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Spatial analysis of rainfall variability and rainfed rice crop using GIS Technique in West Bengal (India)

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सार – वर्षा वाले क्षेत्रों में औसत वार्षिक वर्षा की सीमा 500-1500 मि. मी. तक की अधिक भिन्नताओं के साथ होती है और ये ऋतु के मध्य में सूखे की समस्याओं से घिरे होते तथा फसल की उत्पादकता पर इसका प्रभाव पड़ता है। इस शोध पत्र में पश्चिम बंगाल के सभी स्टेशनों के जहां पर मुख्य रूप से कृषि वर्षा पर आधारित होती है, साप्ताहिक, मासिक, वार्षिक वर्षा और साप्ताहिक वर्षा संभावनाओं का विश्लेषण काल (LGP) तथा जल संतुलन प्राचलों का आकलन पश्चिम बंगाल के तीन जिलों के सभी प्रखण्डों के लिए किया गया है। खरीफ के दौरान औसत उत्पादकता दर्शाती है कि मध्य जिलों बर्दवान, बंकुरा, बीरभूमि, हुगली जिलों के प्रखण्डों में अधिकतम उत्पादकता का मान 3 से 3.5 टन प्रति हेक्टेयर पाया गया है। संभवत: इन जिलों में सिंचाई की सुविधा इतनी अधिक उत्पादकता की दर प्राप्त करने में मददगार है। दक्षिणी 24 परगना और जलपाईगुड़ी जिले के दो से फसल उत्पादकता के संदर्भ में किया गया है। यद्यपि शुष्क दौर की अवधि और उसकी संभाव्यताएं, जलवायविक व्युत्पत्तियां जैसे वर्षा ऋतु का आगमन एवं उसकी समाप्ति, विकास अवधि का तीन प्रखण्डों में 1 से 1.5 टन/हेक्टेयर की उत्पादकता कम देखी गई है। जलपाईगुड़ी, कूचबिहार, पश्चिमी दीनाजपुर जैसे उत्तरी जिलों की अपेक्षा दक्षिणी 24 परगना में उत्पादकता का स्तर 1.5 से 2.0 टन/ हैक्टेयर के दर से घटता-बढ़ता रहता है। वर्ष 1996 में जून के महीने में और पुन: अगस्त के महीने में भारी वर्षा होने के कारण न्यूनतम उत्पादन जलधा में 11.28 क्विंटल/हेक्टेयर तथा मानबाजार में 14.89 क्विंटल/हेक्टेयर हुआ था। इस शेध पत्र में चिन्हित जिलों में खरीफ में चावल की फसल की औसत उत्पादकता का फसल के विकास के भिन्न-भिन्न चरणों में शुष्क दौरे की संख्या का औसत MAI मानों के साथ विश्लेषण किया गया है। उत्पादकता का संबंध जुलाई माह के मासिक वर्षा से भी है और इनके सहसंबंधों को जलधा प्रखण्ड (0.22) तथ मानबाजार प्रखण्ड (0.64) के लिए उदधृत किया गया है। पश्चिम बंगाल के उष्ण अल्पार्द्र से आर्द्र क्षेत्रों में अधिकतम उत्पादन 2 से 3 टन प्रति हेक्टेयर रिकॉर्ड किया गया है जहां पर विकास अवधि के काल में (LGP) 150 से 200 दिनों की भिन्नता रहती है। फसल की भिन्न-भिन्न ऋतुगत अवस्थाओं के दौरान शुष्क एवं नमी युक्त दौरे की संभाव्यता तथा MAI के अध्ययन से पता चला है कि प्रत्येक क्षेत्र में अधिकाधिक अतिसंवेदनशीन अवस्थाओं की पहचान की जा सकती है।

ABSTRACT. The rainfed areas receive mean annual precipitation in range of 500-1500 mm with high degree of variability and are beset with problems of mid-season drought and associated impacts on the crop productivity. In this paper, analysis of weekly, monthly, annual rainfall and weekly rainfall probabilities in relation to crop productivity has been carried out for all the stations of the study area in West Bengal where rain-fed agriculture is predominant. However, duration of dry spells and its probabilities, climatic derivatives like commencement and cessation of rainy season, length of growing period (LGP) and estimates of water balance parameters have been carried out, in respect of all blocks in the identified three districts in West Bengal. The mean productivity during *kharif* season indicated that, highest productivity values of 3 to 3.5 t/ha are noticed in the block of central districts of Burdwan, Bankura, Birbhum, Hoogly districts. Perhaps, irrigation facilities in these districts might have helped in arriving at such high productivity rates. Low productivity of 1 to 1.5 t/ha have been noticed in two to three blocks of South 24-Paraganas and in Jalpaiguri districts. The productivity levels of northern districts, *viz*., Jalpaiguri, Coochbehar, West Dinajpur, South 24-Paranagas vary from 1.5 to 2.0 t/ha. The lowest productivity of 11.28 q /ha in Jaldha and 14.89 q /ha in Manbazar in 1996 can be due to heavy rainfall conditions in June and again in August. The mean productivity pattern of rice crop during *kharif* season in identified districts was analyzed with respect to occurrence of number of dry spells at different growth stages and average MAI values. The productivity was also related to monthly rainfall (July) and correlations have been mentioned for Jaldha block (0.22) and Manbazar block (0.64). The highest productivity of 2-3 t/ha are recorded in hot sub-humid to humid regions of West Bengal where LGP vary from 150 to 200 days. From the study of the probability of dry and wet spells and MAI during different crop phenophases, the most vulnerable phases can be identified in each region.

Key words – Rainfall data, Rainfed rice crop, LGP, MAI, GIS Software, Dry wet spell, Water balance.

1. Introduction

West Bengal's climate varies from tropical savannah in the southern portions to humid subtropical in the north. In early summer brief squalls and thunderstorms known as "Kal-Baisakhi" often arrive from the north or northwest. Monsoons bring rain to the whole state from June to September. West Bengal receives the Bay of Bengal branch of the Indian Ocean monsoon that moves in a northwest direction. However, the Darjeeling Himalayan Hill region experiences a harsh winter, with occasional snowfall at places. The southern parts of West Bengal actually sweat it out with humidity for most time of the year, while the northern and northeastern parts of West Bengal are chilly and cool. Monsoon plays havoc in the northern regions and the southern parts also receive considerable amount of rainfall every year. The average annual rainfall is found to be about 1750 mm ranging from 2500-3500 mm in the Duars and Terai regions to 1200-1800 mm in the plains. 75-80% of the rainfall is recorded during the four months of the monsoon season (June to September).Dry weather prevails during four to five months (November to March) with inadequate rainfall for crop production. Erratic and scattered showers fall between March and May which gradually increase in frequency and intensity and merge into the monsoon. Consequently, sowing of Jute and Aus rice during mid-April and often May is not possible when there is a delay in the onset of monsoon and thus raising only one crop a year is possible under rainfed conditions. Soil of the zone is course textured, shallow and sandy derived weathered debris of the rocks. Soils are subjected to severe wind erosion and have usually boulders with high permeability and low water holding capacity. Some of the flat areas are subjected to floods and are also affected by salinity (Singh, 2010).

As in other states, farmers in West Bengal also have to adjust the cropping system and crop management practices to the limitations imposed by the variability of rainfall. They have developed the farming system, which they practice, by trial and error. The past experience provides them with very broad information on rainfall, floods and water stress. However, for modern agriculture it is not enough. Without proper knowledge of variability of rainfall and other agro meteorological conditions, effective crop management and schedule of supplemental irrigation cannot be undertaken. The variability experienced at the onset and end of the rainy seasons undoubtedly affects the farmer's cropping strategies. The length of the growing seasons for rainfed crop in any region is precisely determined by the time between the first useful rainfall and end of the useful rainfall, although drought can occur during the middle of these periods. Agricultural practices and operations are planned accordingly to the frequency and quantum of rainfall in the region (Singh, 2010).

The choice of crops and cropping systems is mostly governed by LGP (Ramakrishna *et al*., 1987, 1985 & 1980). Ramana Rao (1997) has worked the cropping strategies on agro ecological conditions when LGP varied between 75 to 180 days. The beginning, end and total duration of rainy season and frequency of dry spells for rain gauge stations in Andhra Pradesh have been computed and utilized for crop planning in Andhra Pradesh (Victor *et al*., 1991). The results have been utilized for agricultural planning purposes. Similarly, the rainfall variability and its effect on rainfed crop yields at Hyderabad were studied by Ramana Rao *et al*. (1993) and they have found negative aberration in the rainfall contributing to the fall in crop yields. The concept of water requirement satisfaction index (WRSI) was used to quantify the crop yield under rainfed conditions by Victor *et al*. (1988) and Raman *et al*. (1971). They have found an exponential relationship between the yield and water availability. Rainfall probability analysis for sustainable crop production and strategies for costal Orissa have been reported by Kar (2002). For rainfed agriculture system, Frere and Popov (1979) suggested a technique based on crop water balance using climate data. They have studied the relationship between WRSI and the relative yields of sorghum crop for Botswana region (FAO, 1986). Rainfall probability analysis for sustainable crop production and strategies for Bihar have been reported by Singh *et al*. (2005, 2007, 2008 and 2009) by analyzing 30 years data. Singh *et al.* (2009) has worked out the spatial analysis of Mandal-wise rainfall variability for drought in Anantapur District of Andhra Pradesh in India using the GIS software. Keeping in the view was in this paper spatial analysis of rainfall and rainfed rice of West Bengal.

Thematic maps for all the basic parameters and their derivatives have been prepared for the entire study area using GIS package. The analysis has helped in identified the regions where immediate attention is needed. The fertility status of the soils in all the states and the regions of low and high fertility at different blocks in the state have been identified (Katyal *et al*., 1996b & 1997).

West Bengal is an important rice growing state in the country where the crop is grown in all the three seasons, *kharif* (Amam). Mostly the crop is grown under irrigated conditions in the state. For the study purpose, seven districts, *viz*., Purulia, Midnapur, Bankura, Birbhum, Burdhwan, West Dinajpur and Malda have been identified as rainfed rice growing districts.

2. Materials and method

The daily rainfall data (different districts and blocks of whole state of West Bengal) have been collected from IMD, Pune and rice yield data have been collected from Bureau of Economics and Statistics, West Bengal Government. Drought years were segregated on the basis of their severity following the procedure adopted by Subrahmanyam and Sastri (1969); Sastri *et al*.(2006); Subrahmanyam *et al*. (1965); Singh, (2005) and Singh and Rathore (2008). The levels of classification are given below:

Departure of crop water deficit index value from the median	*Drought intensity*
0 to $1/2\sigma$	Mild
$1/2\sigma$ to σ	Moderate
σ to 2σ	Severe
$>2\sigma$	Disastrous

where, σ is the standard deviation of the crop water deficit index values. The same criteria were adopted for determining phenophasic crop water deficit index and to estimate corresponding yield levels for different categories of drought years. A week receiving more than 50 mm rainfall is taken as wet week and less than 50 mm rainfall is taken as dry week. Based on the historical data of weekly rainfall, initial probabilities were worked out for each station as mention below:

$P(W) = F(W)/n$ and $P(D) = F(D)/n$

where,

P(D) - probability of occurrence of a dry week.

P(W) - probability of occurrence of wet week

F(D) - frequency of occurrence of a dry week.

F(W) - frequency of occurrence of wet week in *n* years

N - Number of years data.

Similarly, the conditional probabilities are calculated by formulae:

$$P(D/D) = F(D/D)/F(D/D) + F(W/D) = F(D/D)/F(D)$$

$$P(W/W) = F(W/W)/F(W/W) + F(D/W)$$

$$= F(W/W)/F(W)$$

$$P(D/W) = F(D/W)/F(W) = 1 - P(W/W)$$

$$P(2D) = PD_{W1}.PDD_{W2}$$

$$P(3D) = PD_{w1}.\ PDDw_2\ .PDD_{W3}$$

$$P(2W) = PW_{W1}.PWW_{W2}$$

$$P(3W) = PW_1.\ PWW_2\ .PWW_3$$

where,

P(D/D) - Probability of occurrence of dry week provided the last week was a dry week.

P (D/W) - Probability of occurrence of a dry week provided the last week was a wet week.

P (W/W) - Probability of occurrence of wet week provided the last week was a wet week provided the last week was a wet week.

2D, 3D - Probability of 2 and 3 consecutive wet weeks respectively starting with the week.

2W, 3W - Probability of 2 and 3 consecutive wet weeks respectively starting with the week.

W_1, W_2, W_3 - indicate three consecutive weeks.

The first letter in the conditional probability is indicating the present week and the second letter is indicating the past week (Singh *et al*., 2008 and 2009; Victor *et al*., 1991 and 1979; Chowdhury, 1981 and 1998).

2.1. *Weekly MAI*

Considering the soil moisture, weekly rainfall and weekly PET of individual stations, the AE was computed following Thornthwaite water balance technique. By using weekly AE and weekly PET (Penman, 1948), the weekly MAI and probability of expedience of weekly moisture availability were calculated by Thornthwaite *et al*., 1955 & 1957.

TABLE 1

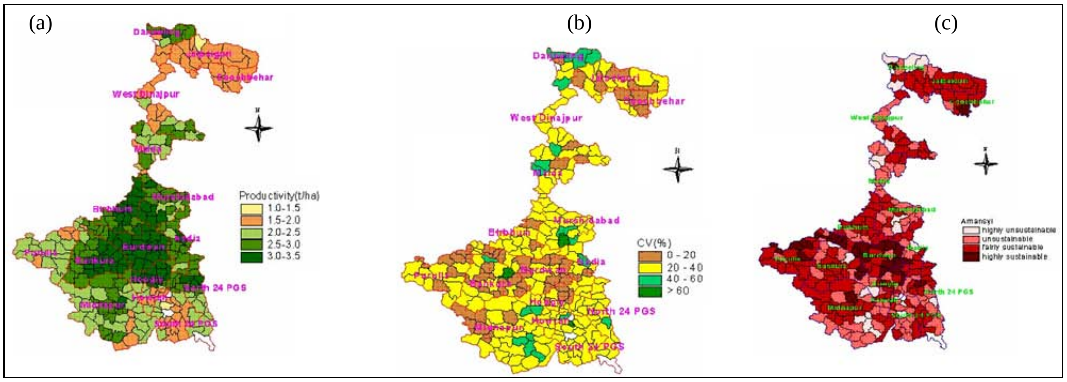
Distribution of stable rainfall week (R>50 mm) in different selected stations of West Bengal

Districts	Stations	No. of stable rainfall weeks	Start from (Week No.)	End on (Week No.)
Midnapur (W)	Midnapur	15	25	38
South 24 Pgs	Alipur	17	23	39
Darjeeling	Darjeeling	19	23	40
Darjeeling	Kalimpong	18	23	40
Coochbehar	Coochbehar	23	18	40
Murshidabad	Baharampur	15	24	37
North 24 Pgs	Dum- Dum	17	23	39
Nadia	Krishnagar	12	24	36
Jalpaiguri	Jalpaiguri	23	18	40
Purulia	Purulia	14	25	39
Burdwan	Burdwan	14	24	37
South Dinajpur	Balurghat	15	22	40
North Dinajpur	Raiganj	16	22	38
Malda	Malda	17	24	40
Midnapur (E)	Contai	17	24	40
Bankura	Bankura	15	24	39
Birbhum	Shantiniketa	15	24	39
Hoogly	Bagati	15	23	39
Howrah	Howrah	14	23	39

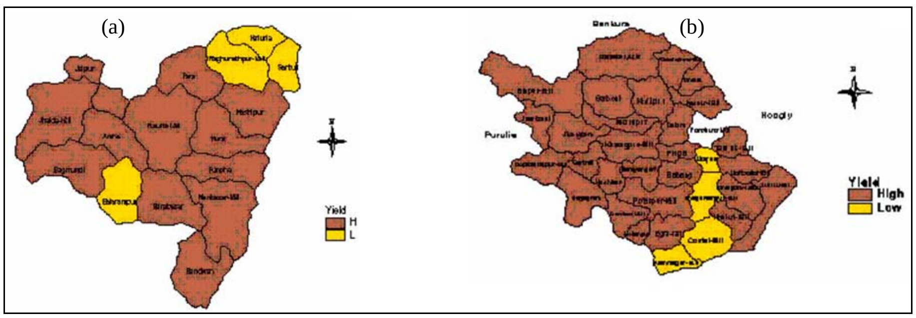
TABLE 2

Earliest week for sowing of rainfed upland rice at some selected stations of WestBengal at different probability levels

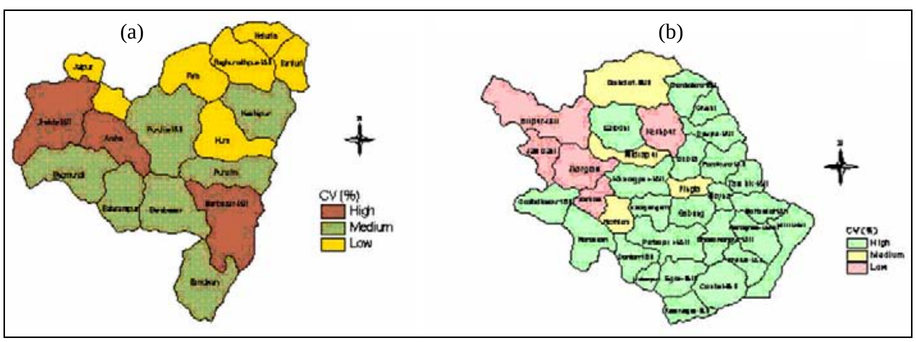
District	Sation	Standard meteorological week number at probability levels (%)				
		10	25	50	75	90
Midnapur (W)	Midnapur	12	15	18	20	22
South 24 Pgs	Alipur	13	16	18	19	22
Darjeeling	Darjeeling	12	13	15	17	18
Darjeeling	Kalimpong	13	14	16	18	19
Coochbehar	Coochbehar	13	14	16	17	19
Murshidabad	Baharampur	15	16	19	21	23
North 24 Pgs	Dum -Dum	14	16	18	19	22
Nadia	Krishnagar	13	15	18	19	21
Jalpaiguri	Jalpaiguri	13	14	16	18	19
Purulia	Purulia	14	17	20	23	24
Burdwan	Burdwan	12	15	18	20	23
South Dinajpur	Balurghat	14	16	18	21	21
North Dinajpur	Raiganj	15	17	19	21	22
Malda	Malda	15	18	19	21	23
Midnapur (E)	Contai	12	16	19	21	23
Bankura	Bankura	14	16	19	23	24
Birbhum	Shantiniketa	13	16	18	20	23
Hoogly	Bagati	13	16	17	19	24
Howrah	Howrah	13	14	18	21	23



Figs. 1(a-c). Mean productivity (t/ha), coefficient of variability and stability yield index of *kharif* rice crop in West Bengal



Figs. 2(a&b). Spatial variability in productivity of rice crop in (a) Purulia and (b) Midnapur districts of West Bengal



Figs. 3(a&b). Coefficient of variability in productivity of rice crop in (a) Purulia and (b) Midnapur districts of West Bengal

$$MAI = \frac{AE}{PE}$$

where,

MAI = Moisture Availability Index (Weekly),

AE = Actual Evapotranspiration (Weekly)

PE = Potential Evapotranspiration (Weekly)

For determination of Actual Evapotranspiration following two conditions have been considered

(*i*) If $P>PE$, then $AE = PE$

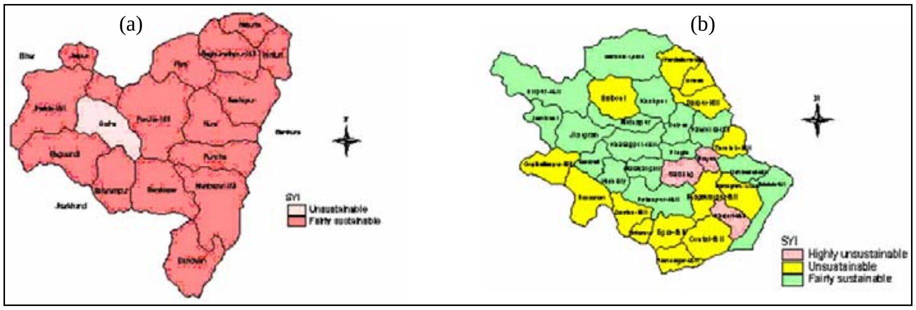
(*ii*) If $P<PE$, then $AE = P + \Delta S$

where,

P = precipitation, ΔS = Change in soil moisture

2.2. *GIS methodologies*

For the preparation of various thematic maps using GIS package, base maps with correct coordinates are essential. The map was digitized manually on the



Figs. 4(a&b). Variability of stability yield index in productivity of rice crop in (a) Purulia and (b) Midnapur districts of West Bengal

computer screen. The errors obtained during the process of digitization were removed. The map has been projected to real coordinates through geo-processing techniques. The attribute table, which is created by default, contains the identity of each polygon (blocks). The names of the blocks in the maps entered against identified blocks to facilitate to enter the different parameters that are required to be analyzed. The analysis can be carried out either from the data available in the attributes table or form the same data available in excel format. With the help of GIS, the drought prone regions have been identified (Singh *et al*., 2009).

2.3. *Spatial Interpolation using Spatial Analyst of Arc View 3.2a*

Interpolation assumes that the phenomenon being predicted is closely approximated by the mathematical function used. The unknown values are then calculated according to this function. The choice of an approximate model is therefore essential in order to obtain reasonable results. Surface interpolation uses a defined or selected set of all the samples to estimate each of the output grid's cell values (Singh, 2010 and Katyal *et al*., 1996b & 1997).

3. Results and discussion

3.1. *Districts-wise of West Bengal*

The water losses from the rice field in the form of evapotranspiration and percolation are assumed to be around 6 to 7 mm/day during the *kharif* season. It amounts to about 50 mm/week, which is considered as a stable rainfall period without stress. From the averages of weekly rainfall of all the district headquarters, period of stable rainfall weeks have been computed and depicted in Table 1. Also the start and end of such period has been worked out and presented in the same table. It is observed from the table that the duration of stable period varied from 12 weeks in the Nadia district to 23 weeks in Coochbehar district adjacent to high rainfall region in Assam and Bangladesh. In the northeastern districts, which comprise Darjeeling, Coochbehar and Jalpaiguri it varied between 18 to 23 weeks and in the rest of the districts it varied from 12 to 17 weeks. The start of the season in the state is early in the northeastern districts (18 week) and ends in 40th week whereas it is around 25th week in Purulia and Midnapur which are typical rainfed areas and ends around 38thand 39th weeks (Singh *et al*., 2008, Chowdhury, 1981 & 1998).

For direct sowing of rice under upland conditions, cumulative amount of rainfall of 75 mm is required for taking up sowings. Using the above criteria, the earliest week of sowing of upland rice at different probabilities of the selected raingauge stations have been analyzed in Table 2. It is observed from the Table 2 that sowing of upland rice could be started as early as 15th week at Darjeeling followed by 16th week in Coochbehar and Jalpaiguri once in two years (50% probabilities). For southern and western districts, sowing could be taken up in 18th-19th week while it would be in 20th week in Purulia. When the probability increased to 75 per cent, a delay of one to two weeks in commencement has been observed in all the stations. However, the delay in commencement was around three weeks in Purulia according to Victor *et al.* (1991). These would provide a basis for preparing management strategies for reducing risks involved in rainfed situation.

3.1.1. *Crop productivity pattern*

From the mean rice crop productivity, the coefficient of variability and the sustainability index (Mean - Sd. Dev. / highest value) in respect of the blocks in season (*kharif*) have been computed. Using GIS, the mean productivity maps, coefficient of variability and SYI maps for the Aman season have been prepared [Figs. 1(a-c)]. As the study is confined to rainfed rice system, the maps for Aman season (*kharif*) are only presented (Katyal *et al*., 1996b & 1997).

The Fig. 1(a), which shows the mean productivity during *kharif* season indicated that highest productivity

TABLE 3

Dry spell, range of yields and fertility status of different Blocks in Purulia districts

Name of Blocks	Probability of dry spells			Range of productivity (q /ha)	Fertility status		
	A	B	C		N	P	K
Baghmundi	31	28	38	1.39 to 2.60	L	ML	L
Barabazar	34	33	37	1.45 to 2.54	L	VL	ML
Hura	31	40	35	1.91 to 3.05	L	L	L
Jaldha	32	37	27	1.12 to 3.07	L	L	L
Kashipur	35	36	44	1.37 to 2.80	L	L	ML
Manbazar	35	43	43	1.79 to 3.80	L	VL	ML

A- Vegetative stage, B- reproductive stage, C- Maturity stage, L - Low, ML - Medium low and VL - Very Low

TABLE 4

Rice Productivity (t/ha) in relation to commencement of rain in Purulia district

Block name	Commencement period			
	10-19 June	20-30 June	1-10 July	> 10 July
Baghmundi	2.20	1.70	2.40	-
Barabazar	2.24	2.10	2.05	-
Hura	2.60	2.38	2.86	-
Jaldha	2.34	1.99	2.76	-
Kashipur	1.86	2.16	-	-
Manbazar	2.55	2.32	2.72	-
Average	2.30	2.11	2.56	-

TABLE 5

Rice Productivity (t/ha) in relation to cessation of rain in Purulia district

Block name	Cessation period				
	21-30 September	01-10 October	11-20 October	20-30 October	>30 October
Baghmundi	1.72	-	2.12	2.41	1.40
Barabazar	2.24	2.51	1.93	1.26	-
Hura	2.22	2.72	2.47	2.56	1.93
Jaldha	-	2.27	2.07	2.80	-
Kashipur	1.80	2.12	2.28	1.37	-
Manbazar	-	2.01	2.59	-	-
Average	1.99	2.33	2.24	2.08	1.66

values of 3 to 3.5 t/ha is noticed in the block of central districts of Burdwan, Bankura, Birbhum, Hoogly districts. Perhaps, irrigation facilities in these districts might have helped in arriving at such high productivity rates. Low productivity of 1 to 1.5 t/ha have been noticed in two to three blocks of South 24-Paraganas and in Jalpaiguri districts. The productivity levels of northern districts, *viz*., Jalpaiguri, Coochbehar, West Dinajpur, South 24-Paranagas vary from 1.5 to 2.0 t/ha.

3.1.2. *Crop variability*

The coefficient of variability (CV%) map [Fig. 1(b)] indicates that the variability is low (0-20%) in few blocks of Burdwan, Purulia, Midnapur and Coochbehar. It is interesting to note that all the higher productivity zones are not stable as the variability is high among these blocks. Most of the area in the state can be categorized as under low and medium variability

Table 6(a)

Rice yields and the corresponding rainfall and its derivatives in different blocks of Jaldha, Purulia district (West Bengal)

Year	Prod (q/ha)	RF(mm) (season)	Crop duration (week)		Crop duration (week)				No. of dry spells at different crop stages							
									5 to 9 days				> 10 days			
			Beginning	End	A	B	C	D	A	B	C	D	A	B	C	D
1985	-	1041	27	38	100	100	97	88	1	-	2	-				1
1986	23.36	1003	25	45	100	100	98	99	-	1	1	1			1	
1987	28.9	1274	27	40	100	100	100	94	-	-	1	1				1
1988	25.91	1101	24	40	100	100	100	99	-	-	1	-				
1989	26.37	1072	25	41	-	-	-	-	1	-	1	-				1
1990	13.49	1514	25	41	-	-	-	-	-	-	-	-				
1991	23.22	1027	30	41	100	100	99	78	-	-	1	-				1
1992	22.9	1322	23	42	74	100	100	100	-	-	-	-				1
1993	21.7	921	25	42	94	100	100	99	-	1	1	2				
1994	28.49	1405	24	43	100	100	100	100	-	-	-	-				1
1995	16.14	1092	25	47	100	89	100	100	-	-	1	1				1
1996	11.28	1435	26	40	100	100	100	97	1	2	-	1				1
1997	30.66	1148	27	40	100	100	100	93	-	-	1	-				1
Mean	22.7	1181	26	42	97	99	99	95								

A-Seedling Stages, B-Vegetative stage, C-Reproductive stage and D-Maturity Stages

Table 6(b)

Rice yields and the corresponding rainfall and its derivatives in different blocks of Manbazar, Purulia district (West Bengal)

Year	Prod (q/ha)	RF (mm) (season)	Crop duration (week)		MAI at different crop stages				No. of dry spells at different crop stages							
									5 to 9 days				> 10 days			
			Beginning	End	A	B	C	D	A	B	C	D	A	B	C	D
1981	-	920	25	38	96	100	100	96	-	-	-	1	-	-	-	1
1982	-	593	26	37	80	85	100	88	2	1	1	-	-	-	-	1
1983	-	818	27	43	90	100	100	100	1	1	1	1	-	-	-	-
1984	-	1149	25	39	100	100	100	98	-	-	-	2	-	-	-	-
1985	-	895	24	42	100	100	100	100	-	1	-	1	-	-	-	-
1987	23.87	1071	25	42	98	100	100	99	2	-	1	2	-	-	-	-
1988	23.57	823	24	40	100	100	99	99	-	1	2	1	-	-	-	-
1991	31.89	1357	27	42	80	100	100	98	-	-	1	3	1	-	-	-
1992	21.5	787	25	41	93	100	100	99	-	-	1	1	-	-	-	1
1993	27.08	1258	24	42	100	100	100	99	1	1	1	-	-	-	-	-
1994	26.68	1362	25	41	100	100	100	98	-	-	-	-	-	-	-	1
1995	19.71	1506	26	45	100	100	100	98	-	-	1	-	-	-	-	1
1996	14.89	1203	26	40	100	99	100	98	-	2	1	1	-	-	-	-
1997	31.79	1464	26	40	100	100	100	92	-	1	-	1	-	-	-	1
Mean	24.55	1086	25	41	96	99	100	97								

A-Seedling Stages, B-Vegetative stage, C-Reproductive stage and D-Maturity Stages

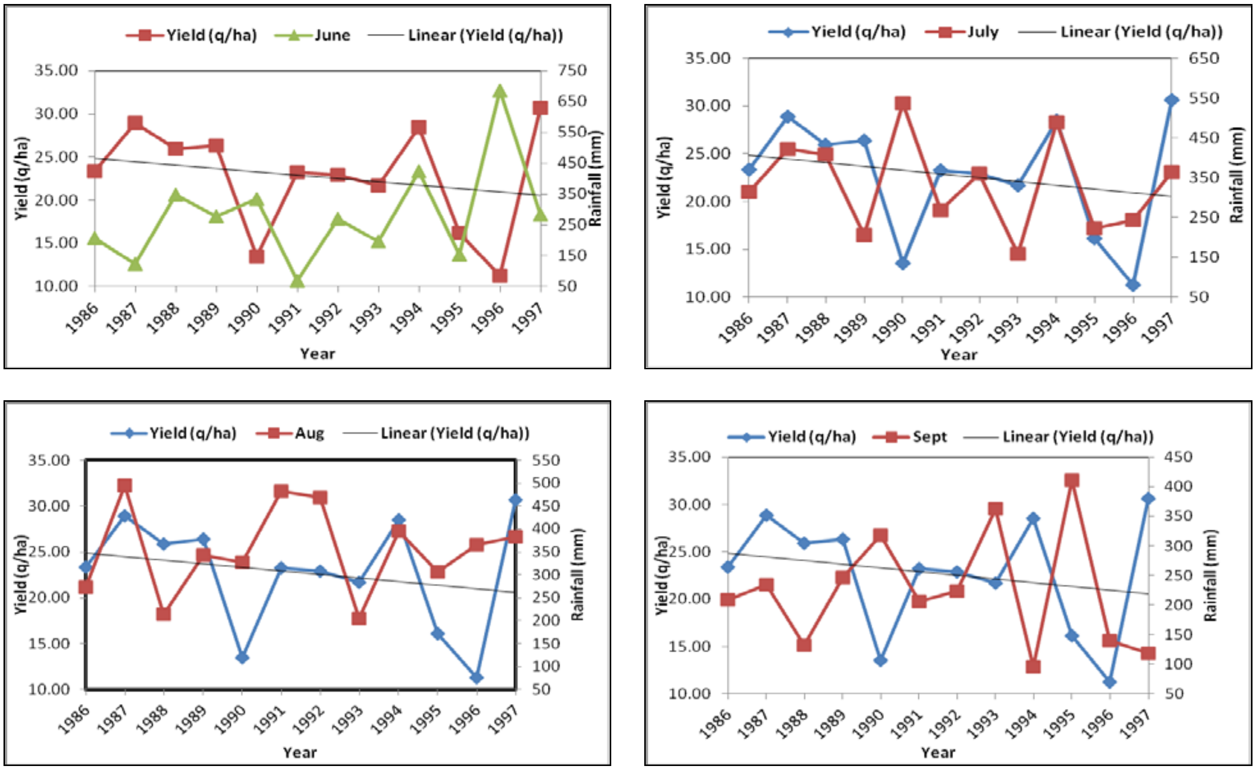


Fig. 5(a). Relation between *kharif* rice yield and monthly rainfall at Jaldha block in Purulia district

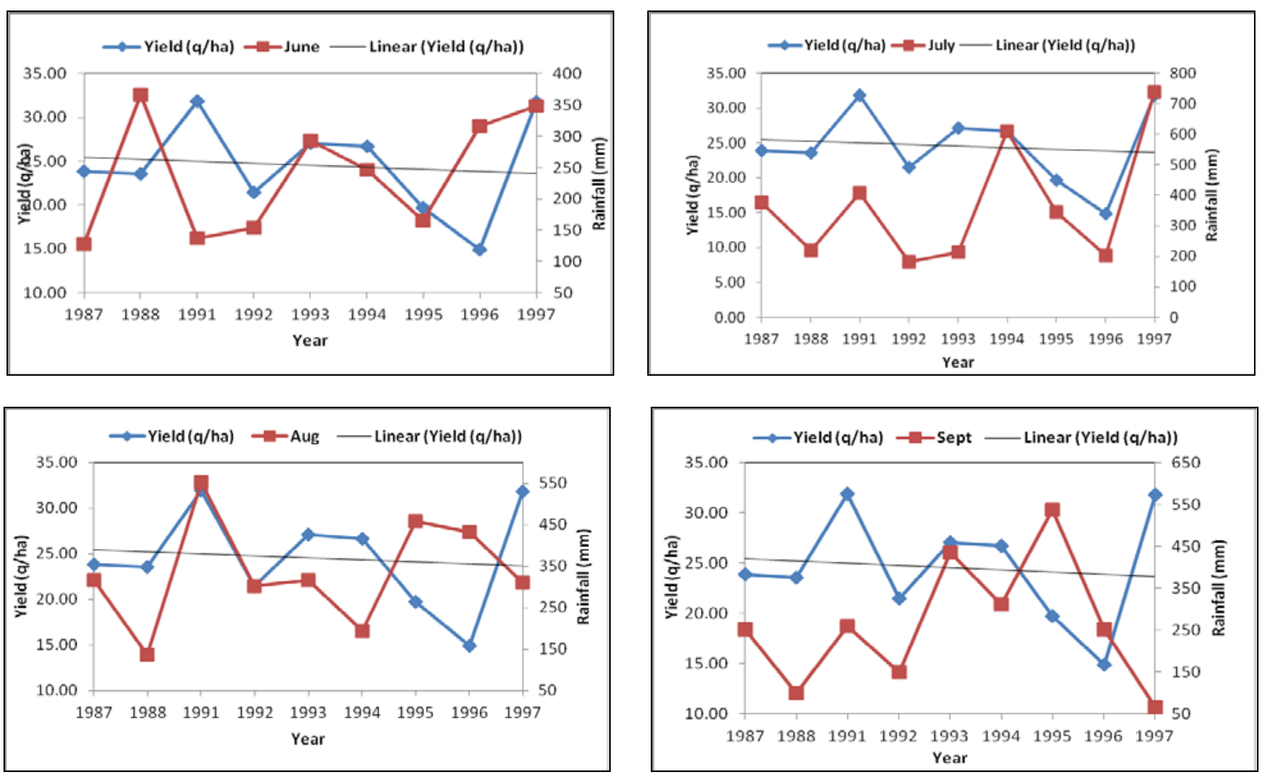


Fig. 5(b). Relation between *kharif* rice yield and monthly rainfall at Manbazar block in Purulia district zones except for few blocks in northern districts and rarely in some other places.

3.1.3. *Sustainable yield Index*

The Sustainable Yield Index (SYI) maps [Fig. 1(c)] delineated the sustainable productivity regions. It is observed from the Fig. 1(c) that highly sustainable regions are mostly high productivity areas in the central parts of the state comprising the districts of Burdwan and few parts in Purulia. Perhaps, better crop management, with extra inputs added with extra-assured irrigation through tube wells might have contributed significantly for sustainable production in these regions. In general, fairly greater area in the state can be categorized under sustainable production zone. Few pockets of unsustainable and highly unsustainable zones have been noticed in Midnapur and also in Bankura and Malda according to Ramakrishna *et al*. (1987).

3.2. *Block-wise analysis*

Block wise (micro-level) analysis with respect to two districts, *viz*., Purulia and Midnapur has been carried out and the results are as follows maps [Fig. 2(a&b) and 3(a&b)]. Though crops statistics data is available for all the blocks over 12-year period (1986-1998).The corresponding rainfall data for all the blocks is not available; hence, block-wise relations between rainfall and productivity could not be carried out. Only single station rainfall at the district of Purulia has been used with the average crop productivity data of the district.

3.2.1. *Probabilities of dry spell analysis at different growth stage of Purulia*

The probabilities of dryspells of greater than 3 days and above, range of productivity and the fertility status in Purulia district is shown in Table 3. It is seen from the Table 3 that the range of Aman season productivity is highest in the block Manbazar. Generally, the productivity ranges from 1.12 to 3.07 q/ha in the Jaldha block to 1.49 to 3.80 q/ha in the Manbazar block. The general fertility status of the soils is mostly categorized as low to medium low indicating the low fertility status of the district. The probabilities of dry spells at various crop stages of the rice crop shows that generally the probabilities are low (less than 40%) indicating assured season over the year (Victor *et al*., 1991; Singh *et al*., 2008 and 2009; Chowdhury, 1981 and 1998).

3.2.2. *Commencement and cessation period of rainy season in different blocks of West Bengal*

The productivity of *kharif* season rice crop in relation to different periods of commencement and cessation of rainy season has been computed in Tables 4 & 5. Sowings / transplanting on the commencement of season indicated that the productivity of the crop sown between 20-30 June is less than the crop either sown early or after this period. Perhaps, July being the highest rainfall month in the country, sowing in July has helped in better establishment of the crop. Similarly, the cessation of rainy season on the productivity of Aman season rice crop indicates that early withdrawal of the season between 21-30 September has shown drop in productivity compared to the other periods (Victor *et al*., 1991 and Singh *et al*., 2008 and 2009). The higher productivity is seen when the monsoon withdraws between 1^{st} to 20^{th} October. If withdrawal occurs beyond October 20, the productivity decreases considerably. Perhaps, late rains during maturity may cause lodging of the rice crop in addition to shattering of grains due to high winds associated with cyclonic storms. Also the fall in minimum temperature during last week of October will have negative impact on productivity.

3.2.3. *Spatial variability of crop productivity*

The spatial variability maps of productivity of different blocks in two districts, *viz*., Purulia and Midnapur have been prepared and presented in Figs. 2(a&b). Also, the coefficient of variability and the map showing the regions of sustainable and unsustainable productivity have been prepared and presented maps [Figs. 2(a&b)]. It is observed from spatial distributed productive maps [Figs. 2(a&b)] that low yields of less than < 2.0 t/ha has been noticed in the blocks of Neturia, Raghunathpur, Santuri and Balrampur in Purulia and Moyna, Bhagwanpur, Contai and Ramnagar in Midnapur.

The rest of the blocks in these two districts have high productivity of greater than 2 t/ha. The coefficient of variability maps [Figs. 3(a&b)]of the districts indicated that interventions for stable productivity is needed in Jaldha, Arsha and Manbazar blocks in Purulia districts while many of the blocks in Midnapur showed higher variability according to Raj *et al*., 2004 and Singh *et al*., 2009.

The sustainable yield index maps [Figs. 4(a&b)] for both the districts indicated that except in the Arsha block, the productivity is fairly sustainable. There is a need to develop strategies to make the productivity more sustainable through better management techniques.

Similarly, the unsustainable productivity in the blocks of Midnapur needs special attention.

3.3. *Rainfed rice yields and rainfall* relationship *between rice yields and corresponding rainfall and its derivatives at different blocks and different districts*

To analyze the variability in productivity in respect of Jaldha and Manbazar where the coefficient of variation value of productivity are on higher side, the moisture adequacy index values at different growth stages and number of dry spells occurring at various stages are shown along with the yield data and seasonal rainfall in Tables 6(a&b). It is observed from the table that the yield has not been affected by the occurrence of dry spell at maturity in both the blocks of Purulia district. Perhaps, the data on different planting systems may help in understanding this feature. Perhaps, more area under low land situation may withstand water stress conditions to a greater length of period. The lowest productivity of 11.28 q /ha in Jaldha and 14.89 q /ha in Manbazar in 1996 can be due to heavy rainfall conditions in June and again in August. Occurrence of low-pressure systems along with monsoon trough may bring in heavy amounts of rainfall in these regions (Victor *et al*., 1991 and Singh *et al*., 2008).

The graphical representation of the relationship between rice yields and monthly rainfall (June, July, August and September) at the above two blocks has been depicted in [Figs. 5(a&b)] and the trend line showing the yields has been given in the diagram. It is seen that the correlation coefficients are positive in the month of July for Jaldha block (0.22) and Manbazar block (0.64) in Jaldha and Manbazar block. It is seen from the figures that higher trends have been observed between July and August rainfall and the yield at both the locations. The yield levels have shown small decreasing trend in Jaldha over the years. However, the trend is significant.

4. Conclusions

The rainfall analysis with respect to weekly, monthly, annual rainfall and weekly rainfall probabilities has been carried out for all the stations of the study area. However, duration of dry spells and its probabilities, climatic derivatives like commencement and cessation of rainy season, length of growing period (LGP) and estimates of water balance parameters have been carried out, in respect of all blocks in the identified three districts in West Bengal. The mean productivity pattern of rice crop during *kharif* season in identified districts was analyzed with respect to occurrence of number of dryspells at different growth stages and average MAI values. It is seen that the correlation coefficients are positive in the month of July for Jaldha block (0.22) and Manbazar block (0.64) in Jaldha and Manbazar block. The rainwater availability maps at different growth stages as against the demand have been worked out for the entire study area. From the block-wise crop data, the statistical parameters like mean, coefficient of variation (CV) and standard deviation (SD) have been worked out. Thematic maps for all the basic parameters and the derivatives have been prepared using GIS package. The spatial variability maps of mean productivity and its changes over 30-year period for the entire study area have been prepared. From the coefficient of variability in productivity, the region where productivity is highly variable has been delineated. This study can be used as a tool for detecting the hazards with regard to water availability during the growth periods. This information can be used by farmers to protect the crop against the damage due to drought by taking alternate measures to mitigate the effect of drought.

This is because of the fact that when the crop phenological calendar will be super imposed upon these sequences, it will provide an insight into the crop water stresses in various phenophase stages. Based upon these conditions, the alternative strategies (for fertilizer application, pesticides etc.) can be recommended to the farmers.

References

Chowdhury, A., 1981, "On the occurrence of wet and dry spells in Bihar", *Mausam*, **32**, 3, 285-290.

Chaudhary, J. L., 1998, "Rainfall analysis using Markov Chain Modeling for Baster district", *Geog., Review of India*, **60**, 73-83.

Frere, M. and Popove, G. F., 1979, "Agro meteorological crop monitoring and forecasting, *FAO plant production and protection paper*, **17**, p64.

Food and Agricultural Organization., 1986, "Early agro meteorological crop yield assessment", FAO plant production and protection paper No.73, FAO of the United Nations, Rome.

Kar, G., 2002, "Rainfall probability for sustainable crop production strategies for costal Orissa", *Journal of Agrometeorology*, **4**, 2, 181-187.

Katyal, J. C., Narayana Reddy, M. and Virmani, S. M., 1996b, "A case study on the spatial and temporal dynamic of area and productivity of sorghum and pigeonpea in India through GIS", The world Bank-NARP Report on "Resource Characterization of Rain fed Farming Systems in Peninsular India", Hyderabad, India: CRIDA.

Katyal, J. C. and Narayana Reddy, M., 1997, "Remote sensing and GIS to address certain issues related to Dry land agriculture", *NNRMS Bulletin*, **20**, 4-15.

Penman, H. L., 1948, "Natural Evaporation from open water, bare soil and grass", *Proc. R. Soc. (A)*, **193**, 120-145.

Ramakrishna, Y. S. and Sastry, A. S. R. A. S., 1980, "Studies on Incidence of Drought over West Rajasthan", *The National Geographical Journal of India*, **26**, 44-49.

Ramakrishna, Y. S., Ramana Rao, B. V. and Rao, G. G. S. N., 1985, "Water Balance and crop planning - A case study of West Rajasthan", *J. of Annals Arid Zones*, **24**, 2, 114-119.

Ramakrishna, Y. S., Ramana Rao, B. V., Rao, G. G. S. N. and Joshi, N. C., 1987, "Moisture reguime variation in agricultural productivity in Rajasthan", *In: Desert Ecology (Ed. Prakash, I)*, Scientific publisher, Jodhpur, 65-88.

Raman, C. R. V. and Srinivasamurthy, B. S., 1971, "Water availability periods for crop planning", *Pre-Pub. Sci. Report*, IMD No. 173.

Raman Rao, B. V., 1997, "Agroecological based cropping strategies for topical rain fed areas in India", Lecture notes on training course on Agrometeorology aspects of agricultural production, February 1997, CRIDA, Hyderabad.

Rao, Raman, B. V., Katyal, J. C., Victor, U. S., Srivastava, N. N. and Vijaya Kumar, P., 1993, "Rainfall variability and its impacts on crop yields at Hyderabad - An agroclimatic case study", *Ind. Jour. of Dryland Agriculture Research and Development*, **8**, 2, 98-108.

Sastri, C. V. S., Srivastava, A. K. and Kumari, P., 2006, "Drought Characterization in dry farming regions of Bihar state in relation to growth phases of rice and wheat", *Researcher*, **1**, 1, 48-51.

Singh, P. K., 2010, "Thesis submitted in Andhra University", 2010.

Singh, P. K., 2005, "Incidence of Drought at Sabour, Bihar", *Indian Journal of Agrometeorology*, **1**, 128-130.

Singh, P. K., Baxla, A. K. and Singh, S. B., 2007, "Rainfall characteristic analysis and crop planning in Sabour region of Bihar", *Indian Journal of Soil Cons*., **35**, 1, 36-39.

Singh, P. K., Lal, S. D. and Ravi Sankar, M., 2005, "Rainfall analysis for crop planning in Sabour of Bhagalpur district of Bihar", *Indian Journal of Dryland Agric Res & Dev*., **20**, 2, 145-150.

Singh, P. K. and Rathore, L. S., 2008, "Some Characteristics and Frequencies of Occurrence of Drought in Sabour" *Journal of Agrometeorology*, Special issue-part-2, 486-488.

Singh, P. K., Rathore, L. S., Singh, K. K., Gupta, A. K., Baxla, A. K. and Athiyaman, B., 2008, "Rainfall probability analysis using Markovchain model in Sabour region of Bihar", *Journal of Agrometeorology*, **10**, 2, 213-217.

Singh, P. K., Rathore, L. S., Mali, P. and Singh, K. K., 2009, "Spatial Analysis of Mandal-wise rainfall Variability for Drought in Anantapur District of Andhra Pradesh in India", *International Journal of Meteorology*, July, **34**, 339, 147-154.

Singh, P. K., Rathore, L. S., Singh, K. K. and Baxla, A. K., 2009, "Rainfall characteristics of North West Alluvial Plain Zone of Bihar", *Indian Journal of Agrometeorology*, **11**, 1, 26-30.

Singh, P. K., Rathore, L. S., Singh, K. K., Baxla, A. K. and Athiyaman, B., 2009, "Incomplete Gamma distribution of rainfall for sustainable crop production strategies at Palampur, Himachal Pradesh", *Mausam*, **60**, 1, 73-80.

Subrahmanyam, V. P. and Subramaniam, A. R., 1965, "Some characteristics and frequencies of occurrence of drought in dry climatic zones of India", *Bull. IASH*, X Annee. No. **3**, 31-37.

Subrahmanyam, V. P. and Sastri, C. V. S., 1969, "Some aspects of drought climatology of the dry sub humid zone of South India" *J. Met. Soc. Japan. Sec. II*., **8**, 4, 239-244.

Thornthwaite, C. W. and Mather, J. R., 1955, "The water balances, Publication in climatology", *Laboratory of climatology, Ceneteron, (NJ)*, **8**, 1, p104.

Thornthwaite, C. W. and Mather, J. R., 1957, "Instructions of Tables for computing potential Evapotranspiration and the water balance", *Publication in climatology Drexel Institute of Technology*, Laboratory of climatology, **10**, p3.

Victor, U. S. and Sastry, P. S. N., 1979, "Dry spell probability by Markov Chain Model and its applications to crop development stages", *Mausam*, **30**, 4, 479-484.

Victor, U. S., Srivastava, N. N. and Ramana Rao, B. V., 1988, "Quantification of crop yields under rainfed conditions using a simple soil water balance model", *Theor. Appl. Climatol*., **39**, 73-80.

Victor, U. S., Srivastava, N. N. and Ramana Rao, B. V., 1991, "Moisture regime, aridity and droughts in the arid region of Andhra Pradesh", *Annals of Arid Zone*, **30**, 2, 81-91.

Victor, U. S., Ramana Rao, B. V., Srivastava, N. N. and Vijaya Kumar, P., 1991, "Rainy season and its variability for contingency crop planning in Andhra Pradesh", *Indian Journal of Dryland Agriculture Research and Development*, **6**, 1&2, 1-12.