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Agroclimatic assessment of watersheds for crop planning and water harvesting

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ABSTRACT

Agroclimatic analysis of two nucleus-watersheds viz., Malleboinpally (Alfisols) in Jadcherla *mandal* of Mahabubnagar district and Nandavaram (Vertisols) in Banaganapalle *mandal* of Kurnool district, Andhra Pradesh (India) was carried out using agromet data for the period 1971-2006 Water balance analysis indicated moderate water surplus at Malleboinpally (179 mm) and at Nandavaram it is low at 40 mm. Both watersheds have similar water deficits of 1050-1100 mm per year. Runoff analyses indicated that about 0 3 to 0.5 million m^3 water is available for storage during normal years at the watershed area of 500 ha. In the wet years, Malleboinpally has a potential of about 1.25 million m^3. Nandavaram has the lowest potential even in wet years. Though both the locations have Semi-Arid type of climate, there is a tendency for the climate to temporarily shift towards drier side. Malleboinpally has the most stable climate (Semi-Arid) climate. In contrast, Nandavaram showed higher tendency towards arid type of climate.

Nandavaram provides greater opportunity for double cropping as the LGP here ranges from 120 to 195 days. Malleboinpally has LGP ranging from 100 to 160 days and provides greater potential for sole cropping during rainy season and intercropping with short to medium-duration crops. Early and mid-season droughts occur at Nandavaram and this watershed would require crop / varieties tolerant to early or mid-season droughts depending upon the location. Malleboinpally has greater potential for water harvesting and offers opportunity for supplemental irrigation. These results help in arriving at efficient and sustainable management of natural resources and thereby sustaining rural livelihoods at watershed level.

Key words : Water shed, water balance, runoff, LGP, water harvesting.

With the ever-increasing need for food, fodder and energy, with growing water scarcity for food production, maximizingthe agricultural production from rainfed areas in a sustainable manner has become the most important aspect of agricultural research. 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 and water release characteristics. Low crop yields in a semi-arid tropical agro-ecosystem are explained and manifested by on-farm blue water losses in terms of both surface runoff, limiting infiltration to the root zone, and percolation to groundwater, and on nonproductive vapor flow (evaporation), reducing the productive vapor flow component (Rockström *et al* 2007). Better understanding of the climatic conditions will help in devising suitable management practices for developing watersheds to conserve, harvest and efficient use of rainwater for increasing agricultural production. In rainfed areas, rainwater management at watershed / catchment scale is used as an entry point for increasing agricultural productivity (Wani *et al*, 2003).

Mahabubnagar and Kurnool are among the most drought-prone districts of Andhra Pradesh and are characterized by low and highly erratic rainfall. Land degradation, improper soil and water management practices, lack of improved crop cultivars, pest and diseases are the major problems experienced by rural communities to meet minimum health and nutrition standards, resulting in a vicious circle of rural poverty. The Andhra Pradesh Rural Livelihood Program (APRLP) adopted 'watershed' as a logical unit for efficient and sustainable management of natural

resources to reduce poverty thereby sustaining rural livelihoods. In this study, agroclimatic analysis of the two nucleus-watersheds viz., Malleboinpally in Jadcherla *mandal* of Mahabubnagar district and Nandavaram in Banaganapalle *mandal* of Kurnool district was carried out.

MATERIAL AND METHODS

Data

Daily rainfall data of the two *mandals* for the period 1971-2006 (36 years) was obtained from the Directorate of Economics and Statistics, Govt. of AP. Daily / weekly weather data on maximum / minimum temperatures, relative humidity (both morning and afternoon), wind speed and sunshine hours for two stations viz., Palem and Nandyal (Both units of Acharya NG Ranga Agricultural University, Hyderabad) were collected for estimating potential evapotranspiration. Soil information published by NBSS & LUP (2000) was used. Agroclimatic characterization of the watersheds was carried out following standard methods.

General description of the target watersheds

The two watersheds separated at 160 km represent 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 these areas. Malleboinpally watershed is located at 16.75°N latitude and 78.10°E longitude with predominantly Alfisols and Nandavaram watershed at 15.37°N latitude and 78.27°E longitude with Vertisols.

Both the watersheds have similar temperature conditions with Nandavaram being relatively hotter in summer. Winds are strong during southwest monsoon period; with speeds up to 18 km h^{-1} are experienced. The area receives 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.

Potential evapotranspiration (PET)

Consistent performance of the Penman-Monteith approach in both arid and humid climates has been indicated in both the ASCE and European studies (Allen *et al* 1998). 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

Field surveys by ICRISAT indicated that Malleboinpally has predominantly medium-deep Alfisols while Nandavaram has mostly Vertisols. The plant-available water profiles for Vertisols and Alfisols at the ICRISAT farm were earlier worked out (ICRISAT, 1978). 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 and 200 mm for 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. 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 and Wani *et al.*, 2004).

RESULTS AND DISCUSSION

Rainfall climatology of watersheds

Results of climatological analysis of seasonal rainfall of the watersheds are presented in Table 1. June to September is considered as southwest monsoon (SW) period and October to December as post-monsoon period.

Both the watersheds receive similar annual rainfall with different seasonal distribution. In the post-

Table 1: Seasonal rainfall characteristics of the watersheds

Parameter	Watershed location	Southwest monsoon	Post-monsoon	Annual
Rainfall (mm)	Malleboinpally	519	116	689
	Nandavaram	419	155	648
Standard Deviation (mm)	Malleboinpally	159	95	162
	Nandavaram	141	101	168
Coefficient of Variation (%)	Malleboinpally	31	82	24
	Nandavaram	34	65	26

Table 2: Extreme rainfall characteristics of the watersheds

Watershed location	Southwest monsoon (mm		Post-monsoon (mm)	
	Highest	Lowest	Highest	Lowest
Malleboinpally	864 (1978)*	225 (1994)	395 (1987)	0 (2004)
Nandavaram	730 (1978)	143 (1994)	440 (1975)	0 (2004)

*Figures in the parenthesis indicate year of occurrence

Table 3: Variation of seasonal rainfall at watersheds

Season	Watershed location	Number of years in rainfall category			
		Excess	Normal	Deficit	Scanty
SW Monsoon	Malleboinpally	10	16	10	0
	Nandavaram	10	12	13	1
Post-Monsoon	Malleboinpally	14	3	9	10
	Nandavaram	10	13	4	9

ionsoon period, Nandavaram receives almost 24% of s annual rainfall while Malleboinpally receives only 6%. Contribution of SW monsoon rainfall to the nual is about 75% at Malleboinpally and 65% at andavaram. Standard deviation and coefficient of iriation indicate considerable year-to-year variability rainfall, which is high in the post-monsoon period mpared to that of the SW monsoon period.

Based on the rainfall data of 36 years, extremes seasonal rainfall were identified (Table 2). There ists a great variation in the rainfall extremes across e watersheds and periods. During the SW monsoon riod, rainfall can vary from 143 to 864 mm. During e post-monsoon period, the variation is high (Zero to 0 mm).

As per the method of India Meteorological partment (IMD), seasonal variability of rainfall was essed based on the rainfall deviation from the normal ble 3). Years were classified into four categories as cess (>20%), Normal (19 to –19%), Deficit (-20 to 9%) and Scanty (less than –59%).

Table 3 shows that during the SW monsoon period, rainfall was generally in either normal or deficit category. In the post-monsoon period, Malleboinpally received normal rainfall in only 3 out of 36 years indicating extreme rainfall variability in this period.

Rainy days

IMD has defined a rainy day as a day that receives at least 2.5 mm of rainfall. Daily rainfall data were classified into four categories (Table 4) receiving rainfall of more than 2.5, 10, 25 and 50 mm per day. Average annual number of rainy days (> 2.5 mm) varied from 25 to 65.Classes with 25 and 50 mm are 10 and 20 times the normal rainy day conditions, which can indicate to some extent the runoff and water harvesting potential of the watershed.

In the 25 and 50 mm per day categories, both watersheds have similar values. More than 70% of the rainy days in the year occur during the four-month period July-October.

Table 4: Average annual number of days with different rainfall intensities

Threshold rainfall per day	Watershed location	No. of days with threshold rainfall		
		Lowest	Average	Highest
≥ 2 5 mm	Malleboinpally	31	39	65
	Nandavaram	25	36	52
≥ 10 mm	Malleboinpally	10	22	39
	Nandavaram	11	20	29
≥ 25 mm	Malleboinpally	2	7	15
	Nandavaram	2	7	14
≥ 50 mm	Malleboinpally	0	1	6
	Nandavaram	0	1	6

Table 5: Initial and conditional probabilities of rainfall exceeding 30 mm per week

Week	Malleboinpally		Nandavaram		Week	Malleboinpally		Nandavaram	
	P(W)	P(W/W)	P(W)	P(W/W)		P(W)	P(W/W)	P(W)	P(W/W)
25	27	22	15	40	34	36	17	30	30
26	24	38	15	40	35	30	30	30	40
27	24	25	18	33	36	21	57	24	38
28	24	38	18	50	37	36	75	30	60
29	30	70	24	50	38	58	53	45	40
30	45	53	24	25	39	48	50	39	54
31	42	50	33	45	40	48	31	45	27
32	45	47	39	38	41	30	60	24	50
33	33	27	21	43	42	27	33	33	36

Table 6: Climatic variability (moisture regime) at watershed locations

Watershed location	Normal climatic type	Percentage of years under	
		Semi-Arid	Arid
Malleboinpally	Semi-Arid	83	17
Nandavaram	Semi-Arid	58	42

Rainfall probabilities

Agricultural operations are determined by the receipt of certain amount of rainfall at each stage of operation. 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 weekly probability P(W) and conditional probability (next week to be a wet week given the condition that the current week is wet) P(W/W) of receiving at least 30 mm of rainfall per week at the watersheds were computed following Virmani *et al* (1982).

At Malleboinpally, initial probabilities of receiving a rainfall of more than 30 mm per week are moderate throughout the period during 29-41 weeks (July 3rd week to middle of October), indicating the possibility of a little moisture stress during the crop-growing period, particularly during the last week of August (Table 5). Conditional probability indicates that there is high probability of more than 70% to receive 30 mm of rainfall in 29th and 37th weeks, provided the 28th and 36th weeks are wet with a rainfall of above 30 mm. At Nandavaram, chances of receiving more than 30 mm per week are around 30% indicating greater risk for rainfed crops. Conditional probability indicates better chances of getting two consecutive wet weeks during middle of September to middle of October. This kind of information will be of great practical use in planning agricultural management operations at the watersheds.

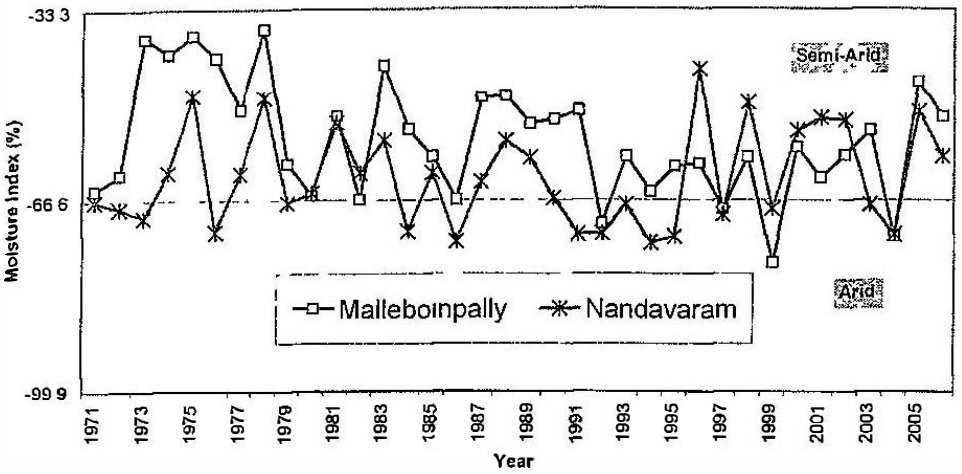

Fig. 1: Climatic variability at Malleboinpally and Nandavaram

Water balance of watersheds

Water surplus in the *Kharif* season cannot prevent the total water deficit in the *Rabi* except that the moisture that was stored in the soil may compensate for the deficit, to a certain 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. Average water surplus at Malleboinpally is about 179 mm and at Nandavaram it is about 40 mm. Water surplus in certain years can go up to 450 mm at Malleboinpally and 250 mm at Nandavaram. Both watersheds have similar water deficits of 1050-1100 mm per year.

As per the climatic classification of Thornthwaite and Mather (1955) with moisture index (Im) between –33.3 and –66.6, Malleboinpally and Nandavaram watersheds fall under Semi-Arid type of climate.

Climatic variability

Climate determines the suitability of crops, varieties and cropping systems to be grown at a location for achieving maximum yields. Changes in the onset and distribution of monsoon rains, lead to climatic variability on a local or regional level. Greatest threat to agricultural production is not the long-term climate change, but the short-term climate variability.

Occasional shifts in the annual water balance at a location may be of such magnitude that the climatic type of the location could be shifted by one or more category levels in the drier or wetter direction.

Though both the locations considered here normally experience Semi-Arid type of climate, a tendency for the climate to temporarily shift towards drier side is observed. Between the two watersheds, Malleboinpally has the most stable climate, as 83% of the total years it experienced normal Semi-Arid climate (Table 6). In contrast, Nandavaram has higher tendency towards arid type of climate with almost 42% of the time experiencing arid climate. Fig. 1 presents moisture changes indicative of the climatic variability during 1971-2006 at Malleboinpally and Nandavaram.

Though the tendency towards aridity is visible, critical examination reveals that this tendency has reversed from 1991 onwards and both the watersheds tend to become slightly wetter. However, the trends are not statistically significant. It may be noted that in the year 2007, both the watersheds had received 'excess' rainfall compared to their normal. These findings are of great importance in choosing crops and varieties that will be tolerant to this kind of climatic variability.

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 second crop season. Considering the local vegetation, slope and soil type, it is assumed that about 55% of the water surplus could

Table 7: Runoff water available for storage at watershed locations

Watershed location	Runoff water (in million m^3)		
	Wet year	Normal year	Dry year
Malleboinpally	1.25	0.45	Nil
Nandavaram	0.67	0.26	Nil

Table 8: Variability in the crop-growing period

Watershed location	Beginning of season		End of season		Length of growing period (days)			
	Normal	Assured	Normal	Assured	Shortest	Normal	Longest	Assured
Malleboinpally	15 Jun	25 Jun	20 Nov	10 Nov	100	160	195	140
Nandavaram	15 Jun	01 Jul	25 Dec	10 Dec	120	195	210	160

be harvested as runoff. Computed runoff water that could be harvested and stored for a typical watershed area of 500 ha shows that 0.3 to 0.5 million m^3 water is available for harvesting during normal years at the watersheds (Table 7). In the wet years, Malleboinpally has a potential of about 1.25 million m^3. Nandavaram relatively has a lower potential even in wet years. During dry years, both watershed locations have either negligible or no runoff.

Length of rainfed crop-growing period

The Length of Growing Period (LGP) is defined as the length of the rainy season, plus the period for which the soil moisture storage at the end of rainy season and the post-rainy season and winter rainfall together, can meet the crop water needs. It depends on water retention and release characteristics of the soil. Several methods were used for estimating the LGP using rainfall (Ashok Raj 1979, IMD 1991, Sivakumar *et al* 1993). The National Bureau of Soil Survey and Land Use Planning estimated LGP using the PET and rainfall.

Using water balance technique, week-wise index of moisture adequacy (IMA) was computed, and beginning and end of the growing season was identified based on this index. 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 worked out backwards starting from the end of December.

Beginning and end of the rainfed crop-growing season were delineated for each year from which, LGP was estimated. Results (Table 8) indicated that there is large year-to-year variation in the parameter. Based on long-term data, probability of beginning and end of the season was computed (Fig. 2 and 3). Assured beginning of the season was assumed to have occurred when the cumulative probability started to cross above 75% value. This means that in 3 out of 4 years, the growing season could start by this date. Similarly, the date on which the cumulative probability fell below 75% was considered as assured date of end of season. A probability value of 50% was considered for identifying the normal dates of beginning and end of the growing season.

It is seen that the normal beginning of the season is 15 June at both the locations. Assured beginning of this parameter varies from 25 June (Malleboinpally) to 01 July (Nandavaram). At both the locations, variability in the beginning of the season is higher compared to the ending. Season ends by the third week of November at Malleboinpally with medium-deep Alfisols. Nandavaram with Vertisols has extended crop-growing season up to the third week of December. Variability in the LGP showed that Malleboinpally experienced shortest growing period of only 100 days in the year 1999, while Nandavaram experienced its shortest growing period of 120 days in the years 1976 and 1995. Longest growing period of 195 days occurred in 1986 at Malleboinpally. Nandavaram has experienced 210 days of rainfed crop-growing period in three years i.e., 1971, 1996 and 2000.

Suitable crops and cropping systems for the watersheds

The soil water balance, LGP and its variability determine suitability of crops and cropping systems for a watershed. Nandavaram (Vertisol) provides greater opportunity for double cropping as the LGP ranges from 120 to 195 days, which could get extended to 210 days

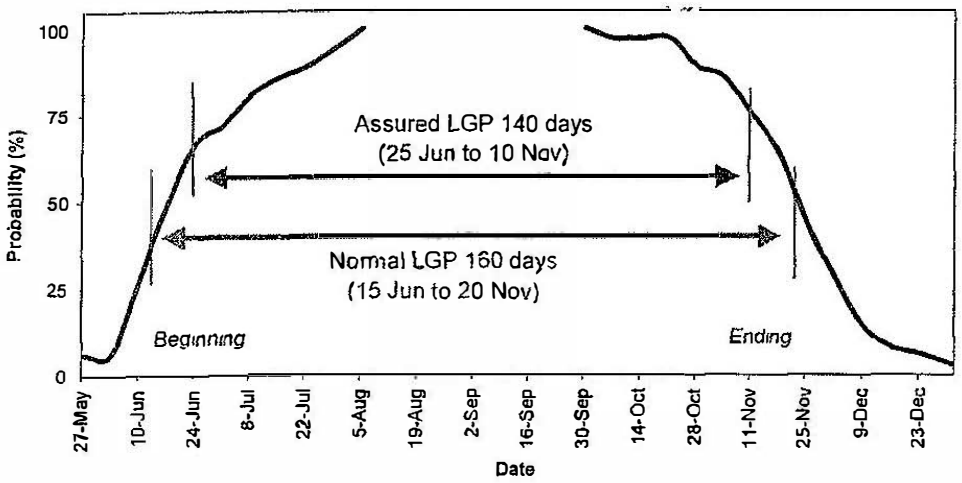

Fig. 2: Rainfed crop-growing period characteristics at Malleboinpally

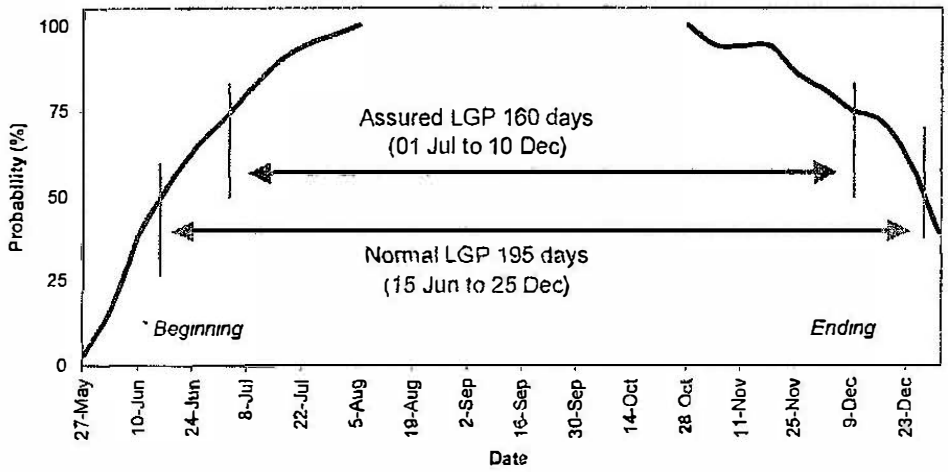

Fig. 3: Rainfed crop-growing period characteristics at Nandavaram

in good rainfall years. Malleboinpally with major soils being medium-deep Alfisols has the LGP ranging from 100 to 160 days and could be extended to 190 days in some years. This watershed provides 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 and mid-season droughts occur at Nandavaram and this watershed would require crop / varieties tolerant to early or mid-season droughts depending upon the location. Malleboinpally has greater potential for water harvesting and offers opportunity for supplemental irrigation to mitigate droughts or an extended crop-growing season.

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