot Dry Semi-Arid ESR
Average annual temperature °C	26.4	26.9	28.1
Annual rainfall (mm)	745	710	660
Onset of monsoon	06 June	05 June	04 June
Withdrawal of monsoon	01 November	05 November	10 November
SW monsoon rainfall (mm)	540	540	450
Post-monsoon rainfall (mm)	150	115	145
Annual PET (mm)	1615	1665	1725
LGP	120–150 days	120–150 days	90–120 days

450 mm is received during the southwest monsoon season. Seasonal rainfall distribution indicates that Mahabubnagar district with low northeast monsoon rainfall is more drought-prone in the late crop-growing season.

Monthly climatic conditions of the target districts are presented in Table 2. All three districts have similar temperature conditions, with Kurnool experiencing slightly more summer temperatures. Winds are strong during southwest monsoon season and wind speed of more than 18 km h^{-1} is experienced in Kurnool district. Morning humidity (RH-1) is always higher than the afternoon humidity (RH-2). Average relative humidity is generally high during southwest and northeast monsoon seasons; RH-2 is low during February–May when compared to other months. Nalgonda district has slightly lower temperatures and higher humidity. The region has plenty of solar radiation and the duration of bright sunshine could be as high as 12.2 hours in April and May. Solar radiation can reach up to 28 MJ m^{-2} in these months. Low radiation of about 1–2 MJ m^{-2} is recorded on days with overcast sky and heavy rainfall.

Spatial distribution of annual rainfall of the target districts at mandal level is shown in Figure 2. There is a great variation in the annual rainfall among the mandals in the three districts. In Nalgonda district, the northeast regions bordering Warangal, Khammam and Guntur districts receive high rainfall ranging from 800 to 950 mm. Other areas of the district receive about 500–800 mm. Mahabubnagar district receives comparatively low rainfall of 500–700 mm with only the eastern parts receiving a rainfall of 700–800 mm. Ghattu, Manopadu, Pangal and Chinnachintakunta mandals receive low rainfall of less than 500 mm. Among the three districts, Kurnool shows greatest spatial variation of rainfall with the eastern parts (Rudravaram, Bandi-Atmakur, Nandyal, Mahanandi and Sirvel mandals) receiving high

Table 2. Monthly climatic conditions of the three target districts.

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
						Nalgonda district						
Max.T °C	28.4	31.7	35.3	37.8	39.0	35.1	30.8	29.1	30.3	30.4	28.8	27.8
Min.T °C	15.1	17.3	20.5	24.6	24.9	23.7	22.8	21.7	21.6	21.0	19.8	16.3
Rainfall (mm)	5	4	7	13	29	99	145	139	154	109	33	7
RH-1 (%)	78	67	58	51	45	78	88	90	91	85	82	79
RH-2 (%)	37	29	24	25	26	46	62	68	66	57	46	38
Wind (km h^{-1})	7.4	8.1	8.4	9.1	11.9	15.9	14.6	12.2	7.5	5.9	6.5	6.2
						Mahabubnagar district						
Max.T °C	29.6	32.7	35.9	38.0	38.9	34.4	30.7	30.2	30.8	31.0	29.6	28.7
Min.T °C	16.3	18.3	21.4	25.0	26.3	24.2	22.7	22.4	22.2	21.1	18.5	16.5
Rainfall (mm)	2	3	5	15	33	88	153	150	145	90	21	4
RH-1 (%)	65	53	46	50	53	72	82	82	80	71	64	64
RH-2 (%)	36	27	24	28	31	50	65	66	65	58	47	41
Wind (km h^{-1})	7.7	7.3	7.1	7.5	10.4	13.8	13.1	12.1	8.9	7.7	9.3	8.6
						Kurnool district						
Max.T °C	31.3	34.4	37.7	39.7	39.8	35.6	32.8	32.0	32.3	32.4	31.1	30.3
Min.T °C	17.0	19.3	22.6	25.8	26.6	24.8	23.7	23.3	23.2	22.3	19.3	16.8
Rainfall (mm)	2	2	6	17	42	76	108	121	141	107	30	7
RH-1 (%)	68	58	50	52	58	70	77	77	77	74	71	71
RH-2 (%)	35	28	25	28	31	47	59	59	57	54	47	41
Wind (km h^{-1})	5.0	5.8	6.3	7.2	11.6	18.2	18.0	16.3	11.2	5.1	4.3	4.2

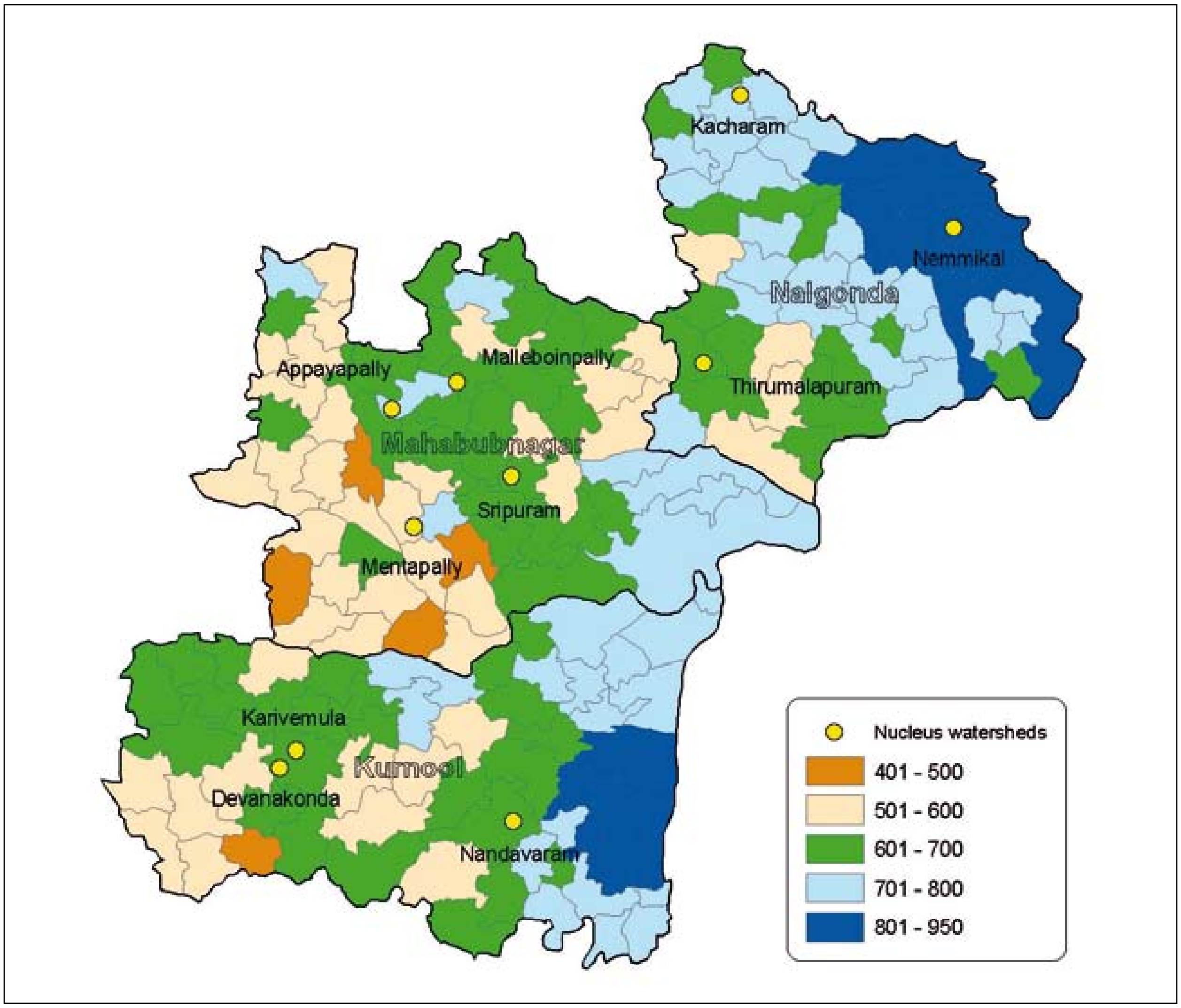


Figure 2. Mandal-wise distribution of annual rainfall (mm) in target districts.

rainfall of 800–950 mm, while Maddikera mandal bordering Anantapur district receives a rainfall of 401–500 mm. In general, the eastern parts of the three districts receive high rainfall compared to their western parts.

Rainfall climatology of watersheds

Analysis of seasonal rainfall of the nucleus watershed locations was carried out using rainfall data of 33 years (1971–2003) and the results are presented in Table 3. June to September is considered as 'southwest monsoon' season and October to December as 'post-monsoon' season.

Table 3 indicates that among the nucleus watersheds, Nemmikal has the highest annual rainfall (816 mm) and Devanakonda/Karivemula recorded the lowest (609 mm). Contribution of southwest monsoon and post-monsoon rainfall to the annual is about 73% and 19%, respectively. Appayapally has the highest contribution (77%) while Nandavaram has the least contribution (65%) through southwest monsoon rainfall. When post-monsoon rainfall is considered, Nandavaram has the highest contribution of 25% indicating the prolonged nature of rainfed crop-growing season. Analysis of

Table 3. Rainfall characteristics of the watershed locations.

Parameter	Watershed location	Southwest monsoon (mm)	Post-monsoon (mm)	Annual (mm)
Total rainfall (mm)	Kacharam	530	143	740
	Nemmikal	612	152	816
	Thirumalapuram	460	131	641
	Sripuram	494	120	671
	Mentapally	528	131	716
	Appayapally	597	116	774
	Malleboinpally	525	120	692
	Nandavaram	418	160	645
	Devanakonda/Karivemula	423	132	609
Standard Deviation (mm)	Kacharam	138	97	171
	Nemmikal	201	116	198
	Thirumalapuram	152	97	172
	Sripuram	148	92	170
	Mentapally	182	101	176
	Appayapally	187	83	184
	Malleboinpally	160	96	160
	Nandavaram	144	100	165
	Devanakonda/Karivemula	129	94	138
Coefficient of Variation (%)	Kacharam	26	68	23
	Nemmikal	33	76	24
	Thirumalapuram	33	74	27
	Sripuram	30	77	25
	Mentapally	34	77	25
	Appayapally	31	72	24
	Malleboinpally	30	80	23
	Nandavaram	34	63	26
	Devanakonda/Karivemula	30	71	23

Table 4. Extreme rainfall characteristics of the watershed locations.

	Southwest monsoon (mm)		Post-monsoon (mm)	
Watershed Location	Highest	Lowest	Highest	Lowest
Kacharam	787 (2000)*	231 (2002)	352 (1987)	7 (2000)
Nemmikal	1038 (1978)	320 (1972)	462 (1977)	8 (1989)
Thirumalapuram	889 (1983)	207 (1994)	370 (1987)	7 (1988)
Sripuram	833 (1983)	260 (1994)	398 (1987)	1 (1999)
Mentapally	911 (1983)	199 (1971)	465 (1975)	0 (1999)
Appayapally	1120 (1983)	292 (1994)	348 (1987)	6 (1986)
Malleboinpally	864 (1978)	225 (1994)	395 (1987)	6 (1986)
Nandavaram	730 (1978)	143 (1994)	440 (1975)	30 (1980)
Devanakonda	660 (1978)	186 (2002)	326 (1987)	0 (1980)

*Figures in the parenthesis indicate the year of occurrence.

standard deviation and coefficient of variation (CV) indicate a great year-to-year variability in rainfall. Rainfall variability in the post-monsoon season is more than twice than that of the southwest monsoon season for all locations (except for Nandavaram).

Based on the rainfall data of 33 years, extremes of rainfall in the southwest monsoon (Jun–Sep) and post-monsoon (Oct–Dec) seasons were identified and presented in Table 4. There exists a great variation in the rainfall extremes across the watersheds. During the southwest monsoon season, more than 1000 mm rainfall could be received at Nemmikal and Appayapally, while the rainfall could be as low as 143 mm at Nandavaram. During the post-monsoon season, the variation in the highest rainfall received among the watersheds is considerably low and ranges between 326 and 465 mm. Lowest rainfall during this season is less than 10 mm for all the locations except at Nandavaram, where it is about 30 mm.

As per the method of IMD, seasonal variability of rainfall was assessed based on the rainfall deviation from the normal (Table 5). Years were classified into four categories as *Excess* (>20%), *Normal* (19 to –19%), *Deficit* (–20 to –59%) and *Scanty* (less than –59%).

Table 5 shows that during the southwest monsoon season, rainfall was generally either *normal* or in the *deficit* category. Very rarely was the rainfall *scanty* during this season. During the post-monsoon season, all the locations have considerable number of years with *scanty* rainfall. Chances to receive *excess* rainfall are high in the post-monsoon season.

Analysis of extreme values of monthly rainfall in the monsoon season at different locations indicated that in certain years, rainfall could exceed more than twice the average for that month. In the other seasons, the variation could be much higher. Results of such analysis for Appayapally are shown in Figure 3. June to October has low variation compared to the average, and May and November show extreme variations, indicating the high risk associated with rainfall.

Table 5. Variation of seasonal rainfall at watershed locations.

		Number of years in rainfall category			
Season	Watershed location	Excess	Normal	Deficit	Scanty
SW Monsoon (June to September)	Kacharam	7	19	7	0
	Nemmikal	8	14	11	0
	Thirumalapuram	8	15	10	0
	Sripuram	7	13	13	0
	Mentapally	9	14	8	2
	Appayapally	8	14	11	0
	Malleboinpally	9	15	9	0
	Nandavaram	9	11	12	1
	Devanakonda	9	14	10	0
Post-Monsoon (October to December)	Kacharam	10	9	7	7
	Nemmikal	10	7	7	9
	Thirumalapuram	9	10	8	6
	Sripuram	12	6	8	7
	Mentapally	12	5	9	7
	Appayapally	12	5	8	8
	Malleboinpally	12	3	9	9
	Nandavaram	8	14	4	7
	Devanakonda	10	6	8	9

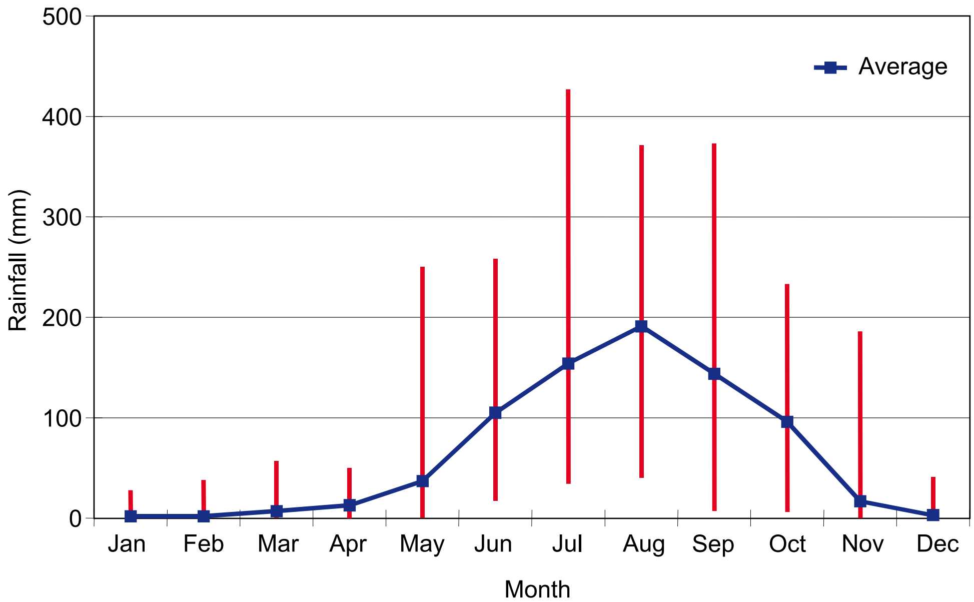


Figure 3. Monthly range of rainfall at Appayapally.

Knowledge on the amount of rainfall and rainfall intensity helps in understanding the water harvesting potential at a location. Daily rainfall data of the nine watersheds are classified into four categories having days receiving rainfall of more than 2.5, 10, 25 and 50 mm and are presented in Table 6.

India Meteorological Department has defined a rainy day as a day that receives at least 2.5 mm. Table 6 shows that the average annual number of rainy days varies from 35 at Devanakonda to 48 at Appayapally, indicating a better distribution of rainfall at Appayapally.

Based on data collected for 33 years, it is observed that among the watersheds, Appayapally recorded the highest number of rainy days (71) in the year 1983 and Devanakonda recorded the lowest (19 days) in the year 1980. When higher rainfall intensities of 10 to 50 mm per day are considered, Nemmikal recorded superior moisture conditions indicating better water harvesting potential. At all the watersheds, rainfall above 50 mm per day is received only for two or three days in a year.

Analysis on monthly rainy days indicated that more than 85% of the rainy days in the year occur during the five-month period June to October. In Nalgonda and Mahabubnagar districts, rainy days are more during July to August, while in Kurnool district, August to September period recorded more rainy days. Figure 4 depicts the monthly rainfall intensities observed at the watershed locations in the Mahabubnagar district. It is seen that Appayapally has better rainfall intensities compared to others, indicating the potential for water harvesting.

Rainfall probabilities

Characterization of a watershed based on average rainfall can yield good results, provided the rainfall distribution is normal. However, in the semi-arid tropics, weekly rainfall totals include a number of zeros. Hence several researchers suggested the fitting of incomplete gamma distribution to this kind of skewed data (Thom 1958; Krishnan and Kushwaha 1972; Khambete and Biswas 1978; Biswas and Khambete 1979; Biswas and Basarkar 1982). Weekly rainfall that can be expected at different probability levels was computed based on incomplete gamma distribution model.

Table 6. Average annual number of days with different rainfall intensities.

Threshold rainfall per day	Watershed location	No. of days with threshold rainfall		
		Average	Highest	Lowest
≥ 2.5 mm	Kacharam	42	62	28
	Nemmikal	44	60	35
	Thirumalapuram	37	60	24
	Sripuram	41	53	27
	Mentapally	42	57	31
	Appayapally	48	71	28
	Malleboinpally	41	65	31
	Nandavaram	38	52	25
	Devanakonda	35	47	19
≥ 10 mm	Kacharam	24	35	13
	Nemmikal	25	42	15
	Thirumalapuram	20	35	9
	Sripuram	21	31	13
	Mentapally	22	32	12
	Appayapally	25	37	14
	Malleboinpally	22	39	10
	Nandavaram	20	29	11
	Devanakonda	19	27	13
≥ 25 mm	Kacharam	9	15	3
	Nemmikal	11	20	6
	Thirumalapuram	8	18	4
	Sripuram	8	14	2
	Mentapally	9	14	1
	Appayapally	8	16	2
	Malleboinpally	8	15	2
	Nandavaram	8	14	2
	Devanakonda	7	15	3
≥ 50 mm	Kacharam	3	6	0
	Nemmikal	3	6	0
	Thirumalapuram	2	5	0
	Sripuram	2	6	0
	Mentapally	3	6	0
	Appayapally	2	5	0
	Malleboinpally	2	6	0
	Nandavaram	2	6	0
	Devanakonda	2	5	0

Results from the nucleus watersheds are presented in Figure 5. Contrasting rainfall characteristics are observed. For example, average annual rainfall at Nemmikal is 815 mm, while at Devanakonda it is about 610 mm. Nemmikal has a better moisture regime with about 15 weeks (26–40 meteorological weeks) receiving an average rainfall of above 30 mm. Even at 75% probability, more than 8 mm per week can be received during this period. Runoff harvesting is possible in this period, particularly during the 29–33 meteorological weeks (middle of July to middle of August) and again during 38–40 weeks (second half of September to first week of October). On the other hand, at Devanakonda the conditions are different and agriculturally significant rains begin only by 28th meteorological week (one month later than at Nemmikal). Rainfall intensity is generally low during the crop-growing season,

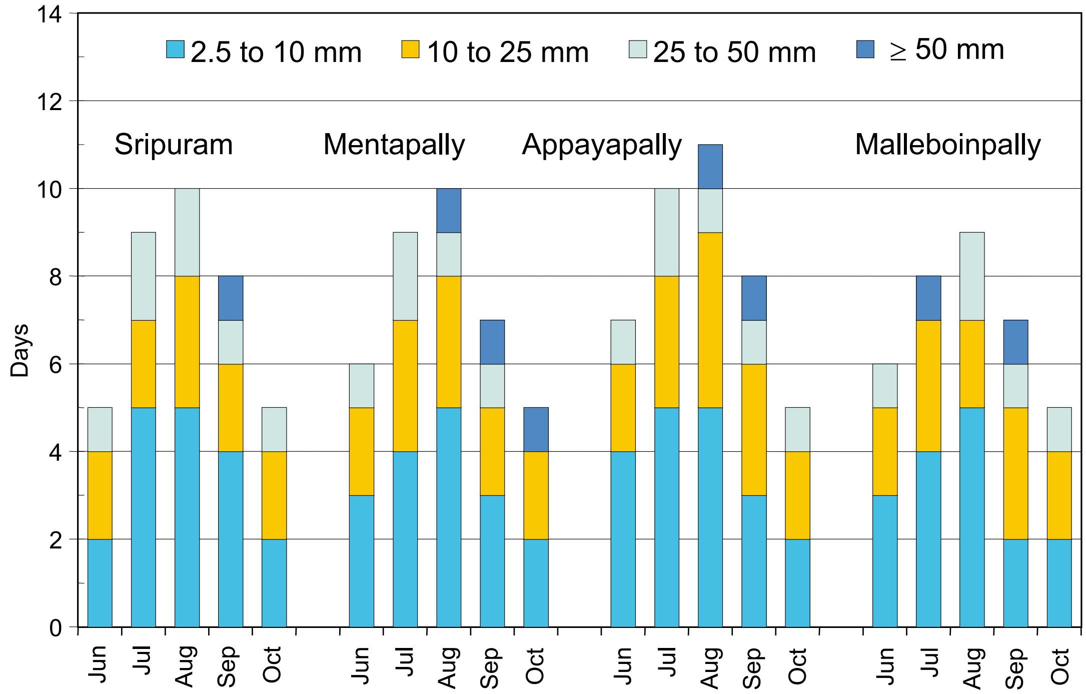


Figure 4. Monthly rainfall intensities in Mahabubnagar district.

except during the 32nd and 38–40 weeks. Runoff harvesting potential is relatively less compared to that of Nemmikal. Rainy season ends more or less in a similar way at these two watersheds.

Agricultural operations are determined by the receipt of certain amount of rainfall at each stage. There are specific amounts of rainfall required for the activities like land preparation, sowing, transplanting, fertilizer application etc. Thus, estimation of probabilities with respect to a given amount of rainfall is useful for rainfed agricultural planning. Initial Probability is the probability of receiving a certain amount of rainfall in a given week and is denoted by P (W). The interesting point to be noted is that the probability of getting a next week as a wet week, given the condition that the current week is a wet week – can now be estimated. These are called Conditional Probabilities and denoted by P (W/W). Initial and conditional probabilities of receiving different amounts of rainfall at the nine watersheds was computed following the method of Virmani et al. (1982) and the results are presented in Appendix.

At Mentapally, the initial probabilities of receiving a rainfall of more than 30 mm per week are generally moderate throughout the period during 28–41 weeks (July second week to middle of October), indicating the possibility of little moisture stress during the crop-growing period (Figure 6). The conditional probability line indicates that there is high probability of more than 65% to receive 30 mm of rainfall on the 24th and 26th week, provided the 23rd and 25th week is wet with a rainfall of above 30 mm. This kind of information will be of great practical use in planning land preparation and sowing operations at Mentapally area.

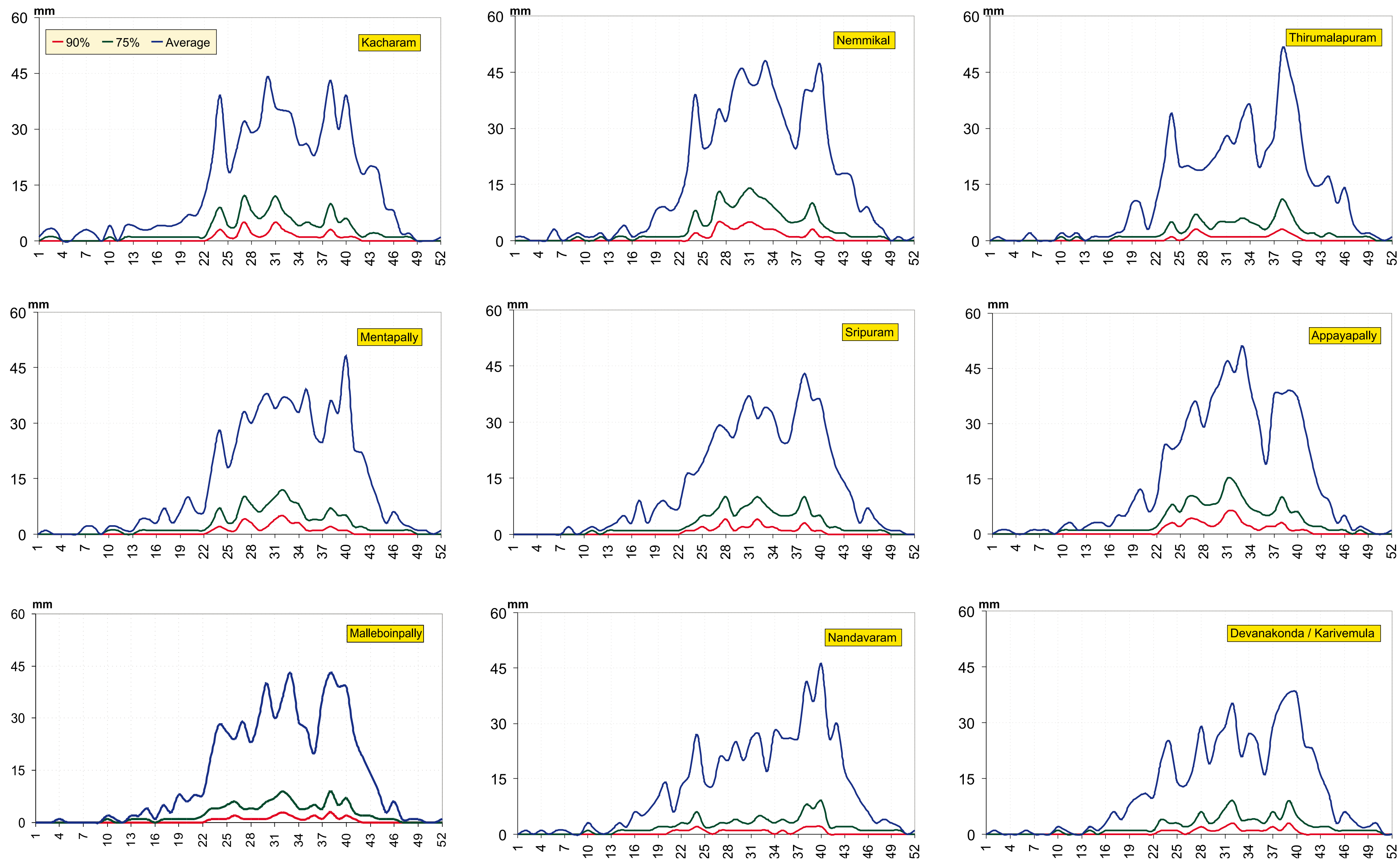


Figure 5. Average and probability rainfall at watershed locations

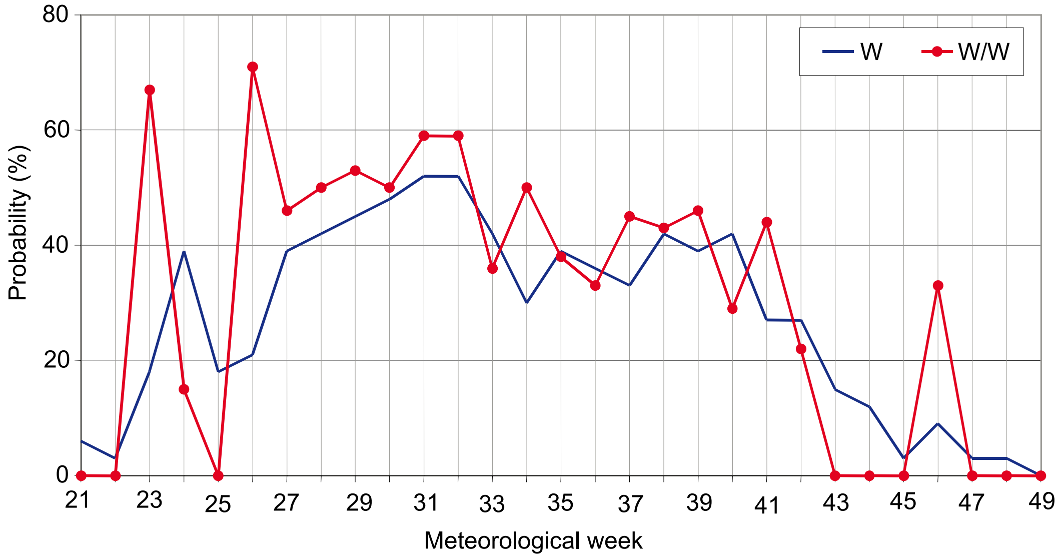


Figure 6. Initial and conditional probabilities of rainfall at Mentapally.

Potential evapotranspiration

Potential Evapotranspiration (PET or ET_o) is the amount of water that can evaporate from the wet soil and transpire from a healthy green grass field, when there is no soil moisture deficit. Information on PET for a location on a short timescale has great importance in agricultural water management. Though the direct measurement of PET is possible with the help of a lysimeter, this method is cumbersome and costly. Many empirical methods are available, viz, Thornthwaite (1948), Blaney and Criddle (1950), Hargreaves and Christiansen (1973) and others. Rao et al. (1971) have computed monthly PET for 300 stations in and around India using the Penman (1948) method. Many researchers interpolated the weekly PET values from monthly PET for want of weekly meteorological data. Khambete and Biswas (1984) have compared the interpolated values with those obtained from different methods and observed that the interpolated values are underestimated and the most efficient method is to use weekly meteorological data. Khambete and Biswas (1992) have computed Penman PET on weekly basis for 62 locations in India using the weekly normal meteorological data.

Guidelines were developed and published in the FAO Irrigation and Drainage Paper No. 24 'Crop water requirements' (Doorenbos and Pruitt 1977) to compute ET_o using several methods. The modified Penman method was considered to offer the best results with minimum possible error in relation to a living grass reference crop. However, in recent years, advances in research and a more accurate assessment of crop water use have revealed weaknesses in the methodologies. The modified Penman was frequently found to overestimate ET_o, even by up to 20% for low evaporative conditions.

The analysis of the performance of the various calculation methods revealed the need for formulating a standard method for the computation of ET_o. The relatively accurate and consistent performance of the Penman-Monteith approach in both arid and humid climates has been indicated in both the

ASCE and European studies and hence, the FAO Penman-Monteith method is recommended as the sole standard method. It is a method with strong likelihood of correctly predicting ET_o in a wide range of locations and climates and has provision for application in data-short situations. The use of older FAO or other reference ET methods is no longer encouraged (Allen et al. 1998).

FAO-Penman-Monteith Method

The FAO-Penman-Monteith method to estimate ET_o is as follows:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where

ET_o = reference evapotranspiration [mm day^{-1}]
R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}]
G = soil heat flux density [MJ m^{-2} day^{-1}]
T = mean daily air temperature at 2 m height [°C]
u_2 = wind speed at 2 m height [m s^{-1}]
e_s = saturation vapour pressure [kPa]
e_a = actual vapour pressure [kPa]
e_s - e_a = saturation vapour pressure deficit [kPa]
Δ = slope of vapour pressure curve [kPa $°C^{-1}$]
γ = psychrometric constant [kPa $°C^{-1}$]

The FAO-Penman-Monteith equation requires information of site location and data on air temperature, humidity, radiation and wind speed for PET calculations. This method was used in the present study to estimate weekly PET for the watershed locations.

Plant extractable water

Alfisols and Vertisols dominate the study area. Soil depth varies to a large extent across the three districts, from as low as 20–30 cm for Alfisols and to more than 150 cm for Vertisols. In general, at the nucleus watersheds, the soil depth varied from 50 to 150 cm. Physical capacity of the soil profile for water retention is determined by its depth and porosity. The amount of water that can be extracted by crops depends on the soil properties, amount, depth and distribution of roots. The plant-available water profiles for four soils, viz, deep and medium-deep Vertisols and Alfisols were earlier worked out at the ICRISAT farm (ICRISAT 1978).

Field surveys indicated that Kacharam, Thirumalapuram, Mentapally, Appayapally, Malleboinpally have predominantly medium-deep Alfisols. Nandavaram has mostly deep Vertisols and at Nemmikal, Sripuram, Devanakonda and Karivemula, both medium Alfisols and medium-deep Vertisols are present.

Plant extractable water is one of the inputs for computing climatic water balances. Considering the general root pattern of the dryland crops and the soil type, amount of extractable water was assumed as 60 mm for the medium-deep Alfisols with a depth of 50 cm, 150 mm for medium-deep Vertisols with a depth of 100 cm, and 200 mm for deep Vertisols with a depth of 150 cm.

Water balance

Availability of water in right quantity and in the right time and its management with suitable agronomic practices are essential for good crop growth and yield. To assess water availability to crops, soil moisture is to be taken into account and the net water available through soil moisture can be estimated using the water balance technique. The concept of water balance was first put forth by Thornthwaite (1948) and later modified by Thornthwaite and Mather (1955). The term *water balance* refers to the climatic balance obtained, by comparing the rainfall as income with evapotranspiration as loss or expenditure, soil being a medium for storing water during periods of excess rainfall and utilizing or releasing moisture during periods of deficit precipitation. The basic water balance equation is

$$P = E + \Delta S + RO$$

Where,

P is rainfall (precipitation)
E is the evapotranspiration
ΔS is the change in soil moisture storage
RO is the runoff

When the seasonal march of rainfall is compared with that of water need (PET or ET_o) of a location, one obtains information on many aspects of water relations of the place like soil moisture storage, actual evapotranspiration, water deficit, water surplus and runoff. The concepts of PET and water balance have been extensively applied to studies such as climatic classification, aridity, droughts, crops and watersheds in India by many researchers (Subrahmanyam 1956; Subramaniam and Kesava Rao 1984; Ramakrishna et al. 2000; Kesava Rao et al. 2002; Wani et al. 2004).

Water balance studies

Water surplus and water deficit occur in different seasons at most places, both are significant to indicate the index of moisture affectivity, the one affecting positively and the other affecting negatively. Thornthwaite termed this as Moisture Index (Im) and it can be computed from the annual water balance parameters such as water surplus (WS), water deficit (WD) and PET.

Aridity Index Ia (%) = 100 * WD/PET
Humidity Index Ih (%) = 100 * WS/PET
Moisture Index Im (%) = Ih – Ia

Although a water surplus in one season cannot prevent water deficit in the other except as moisture, the surplus can be stored in soil, to some extent. Since water surplus means seasonal additions to subsoil moisture and groundwater, deep-rooted perennials may make partial use of subsoil moisture and will be less affected by drought.

Moist climates have positive value of Im, while dry climates have negative values. As per the climatic classification of Thornthwaite and Mather (1955), if the value of Im is between 0 and –33.3, the climate is called ‘dry sub-humid’ and if it is between –33.3 and –66.6, it is called ‘semi-arid’. Arid climates occur when Im is less than –66.6. As per this classification, it can be seen from Table 7 that all the nucleus watersheds in Nalgonda, Mahabubnagar and Kurnool districts fall under the semi-arid type of climate.

Table 7. Annual water balance of watershed locations in normal year.

Watershed location	PET (mm)	Rainfall (mm)	Water Surplus (mm)	Water Deficit (mm)	Humidity Index (%)	Aridity Index (%)	Moisture Index (%)
Kacharam	1736	776	128	1085	7.3	62.5	–55.2
Nemmikal	1740	834	225	1126	12.9	64.7	–51.8
Thirumalapuram	1736	723	154	1165	8.9	67.1	–58.2
Sripuram	1575	649	123	1039	7.8	65.8	–58.0
Mentapally	1573	784	170	950	10.8	60.4	–49.6
Malleboinpally	1580	733	165	994	10.4	62.9	–52.5
Appayapally	1570	783	190	976	12.1	62.2	–50.1
Nandavaram	1720	761	95	1061	5.5	61.7	–56.1
Devanakonda/Karivemula	1726	691	105	1142	6.1	66.2	–60.1

Climatic variability

Climate determines suitable crops, varieties and the cropping systems to be grown at a location for achieving maximum yields. Year-to-year fluctuations in crop yields are in response to the varying weather conditions at a particular location. Changes in the onset and distribution of monsoon rains make up a critical type of climatic variability on a more local or regional level. The greatest threat to agricultural production is not the changes in climate, but the variability in climate.

Occasional shifts in the annual water balance of a location may be of such magnitude that the climatic type of the location could be shifted by one or more categories in the dryer or wetter direction. Such shifts in climate, though temporary, are of great interest to the applied climatologists, as its frequency and magnitude reflect the conservation of climate and determine the stability of deterioration in the climatological potentialities of a region for agricultural development.

Though all the locations have semi-arid type of climate, there is a tendency for the climate to temporarily shift towards the drier side (Table 8). Nandavaram, Devanakonda/Karivemula have shifted 45% climatically during the study period towards an arid type of climate. Nemmikal and Appayapally experienced dry sub-humid climate by 6% during the study period. Thirumalapuram is the only location that moved towards both drier and wetter side from the normal semi-arid climate. Among the watersheds, Malleboinpally has the most stable climate as 85% of the total years it was in its normal semi-arid climate. Figure 7 presents the climatic variability at Nemmikal and Devanakonda/ Karivemula.

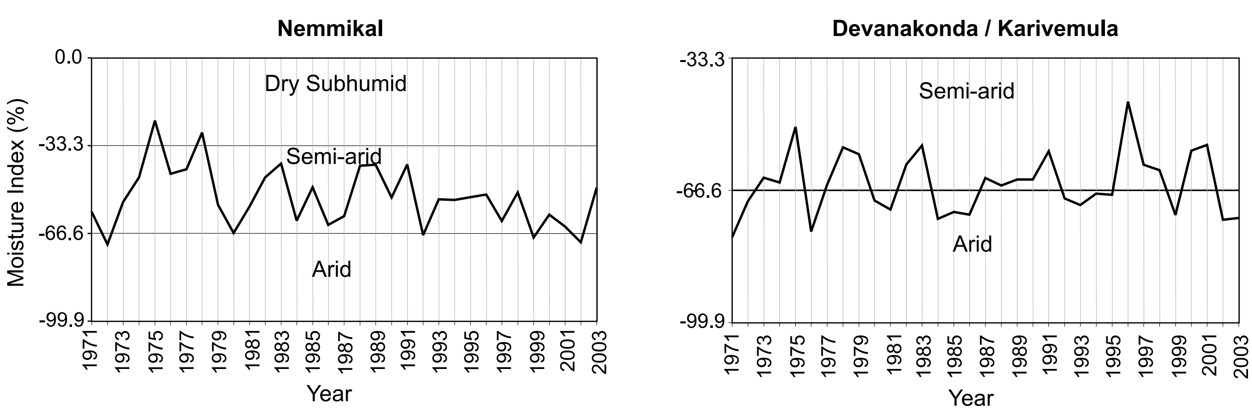


Figure 7. Climatic variability at Nemmikal and Devanakonda/Karivemula.

Table 8. Climatic variability (moisture regime) at watershed locations.

Watershed location	Normal Climatic Type	Percentage of years under		
		Dry Subhumid	Semi-Arid	Arid
Kacharam	Semi-Arid	0	82	18
Nemmikal	Semi-Arid	6	79	15
Thirumalapuram	Semi-Arid	3	61	36
Sripuram	Semi-Arid	0	79	21
Mentapally	Semi-Arid	0	82	18
Malleboinpally	Semi-Arid	0	85	15
Appayapally	Semi-Arid	6	79	15
Nandavaram	Semi-Arid	0	55	45
Devanakonda/Karivemula	Semi-Arid	0	55	45

Nemmikal with a normal semi-arid climate experienced both dry sub-humid and arid climates for a few years, whereas Devanakonda never experienced dry sub-humid climate. At Nemmikal, there appears to be a slight trend towards dryness since the last 25 years, after 1978 as the climate was never of the dry sub-humid type and was slowly tending towards the arid type. Devanakonda/Karivemula show temporary shifts towards arid type of climate several times. These findings are of great importance as they help in choosing crops and seed varieties that will be tolerant to climatic variability.

Extreme event water balance analysis

Changes in the rainfall amount and distribution make considerable changes in the water balance of a location. Based on the water balances of 33 years, dry, normal and wet years were identified at the nucleus watersheds. 1975 and 1983 were wet years for watersheds in Nalgonda and Mahabubnagar districts and 1996 was a wet year for Kurnool. Dry years were found to be 1980, 1985, 1986, 1999 and 2002. Watersheds experienced normal rainfall in several years. Water balance diagrams for the watershed locations were prepared with respect to the wet, normal and dry years and are shown in Figures 8 to 12. Water balance diagrams show the distribution of rainfall, PET and AET over the meteorological weeks. Periods of water deficit, water surplus, soil moisture accretion and soil moisture use are also demarcated on the diagram and their areas represent the quantity. Some locations recorded water surplus even in dry years.

There is more variation present in the water surplus when compared to the water deficit across the dry and wet years. In wet years, water surplus could be two to three times that of normal while in dry years it could be even zero. Water deficits do not show this kind of variation and in the dry years, water deficits could be almost double than that of the normal year. Even in wet years, there is considerable water deficit of more than 100 mm during the crop-growing season. At Kacharam, for example, the water surplus in the wet year is 414 mm and it is only 27 mm in the dry year; corresponding water deficit values are 1079 mm and 1290 mm respectively. Water balance diagrams help in understanding the distribution of various water balance elements and their interpretation helps in planning water harvesting and management of crops.

Climatic water surplus accrued contributes to runoff which could be harvested and stored for use during intra-seasonal dry periods as well as for partially meeting the crop water requirements of the

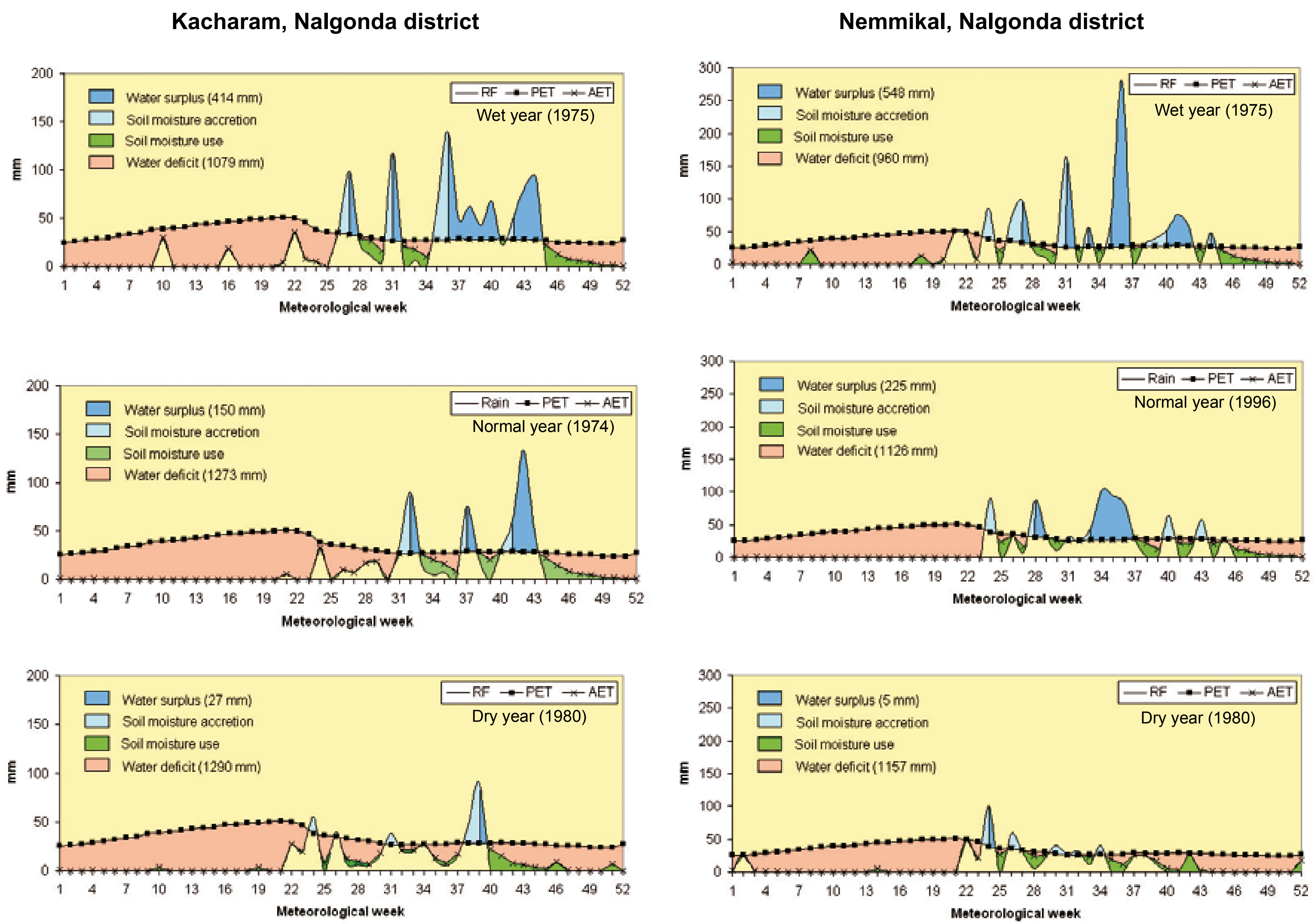


Figure 8. Water balance at watershed locations.

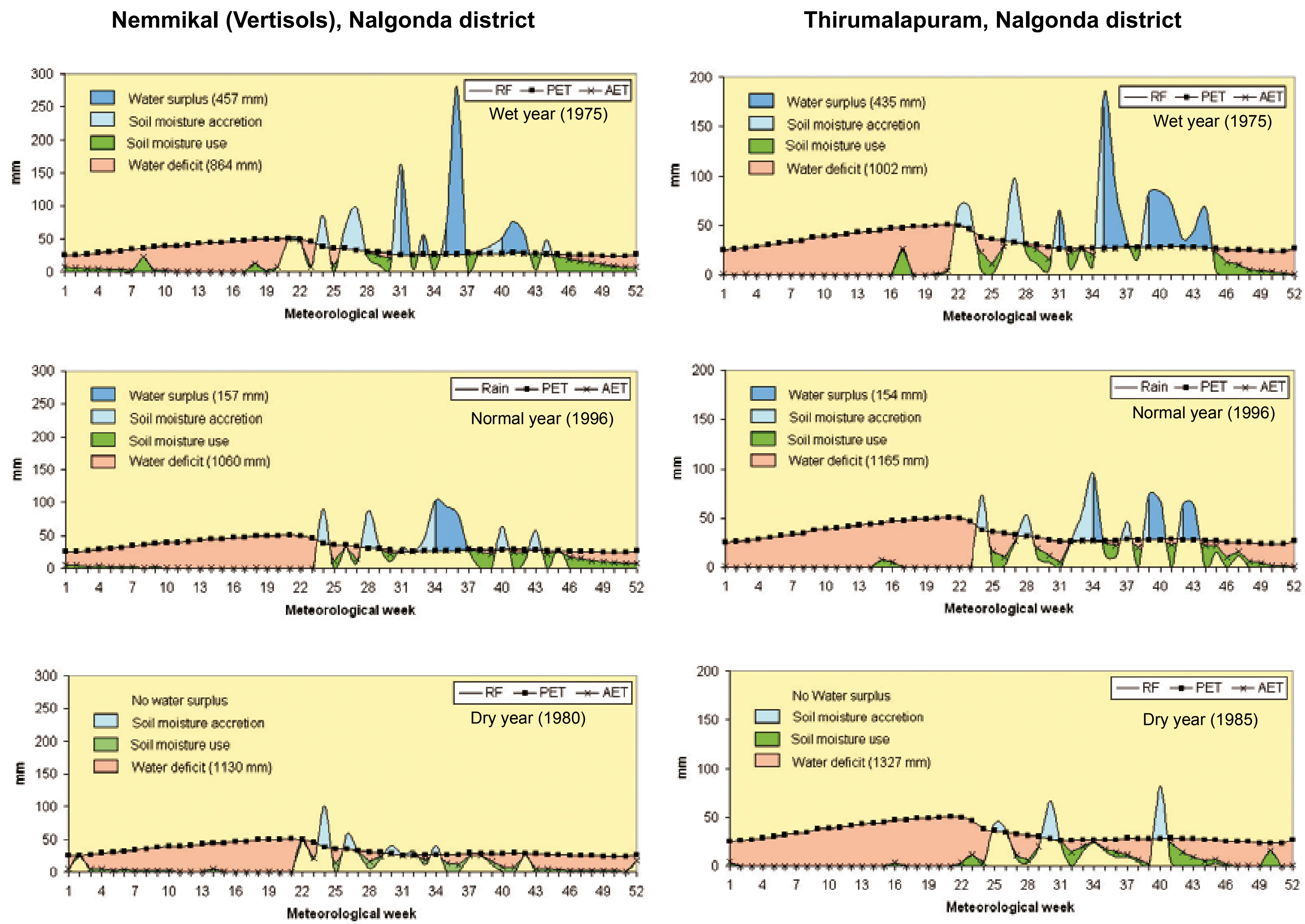


Figure 9. Water balance at watershed locations.

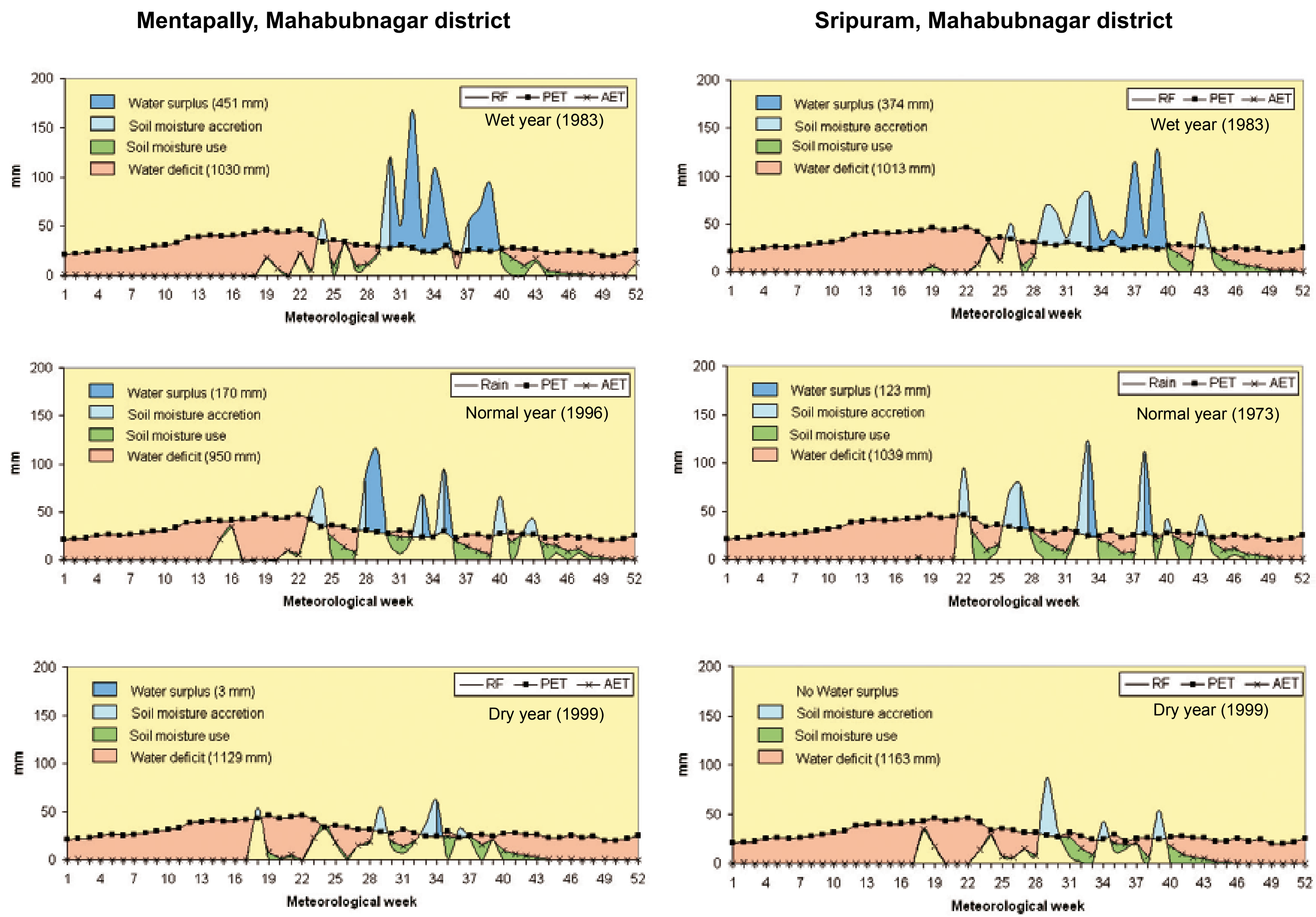


Figure 10. Water balance at watershed locations.

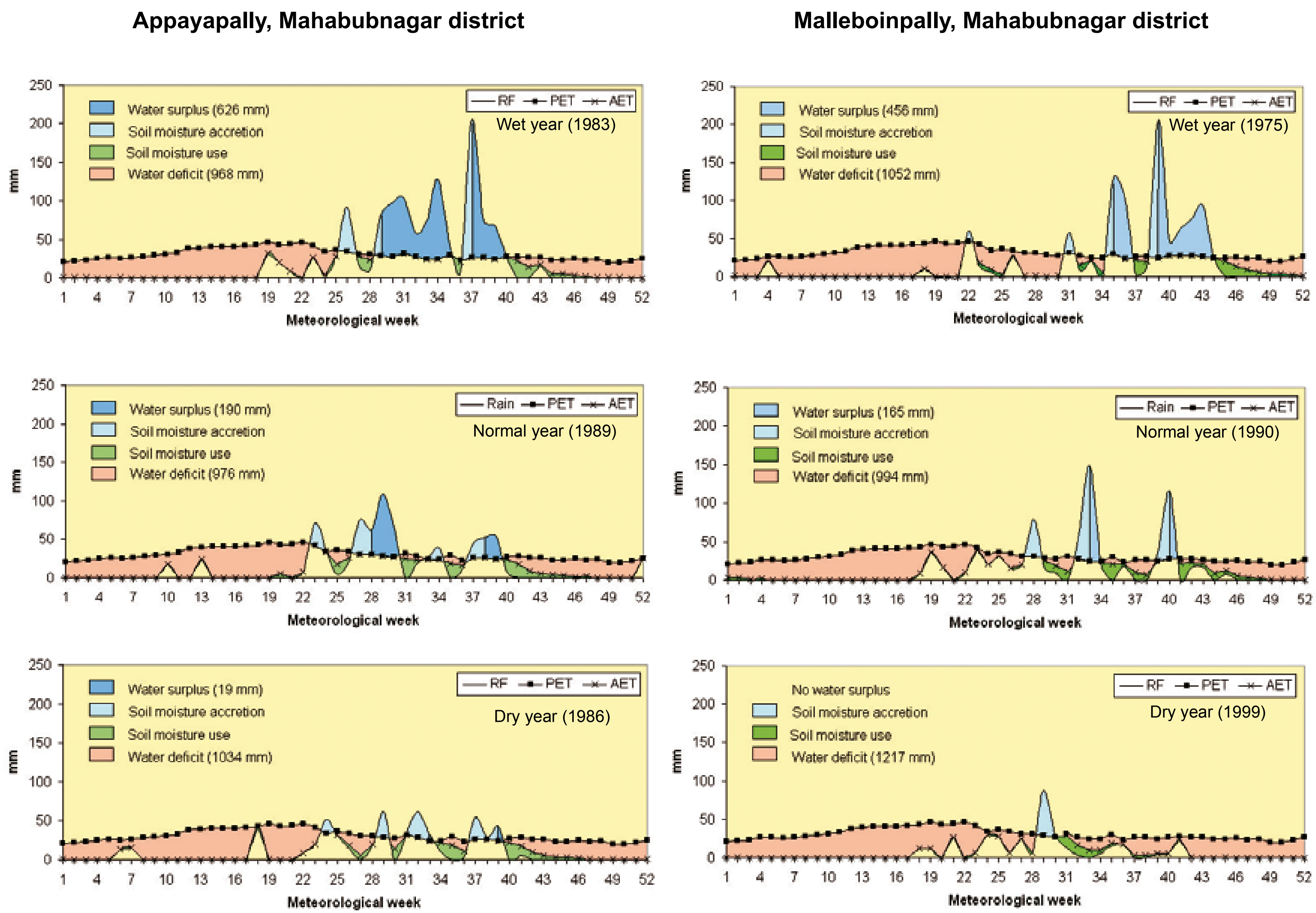


Figure 11. Water balance at watershed locations.

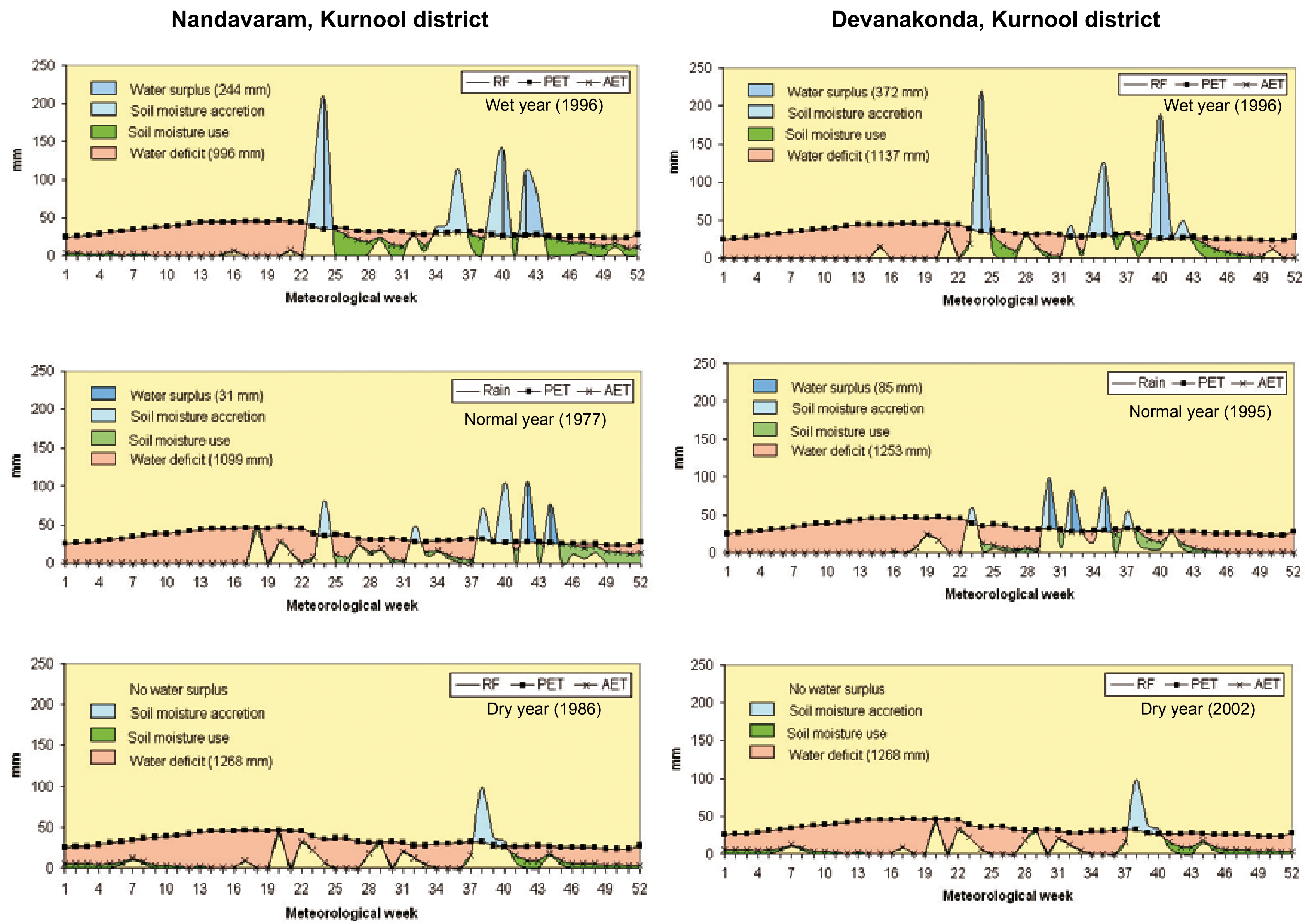


Figure 12. Water balance at watershed locations.

Table 9. Runoff water available for storage at watershed locations.

	Runoff water (in million m^3)		
Watershed location	Wet year	Normal year	Dry year
Kacharam (Medium-deep Alfisols)	1.14	0.35	0.07
Nemmikal (Medium-deep Alfisols)	1.51	0.62	0.01
Nemmikal (Medium-deep Vertisols)	1.26	0.43	Nil
Thirumalapuram (Medium-deep Alfisols)	1.20	0.42	Nil
Mentapally (Medium-deep Alfisols)	1.24	0.47	0.01
Sripuram (Medium-deep Alfisols)	1.03	0.34	0.01
Appayapally (Medium-deep Alfisols)	1.72	0.52	0.05
Malleboinpally (Medium-deep Alfisols)	1.25	0.45	Nil
Nandavaram (Deep Vertisols)	0.67	0.26	Nil
Karivemula (Medium-deep Alfisols)	1.02	0.29	Nil

second crop season. Considering the vegetation, slope and soil type, it is assumed that about 55% of the water surplus could be harvested as runoff. Table 9 shows the runoff water that could be harvested and stored for a watershed area of 500 ha in wet, normal and dry years.

The volume of water available for storing during normal years at the various watersheds varies from 0.3 to 0.6 million m^3 (Table 9). In the wet years, Nemmikal and Appayapally have a potential of about 1.5 to 1.7 million m^3. Nandavaram has the lowest potential even in wet years. During dry years, Kacharam and Appayapally have some potential, while all other locations have either negligible or no runoff.

Length of rainfed crop-growing period

Knowledge on the date of onset of rains will help to plan the agricultural operations better, particularly, land preparation and sowing. The 'length of the rainy season' is the duration between the onset and end of agriculturally significant rains. The length of growing period (LGP) is defined as the length of the rainy season. This includes the period of soil moisture storage at the end of the rainy season, the postrainy season and winter rainfall, which can all meet the crop water needs. Therefore, the LGP depends not only on the rainfall distribution but also on the type of soil, soil depth, water retention and release characteristics of the soil. This assumes greater importance from a watershed perspective where soil depth in a toposequence can also alter the LGP across the watershed being highest in the low-lying regions and lowest in the upper reaches of the watersheds. Several methods were used to estimate the LGP using rainfall (Ashok Raj 1979; IMD 1991; Sivakumar et al. 1993). The National Bureau of Soil Survey and Land Use Planning (Velayutham et al. 1999) estimated LGP using the PET and rainfall.

Using the water balance, week-wise index of moisture adequacy (IMA) was computed, which is defined as the ratio of the actual evapotranspiration to the potential evapotranspiration expressed as a percentage. The beginning and end of the growing season was identified based on the IMA. The growing season begins when the IMA is above 50% consecutively for at least two weeks, starting from the middle of May. The end of the season was identified when the IMA falls below 25% for two consecutive weeks, when seen backwards starting from the end of December.

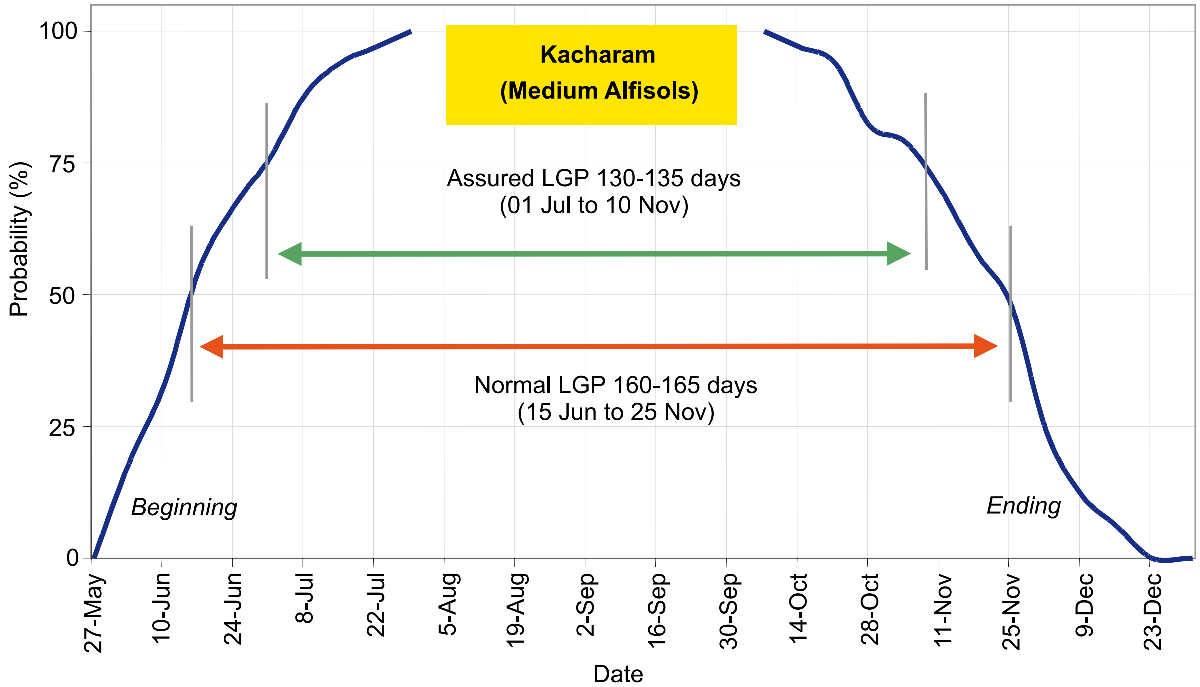
Table 10. Variability at the beginning and end of growing period.

Watershed location	Beginning of season			End of season		
	Normal	Assured	Standard Deviation (Days)	Normal	Assured	Standard Deviation (Days)
Kacharam (Medium-deep Alfisols)	15 Jun	01 Jul	10	25 Nov	10 Nov	18
Nemmikal (Medium-deep Alfisols)	15 Jun	20 Jun	11	30 Nov	10 Nov	19
Nemmikal (Medium-deep Vertisols)	15 Jun	20 Jun	11	20 Dec	05 Dec	19
Thirumalapuram (Medium-deep Alfisols)	15 Jun	25 Jun	11	27 Nov	20 Nov	18
Mentapally (Medium-deep Alfisols)	15 Jun	25 Jun	11	20 Nov	05 Nov	19
Sripuram (Medium-deep Alfisols)	20 Jun	28 Jun	11	20 Nov	07 Nov	19
Appayapally (Medium-deep Alfisols)	15 Jun	20 Jun	10	20 Nov	10 Nov	15
Malleboinpally (Medium-deep Alfisols)	15 Jun	25 Jun	15	18 Nov	10 Nov	16
Nandavaram (Deep Vertisols)	15 Jun	01 Jul	15	31 Dec	18 Dec	14
Karivemula (Medium-deep Alfisols)	15 Jun	28 Jun	16	20 Nov	10 Nov	20

Beginning and end of the rainfed crop-growing season were delineated for each year at all the locations from which, the length of the growing period was estimated. Results indicate that there is a great year-to-year variation in the beginning and end of the growing season at all the locations as shown in Table 10. Based on the long-term data, probability of beginning and end of the season at each week was computed and the results are presented in Figure 13. The LGP is expressed as a range and not as a precise value to make it more realistic and useful for interpretation. Assured beginning of the season

Table 11. Variability in the length of growing period at watershed locations.

Watershed location	Length of Growing Period (days)			
	Shortest	Normal	Longest	Assured
Kacharam (Medium Alfisols)	110	160–165	180	130–135
Nemmikal (Medium Alfisols)	125	165–170	205	140–145
Nemmikal (Medium Vertisols)	145	185–190	225	165–170
Thirumalapuram (Medium Alfisols)	110	160–165	190	145–150
Mentapally (Medium Alfisols)	110	155–160	180	130–135
Sripuram (Medium Alfisols)	110	150–155	190	130–135
Appayapally (Medium Alfisols)	110	155–160	190	140–145
Malleboinpally (Medium Alfisols)	110	155–160	200	135–140
Nandavaram (Deep Vertisols)	145	195–200	215	170–175
Karivemula (Medium Alfisols)	100	155–160	210	135–140



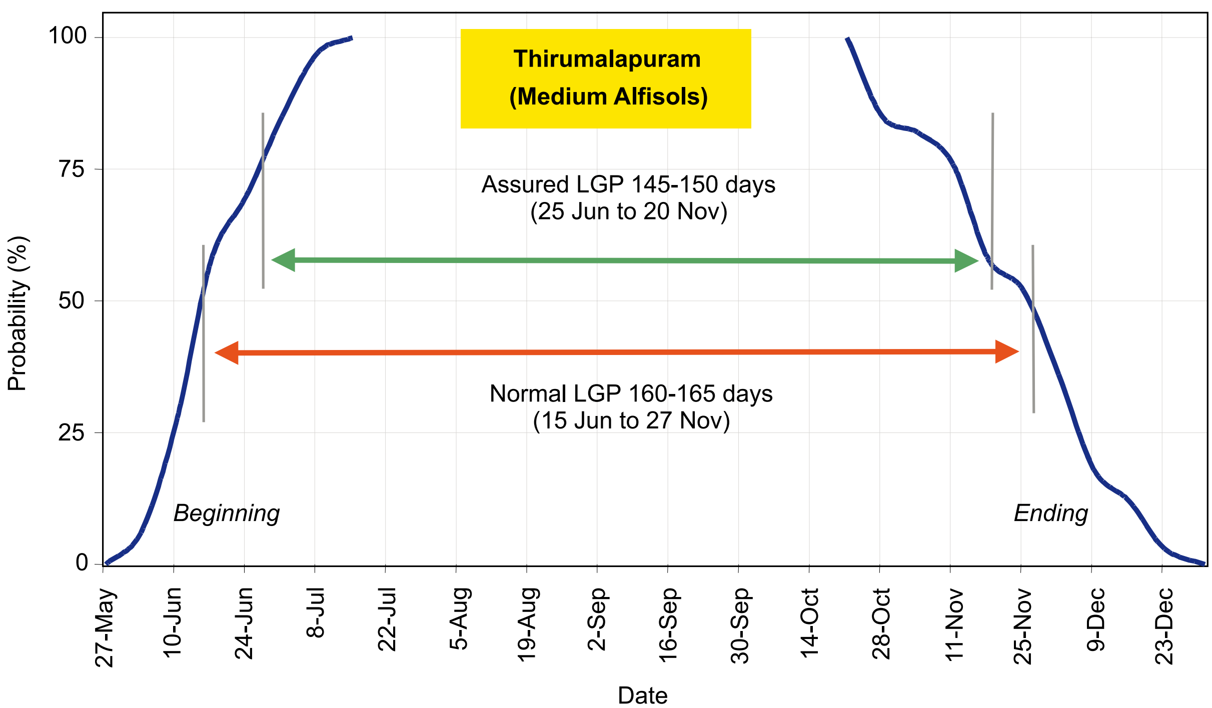
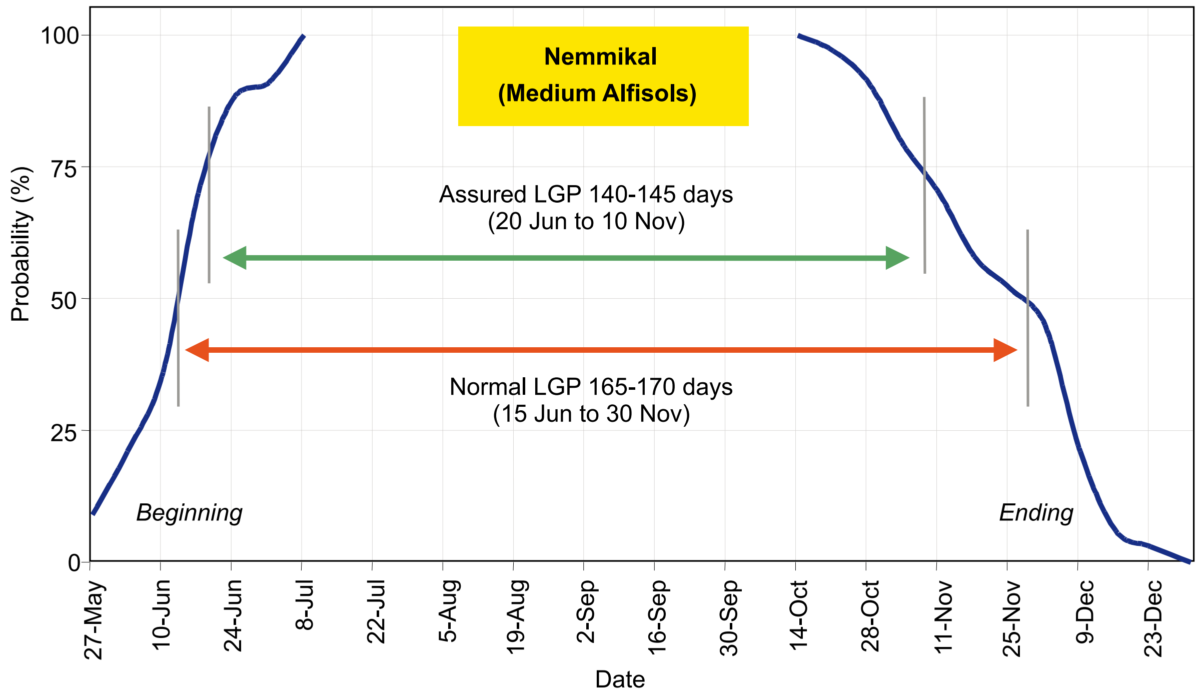


Figure 13. Rainfed crop-growing period characteristics of watersheds (continued...).



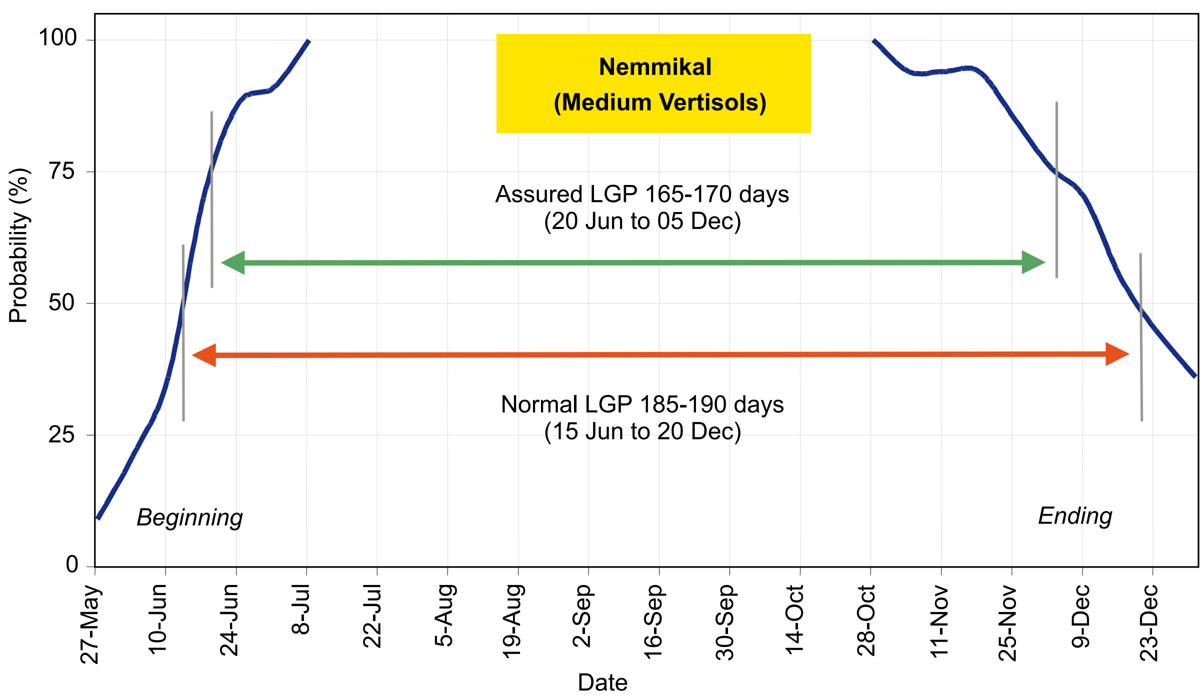
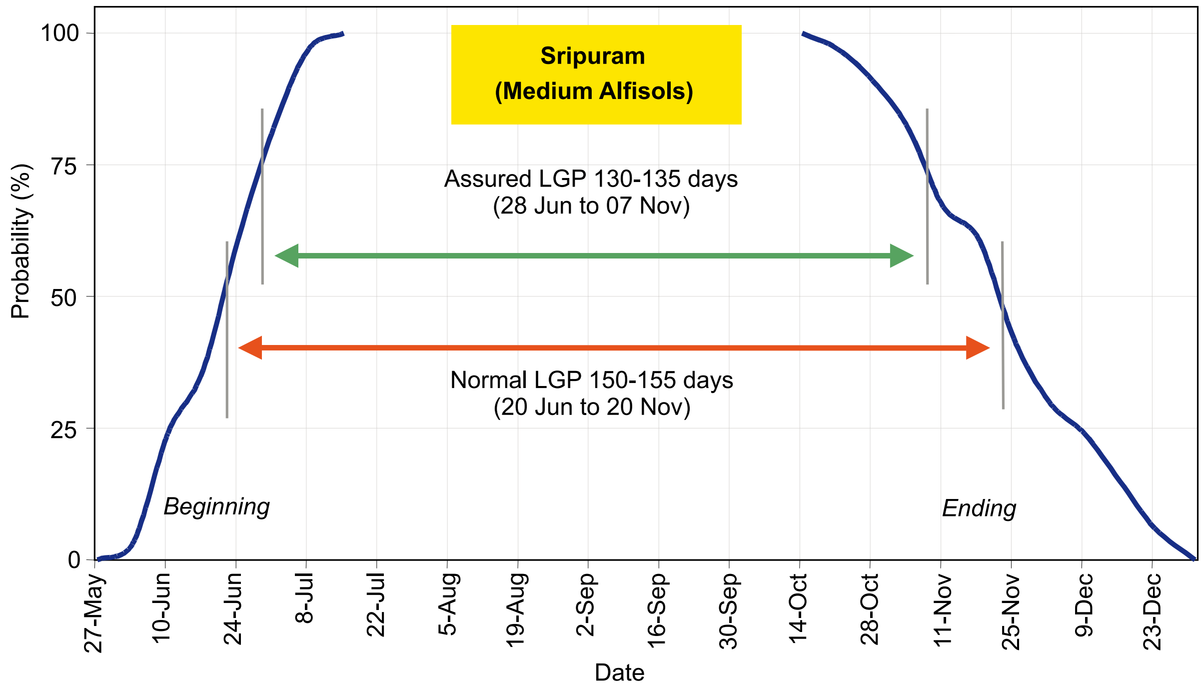


Figure 13. Rainfed crop-growing period characteristics of watersheds (continued...).



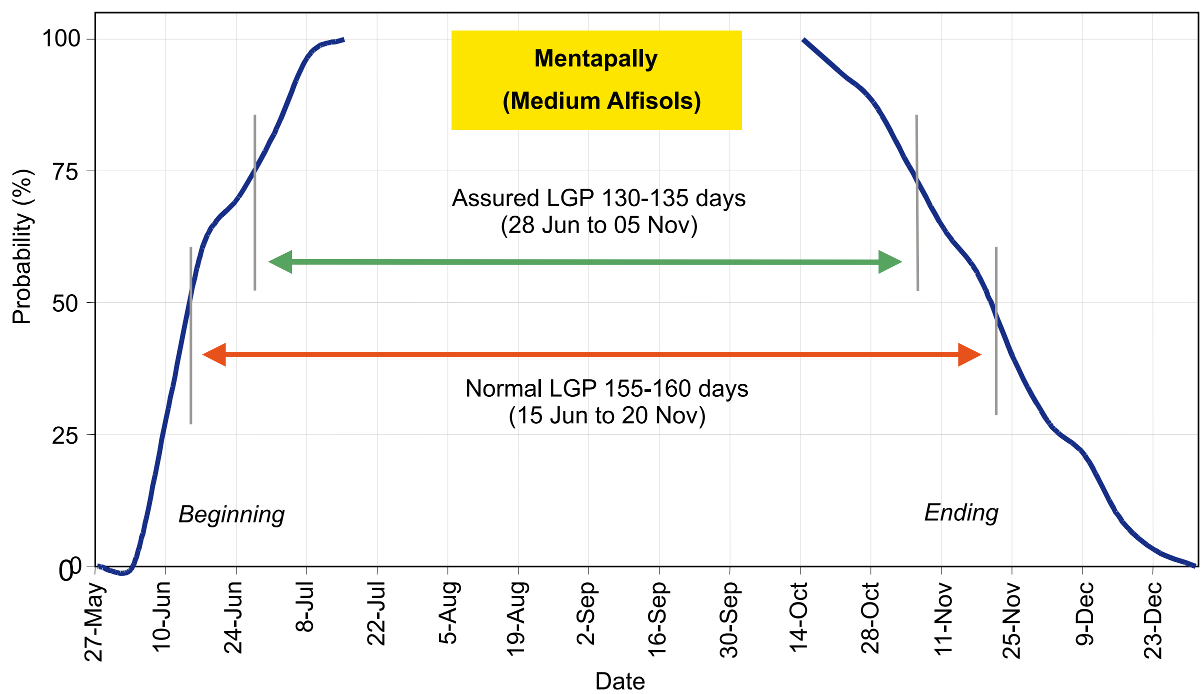
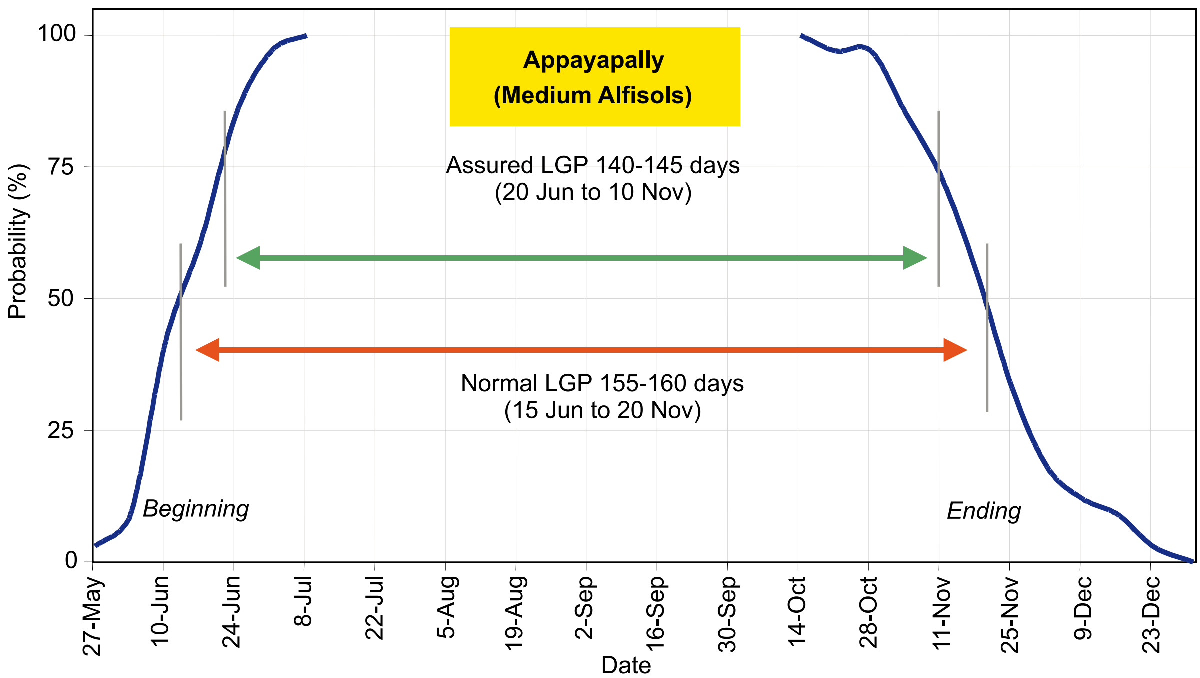


Figure 13. Rainfed crop-growing period characteristics of watersheds (continued...).



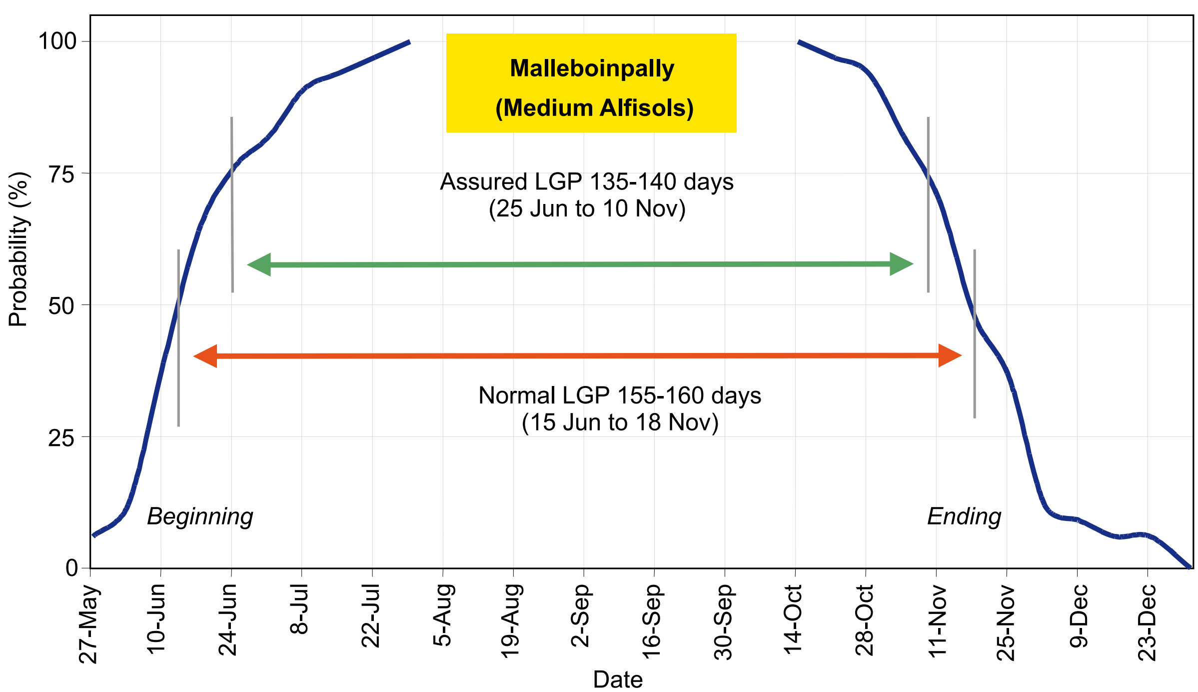
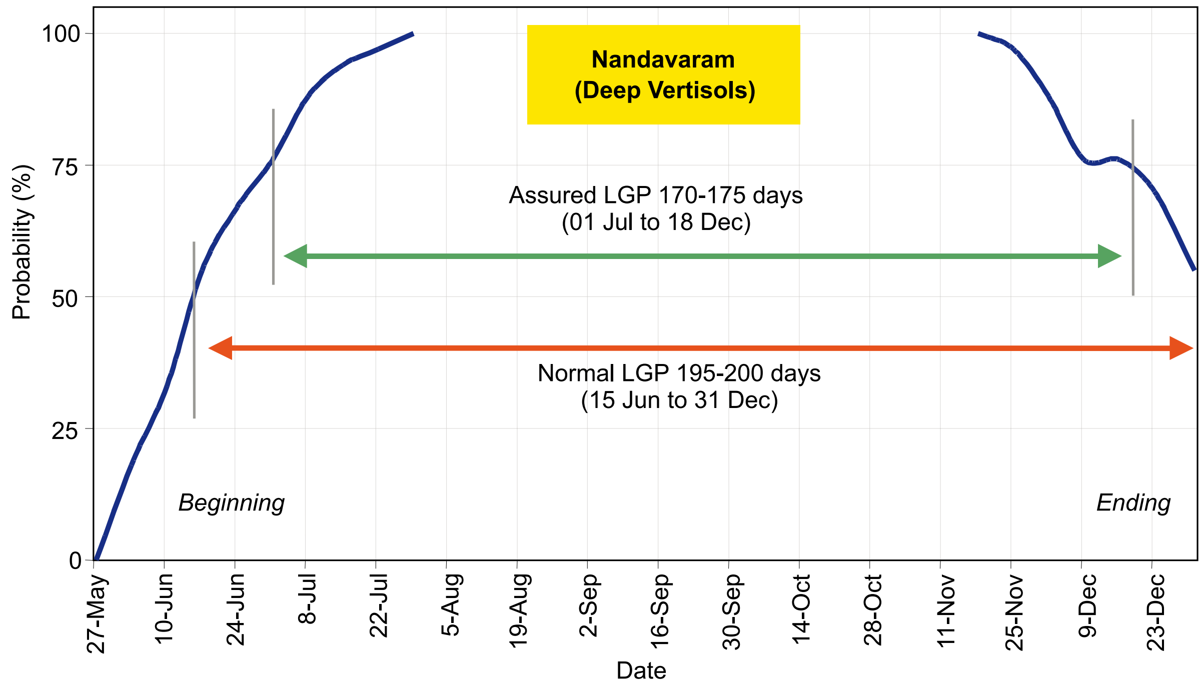


Figure 13. Rainfed crop-growing period characteristics of watersheds (continued...).



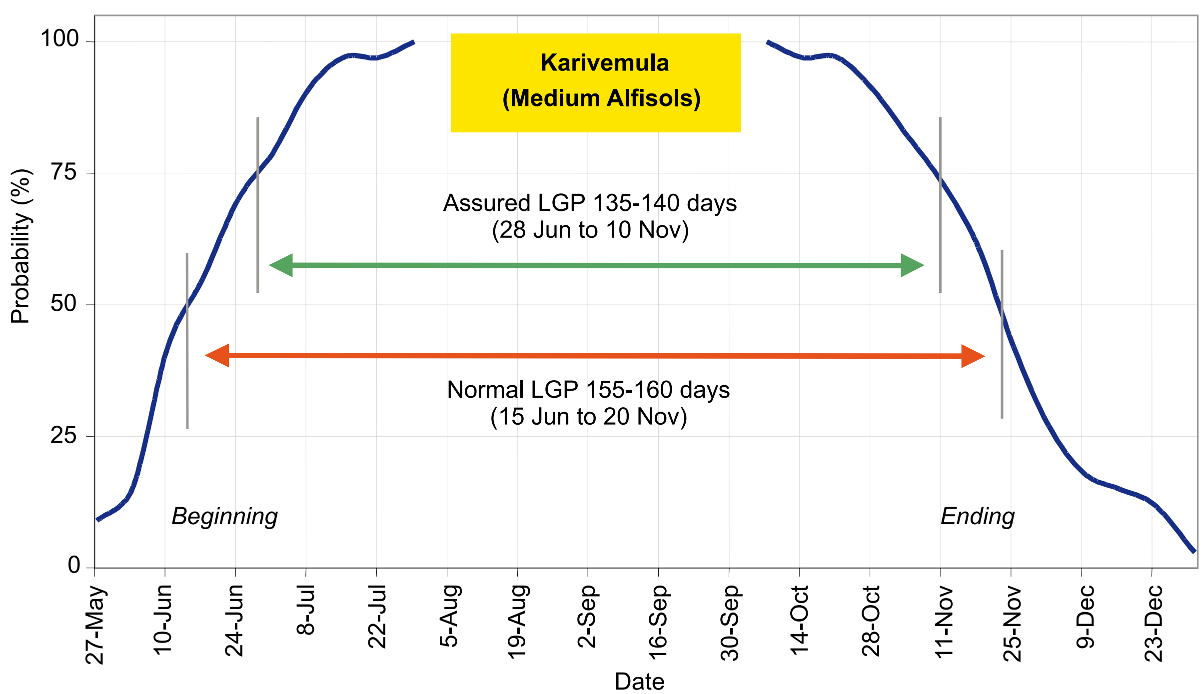


Figure 13. Rainfed crop-growing period characteristics of watersheds.

was assumed to have occurred when the cumulative probability started to cross above 75% value. This means that in three out of four years, the growing season could start by this date. Similarly, the date on which the cumulative probability fell below 75% was considered an assured date for ending of season. A probability value of 50% was considered for identifying the normal dates for the beginning and end of the growing season.

The normal beginning of the season is 15 June at all the locations, except at Sripuram at which the season begins on 20 June. Assured beginning of the season varies from 20 June to 01 July. Kacharam and Nandavaram experience most delayed assured beginning of the season. Variability in the beginning of the season is more at Malleboinpally, Nandavaram and Karivemula compared to other locations as indicated by the Standard Deviation. In general, the season ends by the last week of November for all the locations with medium-deep Alfisols. Nemmikal with medium-deep Vertisols and Nandavaram with deep Vertisols extended crop-growing season up to the last week of December.

Variability in the LGP

A study on the variability in the length of the growing period (Table 11) shows that normally the LGP varies from 150 to 200 days across the watershed locations in all the three districts of AP. Locations with medium-deep and deep Vertisols experience longer duration of 185 to 200 days, while other locations with medium-deep Alfisols have a normal growing season of 150 to 170 days. Assured rainfed crop-growing season is about 165 to 175 days for the Vertisols areas and about 130 to 150 days for the Alfisols areas. Karivemula experienced the shortest growing period of only 100 days in the year 1980. Nemmikal (Vertisols) and Nandavaram have never experienced a growing period of less than 145 days indicating a dependable moisture regime for crops at these locations. All the locations show longest duration of 180 days or more, with Nemmikal (Vertisols) at the top with 225 days (more than seven months). Karivemula has the dubious distinction of having both the shortest (100 days) as well as a very long duration of 210 days indicating extreme variability in the length of the growing period, leading to high risks associated with rainfed agriculture.

Dry and wet spells

High variability in the distribution of rainfall in the crop-growing period results in dry and wet spells of varying durations. Dry and wet spells during the crop-growing season have been defined based on the Index of Moisture Adequacy (IMA). When the rainfall and the soil moisture contribution put together cannot satisfy even 25% of the crop requirement, the period is termed as 'very dry'. If the IMA is between 76 and 99%, crops in general do not suffer from water stress. Some of the 'wet' weeks are with heavy rainfall leading to accumulation of runoff for water harvesting and also soil erosion. The classification of the spells proposed is as follows:

Type of spell	IMA (%)
Very Dry	0 to 25
Dry	26 to 50
Semi-moist	51 to 75
Moist	76 to 99
Wet	100

Based on the above classification, dry and wet spells at the watershed locations for 33 years were delineated using the Geographical Information Systems (GIS) technique (Avenue script in Arcview).

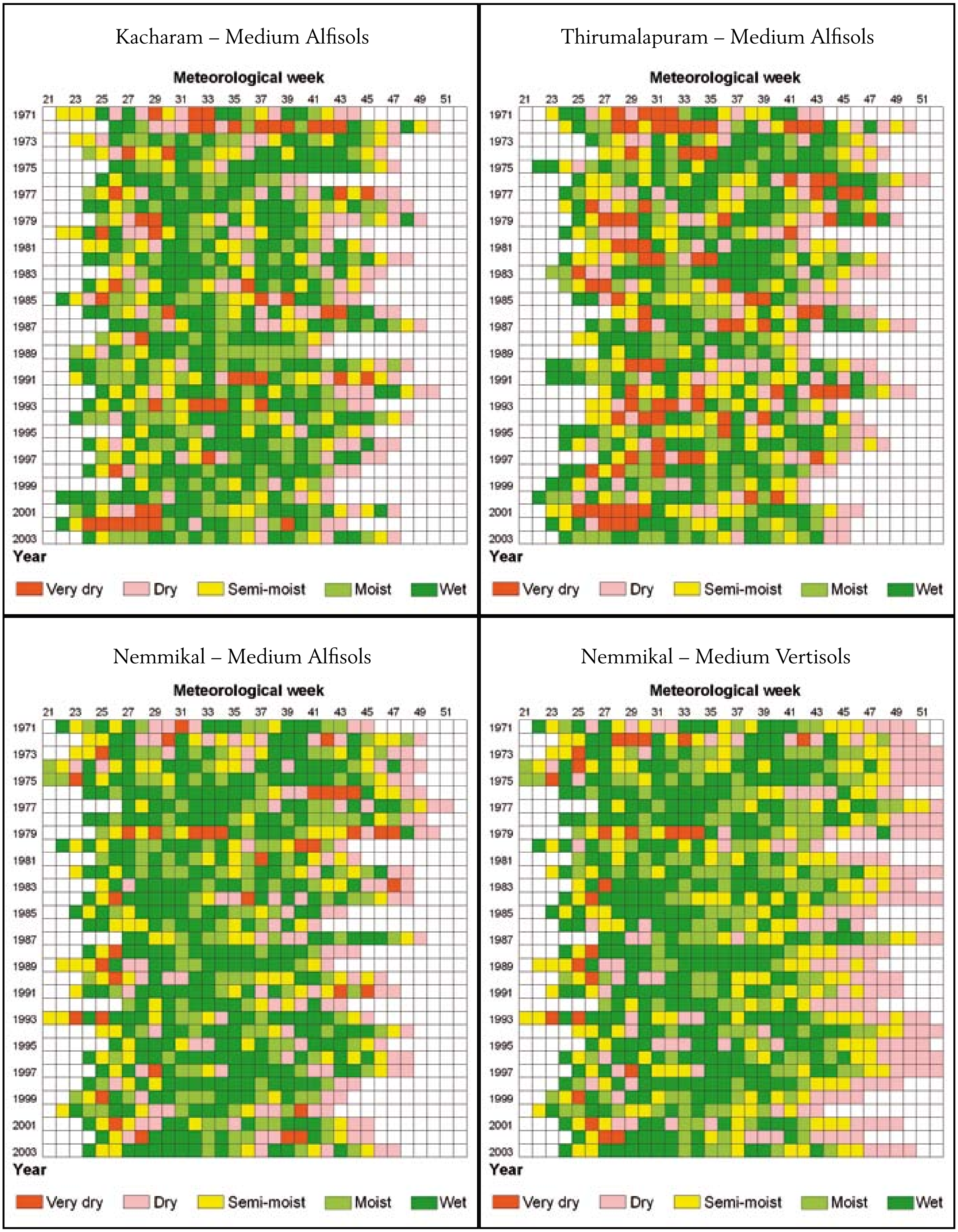


Figure 14. LGP, dry and wet spells at watershed locations.

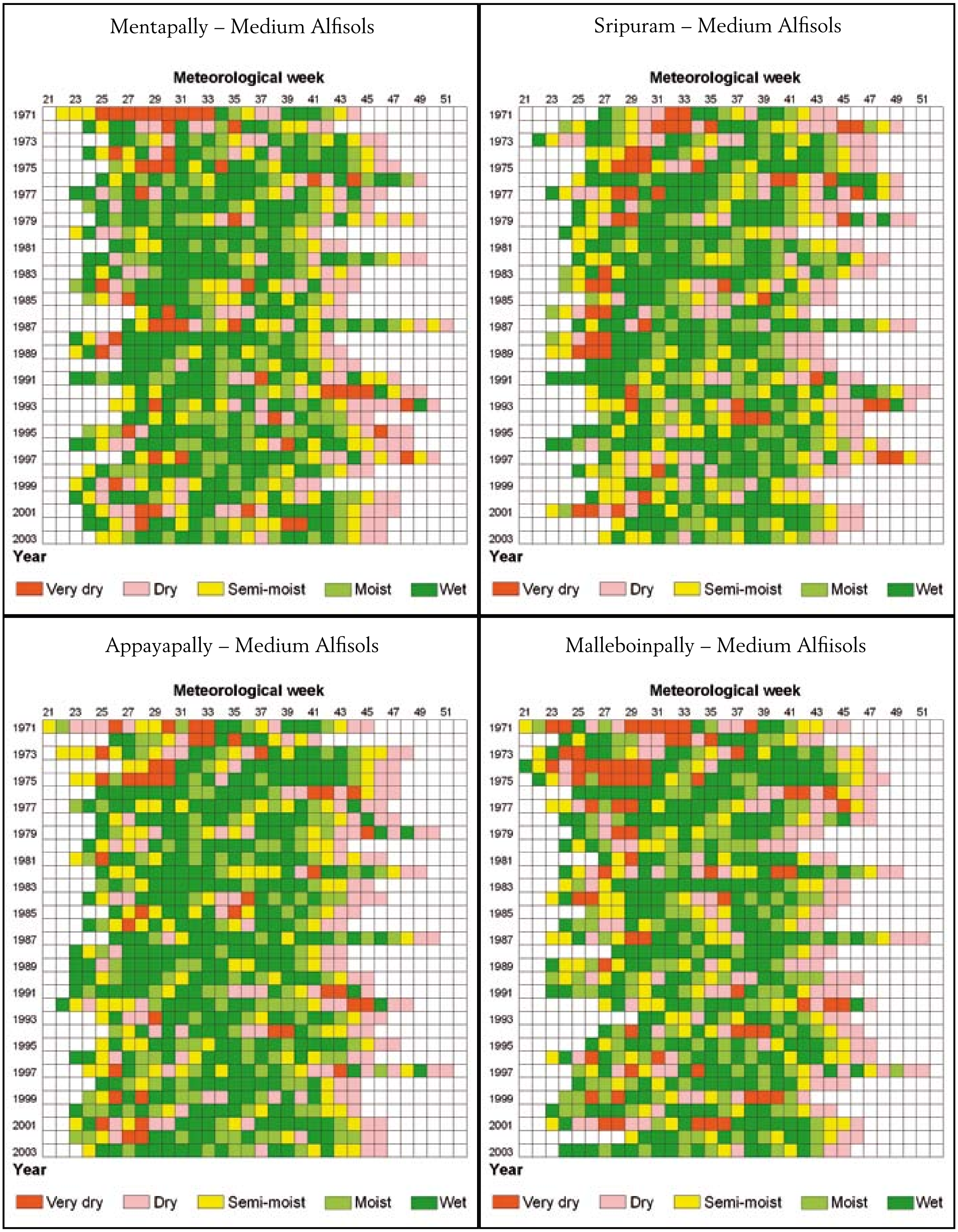


Figure 15. LGP, dry and wet spells at watershed locations.

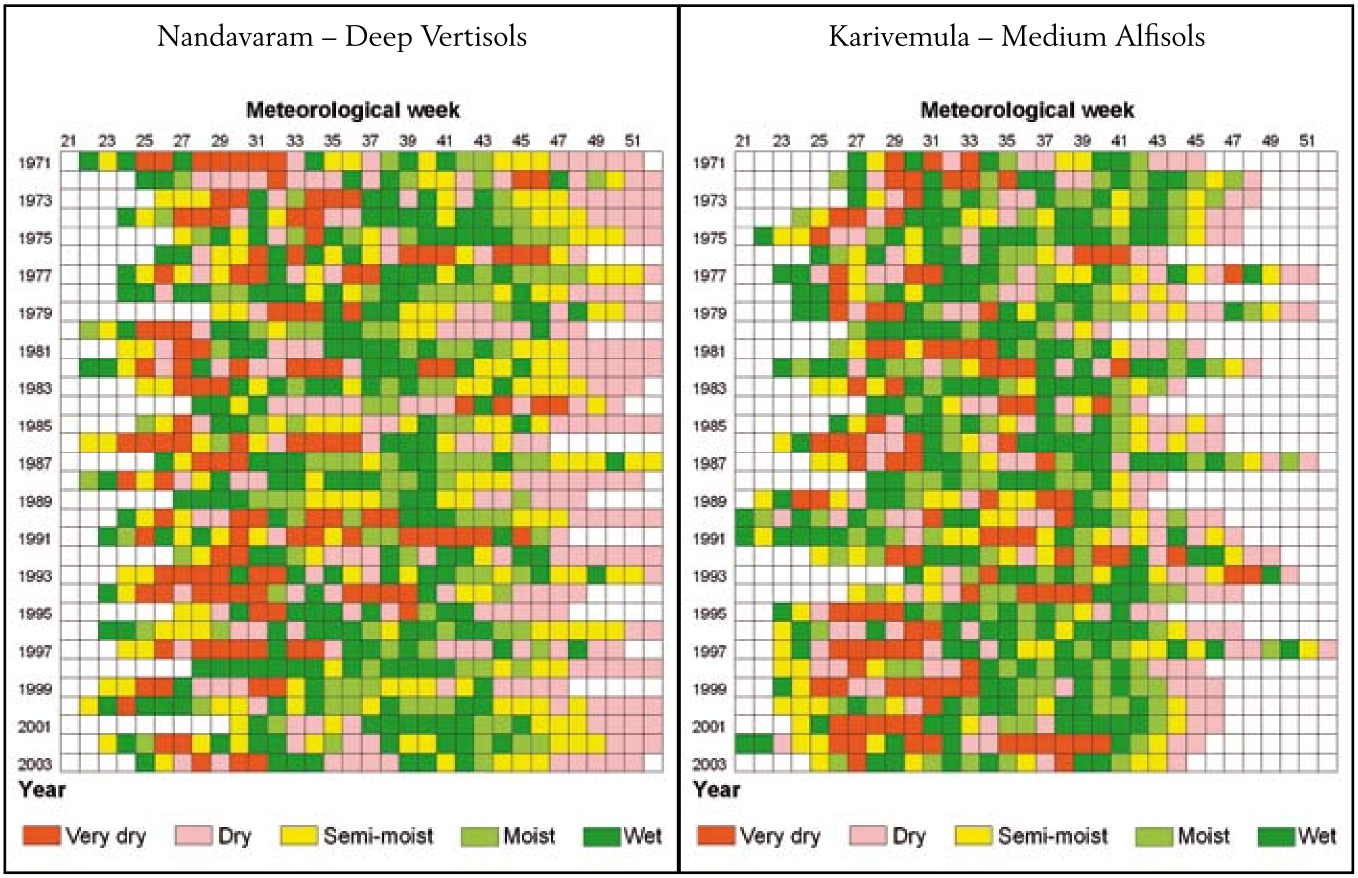
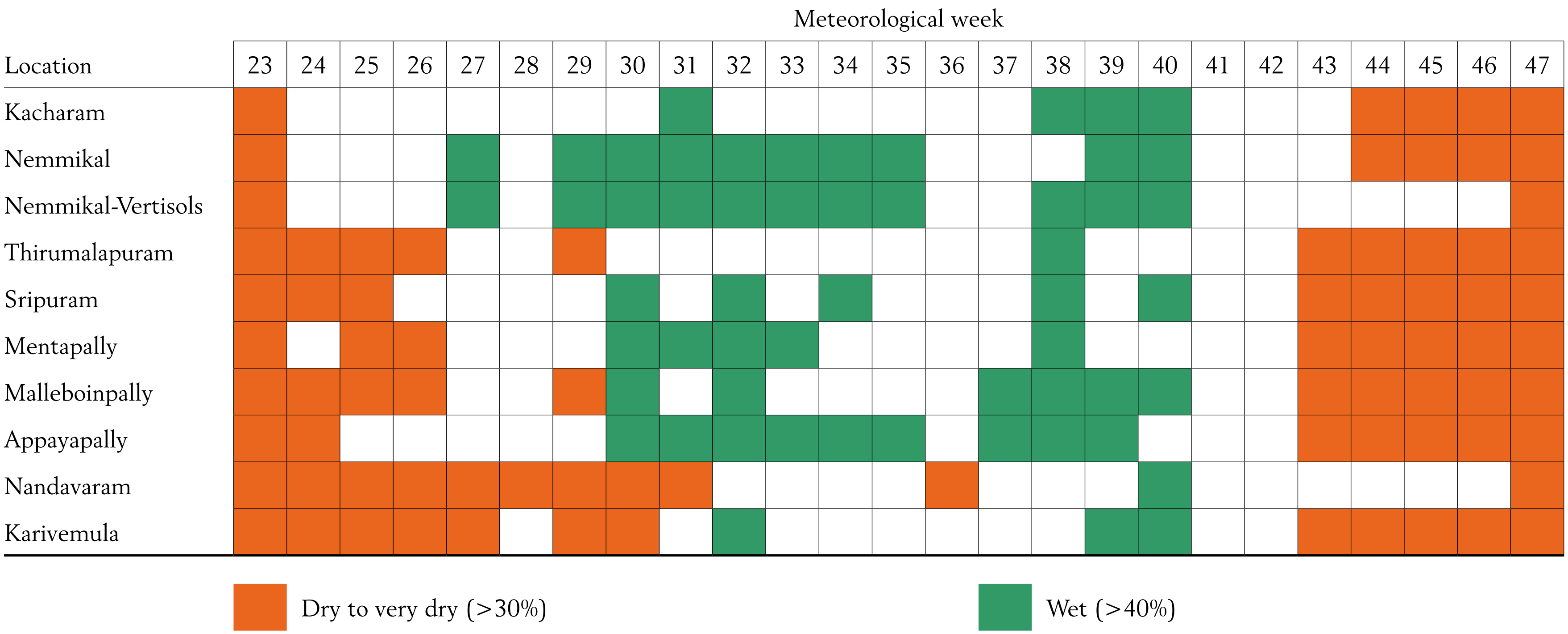


Figure 16. LGP, dry and wet spells at watershed locations.

Figures 14, 15 and 16 show the year-to-year variation of the LGP as well as the dry and wet spells in the rainfed crop-growing season at the watershed locations. At Kacharam, the crop-growing season starts as early as the last week of May or as late as the 2nd week of July and generally ends by the middle of November. There is variation in both the beginning and ending of the season. However, the end is more variable compared to the beginning. There is no definite relationship between the beginning and length of growing season. Droughts (more than two consecutive weeks with very dry conditions) occur at various stages of crop growth. Late-season droughts appear to decrease at Kacharam. At Nemmikal (medium-deep Vertisols) and Nandavaram (deep Vertisols), the growing season is extended up to December. At Nandavaram, the season extended beyond 31 December 1987. This kind of analysis and presentation using new science tools of GIS help the selection of best time for sowing and choosing suitable crops, varieties and cropping systems matching to the moisture regime of that location.

Normal date of onset of southwest monsoon over the target districts is 4 to 6 June and the crop-growing period terminates by the end of November. Probability of occurrence of dry and wet spells in the crop-growing period starting from the 23rd meteorological week (4 Jun) to 47th meteorological week (25 Nov) on a weekly basis was computed and shown in the Table 12. A week having more than 30% chances of being dry to very dry is shown in orange and having more than 40% chance of being wet is shown in green. Table 12 shows that in the beginning of the season, Kacharam, Nemmikal and Appayapally have relatively less dry spell occurrences while it is for a longer period at Thirumalapuram, Sripuram, Mentapally and Malleboinpally. Nandavaram and Karivemula in Kurnool district have greater risk of dry spells until the last week of July. Crop water requirements are fully

Table 12. Percent probability of occurrence of dry and wet spells at watershed locations.



satisfied for a period of 9 to 11 weeks at Nemmikal and Appayapally and at Kacharam for four weeks. Such periods are shorter for other locations. Probability of occurrence of dry spells increases from the last week of October.

Suitable crops and cropping systems for the watersheds

The soil water balance, LGP and its variability determine suitability of crops and cropping systems at a selected location. Considerable variability has been observed in these parameters for the selected nucleus watersheds. Out of all the watersheds, Nemmikal (medium-deep Vertisol) and Nandavaram (deep Vertisol) watersheds provide greater opportunity for double cropping as the average LGP at these sites ranges from 185 to 200 days, which could get extended to 215 to 225 days in good rainfall years. Appayapally, Thirumalapuram and parts of Nemmikal watersheds have medium-deep Alfisols, where the mean LGP ranges from 155 to 170 days and could be extended to 190 to 205 days in some years. These watershed sites provide opportunity for double cropping with relatively short duration crops, but are more suitable for intercropping with medium-duration crops such as pigeonpea and castor. Other watersheds, viz, Kacharam, Mentapally, Sripuram, Malleboinpally and Karivemula have medium-deep Alfisols which provide greater potential for sole cropping during rainy season with crops 120 to 130 days duration and intercropping with short to medium-duration crops to make better use of soil water availability. Early season drought occurs at Karivemula and Thirumalapuram and early and mid-season droughts occur at Nandavaram. These sites would require crop varieties tolerant to early or mid-season droughts depending upon the location.

Mentapally, Malleboinpally, Nemmikal and Appayapally have greater chance for water surpluses during the rainy season, thus offer opportunity for water harvesting and supplemental irrigation to mitigate droughts or an extended growing season.

Conclusions

- Agroclimatic analysis of the APRLP-ICRISAT nucleus watersheds in the three target districts – Nalgonda, Mahabubnagar and Kurnool – indicated great variation in the monsoon rainfall.
- Among the watersheds, Malleboinpally has the most stable climate, as in 85% of the total years it was in its normal semi-arid climate. Nandavaram, Devanakonda/Karivemula shifted 45% of the study period towards arid type of climate. At Nemmikal, there appears to be a slight trend towards dryness in the past 25 years, after 1978, and though the climate was never of the dry sub-humid type it has slowly tilting towards an arid type of climate.
- Many locations recorded water surplus even in dry years. Between the wet and dry years, variation in the water surplus is much higher compared to the water deficit.
- Assured rainfed crop-growing season is about 165 to 175 days for the Vertisols area and about 130 to 150 days for the Alfisols area.
- The beginning and ending of the crop-growing season varied across the years. The end has more variable compared to the beginning. There has been no definite relationship between the beginning and length of growing season.
- Nemmikal (medium-deep Vertisol) and Nandavaram (deep Vertisol) watersheds provide greater opportunity for double cropping.

- Appayapally, Thirumalapuram and parts of Nemmikal watersheds with medium-deep Alfisols, provide opportunity for double cropping with relatively short duration crops, but are more suitable for intercropping with medium-duration crops such as pigeonpea and castor.
- Kacharam, Mentapally, Sripuram, Malleboinpally and Karivemula have medium-deep Alfisols and provide greater potential for sole cropping during rainy season with crops of 120 to 130 days duration and intercropping with short to medium-duration crops to make better use of soil water availability.
- Early season drought occurs at Karivemula and Thirumalapuram and early and mid-season droughts occur at Nandavaram. These sites would require crop/varieties tolerant to early or mid-season droughts depending upon the location. Mentapally, Malleboinpally, Nemmikal and Appayapally have greater potential for water harvesting.
- The conclusions drawn for this study are based upon the analysis of water availability for the dominant soil type existing in the watersheds. Spatial variability in the soil and topography would alter the water balance of some pockets in the watersheds and may thus provide different opportunities to manage rainfall and potential for increasing crop productivity.

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Appendix

Initial and conditional probabilities of rainfall at Kacharam

Database: 33 years (1971–2003)

Week	> 10 mm			> 30 mm			> 50 mm		
	W	W/W	W/D	W	W/W	W/D	W	W/W	W/D
1	3	0	6	3	0	3	0	0	3
2	6	0	6	3	0	6	3	0	3
3	6	0	0	6	0	0	3	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	6	0	0	0	0	0	0
6	6	0	6	0	0	3	0	0	3
7	6	50	3	3	0	0	3	0	0
8	6	0	0	0	0	0	0	0	0
9	0	0	6	0	0	3	0	0	3
10	6	0	3	3	0	0	3	0	0
11	3	100	9	0	0	3	0	0	3
12	12	25	7	3	0	6	3	0	3
13	9	33	10	6	0	3	3	0	0
14	12	0	14	3	0	0	0	0	0
15	12	0	10	0	0	6	0	0	0
16	9	0	13	6	0	3	0	0	0
17	12	0	17	3	0	6	0	0	0
18	15	40	4	6	0	6	0	0	3
19	9	33	20	6	50	10	3	0	0
20	21	14	15	12	0	7	0	0	6
21	15	20	32	6	0	13	6	0	10
22	30	60	52	12	25	21	9	33	7
23	55	78	67	21	43	54	9	67	30
24	73	42	67	52	18	31	33	18	14
25	48	44	53	24	0	40	15	0	21
26	48	81	71	30	40	30	18	33	22
27	76	76	38	33	18	23	24	25	16
28	67	68	36	21	0	42	18	0	30
29	58	68	71	33	73	32	24	38	20
30	70	74	80	45	47	56	24	12	32
31	76	64	88	52	47	44	27	33	33
32	70	70	50	45	47	50	33	45	27
33	64	52	58	48	19	29	33	0	23
34	55	56	53	24	50	28	15	20	14
35	55	50	47	33	36	18	15	60	11
36	48	50	59	24	50	36	18	33	26
37	55	78	67	39	54	45	27	22	29
38	73	67	67	48	50	41	27	11	25
39	67	68	64	45	40	39	21	14	35
40	67	50	45	39	31	25	30	20	26
41	48	31	24	27	33	8	24	25	8
42	27	44	33	15	60	25	12	75	14
43	36	50	24	30	50	17	21	14	12
44	33	27	18	27	22	12	12	0	0
45	21	29	19	15	0	7	0	0	6
46	21	14	8	6	0	0	6	0	0
47	9	0	7	0	0	3	0	0	0
48	6	0	0	3	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0
51	0	0	3	0	0	0	0	0	0
52	3	0	3	0	0	3	0	0	0

Initial and conditional probabilities of rainfall at Nemmikal

Database: 33 years (1971–2003)

Week	> 10 mm			> 30 mm			> 50 mm		
	W	W/W	W/D	W	W/W	W/D	W	W/W	W/D
1	6	0	3	0	0	0	0	0	0
2	3	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	6	0	0	3	0	0	3
6	6	0	0	3	0	0	3	0	0
7	0	0	3	0	0	0	0	0	0
8	3	0	3	0	0	3	0	0	3
9	3	0	3	3	0	0	3	0	0
10	3	0	3	0	0	0	0	0	0
11	3	100	0	0	0	3	0	0	3
12	3	0	0	3	0	0	3	0	0
13	0	0	3	0	0	3	0	0	0
14	3	0	12	3	0	3	0	0	3
15	12	0	7	3	0	0	3	0	0
16	6	0	6	0	0	3	0	0	0
17	6	0	19	3	0	0	0	0	0
18	18	33	7	0	0	3	0	0	3
19	12	50	21	3	0	6	3	0	6
20	24	12	20	6	0	13	6	0	3
21	18	50	19	12	75	7	3	0	6
22	24	50	36	15	0	18	6	0	6
23	39	69	75	15	0	57	6	0	45
24	73	42	78	48	31	35	42	7	16
25	52	59	62	33	9	50	12	0	24
26	61	75	85	36	58	57	21	29	23
27	79	62	71	58	37	50	24	12	24
28	64	71	75	42	71	37	21	57	27
29	73	71	67	52	59	56	33	27	32
30	70	78	80	58	37	50	30	30	35
31	79	77	57	42	43	58	33	36	36
32	73	83	44	52	53	44	36	50	33
33	73	75	56	48	56	53	39	23	30
34	70	70	50	55	61	33	27	22	33
35	64	57	58	48	44	18	30	20	9
36	58	47	71	30	20	30	12	0	17
37	58	63	64	27	67	29	15	20	21
38	64	81	67	39	62	40	21	14	35
39	76	52	62	48	56	41	30	40	35
40	55	56	33	48	50	29	36	25	19
41	45	40	39	39	38	5	21	57	4
42	39	38	35	18	33	19	15	20	14
43	36	42	24	21	29	19	15	20	14
44	30	30	26	21	14	12	15	0	0
45	27	22	12	12	0	7	0	0	6
46	15	20	11	6	50	3	6	50	0
47	12	25	3	6	0	3	3	0	0
48	6	0	0	3	0	0	0	0	0
49	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0
51	0	0	6	0	0	0	0	0	0
52	3	0	3	0	0	3	0	0	0

Initial and conditional probabilities of rainfall at Thirumalapuram

Database: 33 years (1971–2003)

Week	> 10 mm			> 30 mm			> 50 mm		
	W	W/W	W/D	W	W/W	W/D	W	W/W	W/D
1	0	0	3	0	0	0	0	0	0
2	3	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	6	0	0	3	0	0	0
6	6	0	0	3	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	3	0	0	3	0	0	3
10	3	0	3	3	0	0	3	0	0
11	3	0	6	0	0	6	0	0	0
12	6	0	0	6	0	0	0	0	0
13	0	0	6	0	0	0	0	0	0
14	6	0	0	0	0	0	0	0	0
15	0	0	6	0	0	0	0	0	0
16	6	50	3	0	0	3	0	0	3
17	6	50	6	3	100	0	3	100	0
18	9	33	20	3	0	16	3	0	6
19	21	86	12	15	60	0	6	100	0
20	27	22	4	9	0	3	6	0	0
21	9	0	23	3	0	12	0	0	9
22	21	57	42	12	50	24	9	33	10
23	45	53	61	27	44	33	12	50	24
24	58	42	43	36	33	29	27	11	12
25	42	50	47	30	30	13	12	25	10
26	48	69	71	18	0	19	12	0	3
27	70	61	50	15	20	21	3	0	12
28	58	58	36	21	43	12	12	25	14
29	48	69	53	18	50	22	15	60	14
30	61	55	54	27	22	42	21	14	31
31	55	56	53	36	25	29	27	22	17
32	55	67	47	27	56	21	18	33	22
33	58	63	36	30	50	30	24	50	20
34	52	59	50	36	17	19	27	0	8
35	55	44	53	18	50	26	6	50	16
36	48	75	53	30	50	35	18	17	19
37	64	81	75	39	62	40	18	67	30
38	79	81	57	48	44	41	36	50	24
39	76	48	62	42	50	37	33	55	23
40	52	35	38	42	21	26	33	18	23
41	36	42	29	24	38	20	21	14	8
42	33	45	14	24	25	16	9	33	10
43	24	38	36	18	17	22	12	0	14
44	36	25	24	21	0	12	12	0	10
45	24	38	8	9	33	10	9	33	7
46	15	40	11	12	25	3	9	0	0
47	15	20	4	6	0	0	0	0	0
48	6	0	3	0	0	3	0	0	0
49	3	0	3	3	0	0	0	0	0
50	3	0	0	0	0	0	0	0	0
51	0	0	3	0	0	3	0	0	0
52	3	0	0	3	0	0	0	0	0

Initial and conditional probabilities of rainfall at Mentapally

Database: 33 years (1971–2003)

Week	> 10 mm			> 30 mm			> 50 mm		
	W	W/W	W/D	W	W/W	W/D	W	W/W	W/D
1	0	0	3	0	0	0	0	0	0
2	3	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	3	0	0	0	0	0	0
6	3	0	6	0	0	3	0	0	0
7	6	50	0	3	100	0	0	0	0
8	3	100	0	3	0	0	0	0	0
9	3	0	6	0	0	3	0	0	0
10	6	0	3	3	0	3	0	0	3
11	3	100	6	3	0	0	3	0	0
12	9	0	3	0	0	0	0	0	0
13	3	0	9	0	0	6	0	0	3
14	9	0	17	6	0	3	3	0	3
15	15	60	7	3	0	3	3	0	0
16	15	0	21	3	0	6	0	0	3
17	18	0	7	6	0	3	3	0	3
18	6	0	16	3	0	9	3	0	9
19	15	40	18	9	67	10	9	33	0
20	21	14	15	15	0	7	3	0	3
21	15	20	25	6	0	3	3	0	0
22	24	38	48	3	0	19	0	0	12
23	45	67	67	18	67	33	12	50	14
24	67	45	27	39	15	20	18	0	19
25	39	46	35	18	0	26	15	0	11
26	39	69	75	21	71	31	9	67	13
27	73	88	44	39	46	40	18	17	19
28	76	68	25	42	50	42	18	33	26
29	58	84	43	45	53	44	27	33	33
30	67	64	73	48	50	53	33	18	23
31	67	86	73	52	59	44	21	43	23
32	82	81	50	52	59	25	27	33	17
33	76	68	75	42	36	26	21	14	35
34	70	52	30	30	50	35	30	30	30
35	45	60	50	39	38	35	30	20	17
36	55	50	53	36	33	33	18	50	19
37	52	76	56	33	45	41	24	25	32
38	67	55	55	42	43	37	30	50	17
39	55	50	53	39	46	40	27	33	38
40	52	47	44	42	29	26	36	17	14
41	45	47	22	27	44	21	15	40	18
42	33	73	18	27	22	12	21	14	8
43	36	25	19	15	0	14	9	0	7
44	21	0	8	12	0	3	6	0	0
45	6	50	16	3	0	9	0	0	3
46	18	33	4	9	33	0	3	0	0
47	9	67	3	3	0	3	0	0	0
48	9	0	3	3	0	0	0	0	0
49	3	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0
51	0	0	3	0	0	0	0	0	0
52	3	0	0	0	0	0	0	0	0

Initial and conditional probabilities of rainfall at Sripuram

Database: 33 years (1971–2003)

Week	> 10 mm			> 30 mm			> 50 mm		
	W	W/W	W/D	W	W/W	W/D	W	W/W	W/D
1	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	3	0	0	0	0	0	0
6	3	0	0	0	0	0	0	0	0
7	0	0	6	0	0	3	0	0	0
8	6	0	0	3	0	0	0	0	0
9	0	0	6	0	0	0	0	0	0
10	6	0	3	0	0	3	0	0	0
11	3	0	3	3	0	0	0	0	0
12	3	100	0	0	0	3	0	0	0
13	3	0	6	3	0	3	0	0	3
14	6	50	13	3	100	6	3	100	0
15	15	0	11	9	0	3	3	0	3
16	9	33	17	3	0	12	3	0	3
17	18	0	7	12	0	3	3	0	0
18	6	50	16	3	0	9	0	0	6
19	18	50	11	9	67	3	6	50	0
20	18	17	19	9	0	13	3	0	0
21	18	0	19	12	0	7	0	0	3
22	15	40	43	6	0	19	3	0	12
23	42	71	26	18	33	11	12	50	0
24	45	47	56	15	20	21	6	0	13
25	52	53	50	21	29	31	12	0	21
26	52	59	56	30	70	22	18	67	15
27	58	79	79	36	50	43	24	38	12
28	79	62	14	45	47	22	18	33	15
29	52	71	50	33	55	32	18	50	26
30	61	65	62	39	54	40	30	20	30
31	64	76	58	45	40	50	27	11	25
32	70	65	50	45	67	22	21	29	27
33	61	60	46	42	57	42	27	22	21
34	55	67	40	48	31	35	21	14	23
35	55	56	60	33	45	27	21	14	15
36	58	58	57	33	18	36	15	0	32
37	58	84	57	30	70	39	27	44	29
38	73	58	67	48	38	41	33	18	32
39	61	55	54	39	46	45	27	33	29
40	55	39	33	45	27	28	30	10	22
41	36	50	29	27	56	8	18	33	11
42	36	33	19	21	14	15	15	20	7
43	24	0	24	15	0	11	9	0	3
44	18	33	7	9	0	0	3	0	0
45	12	50	10	0	0	12	0	0	3
46	15	40	7	12	25	0	3	0	0
47	12	50	3	3	0	0	0	0	0
48	9	0	3	0	0	3	0	0	0
49	3	0	3	3	0	0	0	0	0
50	3	0	0	0	0	0	0	0	0
51	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0

Initial and conditional probabilities of rainfall at Appayapally

Database: 33 years (1971–2003)

Week	> 10 mm			> 30 mm			> 50 mm		
	W	W/W	W/D	W	W/W	W/D	W	W/W	W/D
1	0	0	3	0	0	0	0	0	0
2	3	0	3	0	0	0	0	0	0
3	3	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	6	0	0	0	0	0	0
6	6	50	0	0	0	0	0	0	0
7	3	0	3	0	0	3	0	0	0
8	3	0	0	3	0	0	0	0	0
9	0	0	12	0	0	0	0	0	0
10	12	25	3	0	0	6	0	0	0
11	6	0	3	6	0	0	0	0	0
12	3	0	6	0	0	3	0	0	0
13	6	0	10	3	0	3	0	0	0
14	9	33	10	3	0	0	0	0	0
15	12	25	0	0	0	0	0	0	0
16	3	0	16	0	0	3	0	0	0
17	15	0	18	3	0	6	0	0	0
18	15	20	25	6	0	16	0	0	6
19	24	62	24	15	40	0	6	50	0
20	33	36	9	6	0	3	3	0	3
21	18	17	30	3	0	9	3	0	3
22	27	56	62	9	0	30	3	0	19
23	61	70	46	27	44	21	18	17	11
24	61	45	85	27	11	33	12	0	14
25	61	75	69	27	44	38	12	0	24
26	73	67	78	39	54	30	21	43	19
27	70	57	70	39	46	30	24	38	20
28	61	65	69	36	67	29	24	50	24
29	67	82	36	42	71	42	30	60	17
30	67	77	73	55	61	47	30	50	30
31	76	80	88	55	44	47	36	33	38
32	82	74	50	45	73	39	36	33	29
33	70	57	60	55	39	47	30	40	22
34	58	68	50	42	50	37	27	11	17
35	61	60	46	42	29	21	15	20	11
36	55	44	67	24	38	48	12	25	41
37	55	72	73	45	53	33	39	31	30
38	73	67	56	42	50	47	30	40	35
39	64	52	67	48	44	41	36	33	29
40	58	58	36	42	57	26	30	20	26
41	48	44	29	39	46	5	24	25	4
42	36	42	14	21	43	4	9	0	10
43	24	0	20	12	0	7	9	0	3
44	15	0	11	6	0	3	3	0	0
45	9	33	17	3	0	9	0	0	0
46	18	0	0	9	0	0	0	0	0
47	0	0	9	0	0	3	0	0	0
48	9	33	3	3	0	0	0	0	0
49	6	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0
51	0	0	3	0	0	0	0	0	0

Initial and conditional probabilities of rainfall at Malleboinpally

Database: 33 years (1971–2003)

Week	> 10 mm			> 30 mm			> 50 mm		
	W	W/W	W/D	W	W/W	W/D	W	W/W	W/D
1	0	0	3	0	0	0	0	0	0
2	3	0	0	0	0	0	0	0	0
3	0	0	3	0	0	0	0	0	0
4	3	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	12	0	0	0	0	0	0
10	12	25	0	0	0	0	0	0	0
11	3	0	0	0	0	0	0	0	0
12	0	0	6	0	0	3	0	0	0
13	6	0	6	3	0	3	0	0	0
14	6	50	16	3	0	3	0	0	0
15	18	0	4	3	0	0	0	0	0
16	3	0	16	0	0	6	0	0	3
17	15	20	7	6	0	0	3	0	0
18	9	67	23	0	0	9	0	0	6
19	27	44	12	9	33	0	6	50	0
20	21	43	19	3	0	12	3	0	3
21	24	25	28	12	0	10	3	0	3
22	27	67	50	9	0	20	3	0	6
23	55	61	53	18	17	33	6	50	13
24	58	68	50	30	20	30	15	0	21
25	61	80	38	27	22	25	18	0	15
26	64	67	50	24	38	20	12	50	14
27	61	65	38	24	25	24	18	33	15
28	55	72	27	24	38	28	18	33	22
29	52	82	50	30	70	35	24	38	24
30	67	73	55	45	53	33	27	22	17
31	67	77	73	42	50	42	18	17	37
32	76	64	62	45	47	22	33	36	14
33	64	52	50	33	27	41	21	43	23
34	52	59	44	36	17	38	27	0	29
35	52	65	31	30	30	17	21	14	8
36	48	69	53	21	57	31	9	33	37
37	61	75	62	36	75	48	36	50	38
38	70	65	50	58	53	43	42	36	16
39	61	70	62	48	50	47	24	12	32
40	67	50	45	48	31	29	27	11	25
41	48	38	35	30	60	13	21	57	4
42	36	50	14	27	33	8	15	40	4
43	27	11	12	15	0	7	9	0	3
44	12	25	7	6	0	0	3	0	0
45	9	33	20	0	0	9	0	0	3
46	21	14	0	9	0	0	3	0	0
47	3	0	3	0	0	0	0	0	0
48	3	0	6	0	0	0	0	0	0
49	6	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0
51	0	0	3	0	0	3	0	0	0
52	3	0	0	3	0	0	0	0	0

Initial and conditional probabilities of rainfall at Nandavaram

Database: 33 years (1971–2003)

Week	> 10 mm			> 30 mm			> 50 mm		
	W	W/W	W/D	W	W/W	W/D	W	W/W	W/D
1	0	0	3	0	0	0	0	0	0
2	3	0	0	0	0	0	0	0	0
3	0	0	3	0	0	0	0	0	0
4	3	0	0	0	0	0	0	0	0
5	0	0	3	0	0	3	0	0	0
6	3	0	0	3	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	6	0	0	6	0	0	3
10	6	0	6	6	0	0	3	0	0
11	6	0	0	0	0	0	0	0	0
12	0	0	3	0	0	0	0	0	0
13	3	0	9	0	0	3	0	0	3
14	9	33	3	3	0	0	3	0	0
15	6	50	13	0	0	6	0	0	3
16	15	20	18	6	0	3	3	0	0
17	18	0	26	3	0	9	0	0	3
18	21	29	38	9	0	10	3	0	6
19	36	50	24	9	0	27	6	0	6
20	33	45	14	24	12	0	6	0	0
21	24	0	64	3	0	19	0	0	3
22	48	38	41	18	33	15	3	0	12
23	39	54	55	18	33	30	12	25	14
24	55	33	60	30	20	13	15	0	7
25	45	60	17	15	40	11	6	100	3
26	36	58	43	15	40	14	9	33	13
27	48	56	35	18	33	15	15	20	4
28	45	80	28	18	50	19	6	50	16
29	52	59	25	24	50	16	18	33	11
30	42	64	37	24	25	36	15	0	21
31	48	56	53	33	45	36	18	33	19
32	55	50	53	39	38	10	21	29	0
33	52	41	31	21	43	27	6	0	19
34	36	50	48	30	30	30	18	17	19
35	48	50	29	30	40	17	18	33	15
36	39	38	65	24	38	28	18	33	19
37	55	72	60	30	60	39	21	43	31
38	67	68	55	45	40	39	33	18	27
39	64	81	42	39	54	40	24	50	28
40	67	32	45	45	27	22	33	27	18
41	36	50	29	24	50	28	21	29	27
42	36	50	29	33	36	18	27	22	8
43	36	25	38	24	12	16	12	25	7
44	33	27	27	15	0	7	9	0	3
45	27	22	25	6	50	6	3	0	0
46	24	0	8	9	0	3	0	0	3
47	6	0	10	3	0	3	3	0	3
48	9	0	10	3	0	3	3	0	3
49	9	0	7	3	0	3	3	0	0
50	6	0	0	3	0	0	0	0	0
51	0	0	6	0	0	0	0	0	0
52	6	0	0	0	0	0	0	0	0

Initial and conditional probabilities of rainfall at Devanakonda/Karivemula

Database: 33 years (1971-2003)

Week	> 10 mm			> 30 mm			> 50 mm		
	W	W/W	W/D	W	W/W	W/D	W	W/W	W/D
1	0	0	3	0	0	0	0	0	0
2	3	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0
5	0	0	3	0	0	0	0	0	0
6	3	0	3	0	0	0	0	0	0
7	3	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0
9	0	0	3	0	0	3	0	0	3
10	3	0	3	3	0	0	3	0	0
11	3	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0
13	0	0	9	0	0	0	0	0	0
14	9	33	3	0	0	0	0	0	0
15	6	50	10	0	0	6	0	0	0
16	12	25	28	6	0	6	0	0	0
17	27	0	8	6	0	3	0	0	3
18	6	100	26	3	0	3	3	0	3
19	30	50	17	3	0	16	3	0	6
20	27	22	21	15	20	14	6	0	10
21	21	57	23	15	20	7	9	0	0
22	30	20	57	9	0	27	0	0	12
23	45	60	39	24	25	28	12	25	14
24	48	50	35	27	33	12	15	0	4
25	42	50	26	18	33	7	3	0	6
26	36	50	52	12	0	17	6	0	10
27	52	71	50	15	0	32	9	0	20
28	61	55	23	27	56	12	18	33	4
29	42	36	47	24	12	28	9	0	23
30	42	64	63	24	38	44	21	29	15
31	67	59	82	42	36	53	18	0	33
32	67	59	36	45	33	11	27	22	17
33	52	35	62	21	14	38	18	17	22
34	48	62	35	33	36	27	21	14	19
35	48	81	18	30	40	13	18	17	4
36	48	62	59	21	43	35	6	0	19
37	61	55	54	36	25	43	18	17	26
38	55	83	67	36	58	33	24	38	20
39	76	60	50	42	21	53	24	12	36
40	58	42	43	39	31	25	30	10	22
41	42	57	32	27	22	25	18	0	19
42	42	43	37	24	50	8	15	20	4
43	39	31	35	18	33	11	6	0	6
44	33	0	9	15	0	7	6	0	0
45	6	50	10	6	50	3	0	0	6
46	12	25	10	6	0	3	6	0	3
47	12	0	3	3	0	3	3	0	3
48	3	0	6	3	0	0	3	0	0
49	6	50	6	0	0	3	0	0	3
50	9	0	0	3	0	0	3	0	0
51	0	0	3	0	0	0	0	0	0
52	3	0	0	0	0	0	0	0	0

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The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political organization that does innovative agricultural research and capacity building for sustainable development with a wide array of partners across the globe. ICRISAT's mission is to help empower 600 million poor people to overcome hunger, poverty and a degraded environment in the dry tropics through better agriculture. ICRISAT belongs to the Alliance of Centers of the Consultative Group on International Agricultural Research (CGIAR).

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591-2006