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Some studies on rainfall climatology of the Nagpur region

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सार – नागपुर क्षेत्र में फसल उत्पादन और फसल पैटर्न के लिये वर्षा की विशेषताओं का अध्ययन किया गया है। फसल उत्पादन के लिये वर्षा की पर्याप्तता को दर्शाने के लिये पांच प्राचलों पर आधारित शततमक इन्डेक्स को विकसित किया गया है और विवेचित मानसून निष्पादन सन्तोषजनक पाया गया है। इन अध्ययनों ने यह दर्शाया है कि वर्षा के दिनों में खरीफ मौसम की माध्य वर्षा 52.3 (सी० वी० 17.3%) सहित 861.5 मि० मी० (सी० वी० 20.8%) रही। 75, 80, 85, 90% संभाव्यता स्तर पर निर्भर वर्षा सहित 13 सप्ताहों (25-37 एम डब्ल्यू) के फसल मौसम सुनिश्चित और खतरे से मुक्त पाये गए। 75% और 50% संभाव्यता स्तर पर फसल की अवधि थोड़े से खतरे के साथ 18 सप्ताहों (23–40 एम डब्ल्यू) तक बढ़ायी जा सकती है। रबी और ग्रीष्म में बढ़ती फसल की ऋतु में किसी भी व्यवहार्य निर्भरता स्तर पर वर्षा नहीं हुई थी और इस स्थिति में सिंचाई की आवश्यकता पड़ती है। वर्षा पर निर्भर फसल उत्पादन को स्थिर करने की योजना में अल्प से मध्यम अवधि वाली (16–18 सप्ताह) (500 से 900 मि० मी०) जल आवश्यकताओं वाली फसलें अर्थात् मूंगफली, सोयाबीन, सूरजमुखी, मकई, सोरघम जैसी फसलों को अपनाना शामिल है। अधिक जल की आवश्यकताओं वाली फसलों अर्थात् कपास और चावल जैसी लम्बी अवधि वाली फसलों को निश्चित खतरे के साथ अपनाया जा सकता है।

ABSTRACT. Characterisation of rainfall of the Nagpur region for crop production and cropping patterns is studied. Percentile index based on five parameters to show adequacy of rainfall for crop production is developed and found to describe monsoon performance satisfactorily. These studies have revealed that the mean rainfall of kharif season is 861.5 mm (CV 20.8%) with 52.3 (CV 17.3%) rainy days. Cropping season of 13 weeks (25-37MW) with dependable rainfall at 75, 80, 85, 90% probability levels was found to be most assured and risk-free. The cropping period at 75% and 50% probability levels can be extended up to 18 weeks (23-40MW) with marginal risk. In rabi and summer growing seasons, there was no rainfall at all at any feasible, dependable level and this situation asked for irrigation. Strategy for stabilizing rainfed crop yields included the adaptation of short to medium duration crops (16-18 weeks) with water requirements 500-900 mm, *viz.*, groundnut, soybean, sunflower, maize, sorghum. Long duration crops like cotton and rice with high water requirements can be adapted with certain risk.

Key words — Rainfall, climatology, crop production.

1. Introduction

Under dryland agriculture, the production and productivity is largely confined by the rainfall vagaries, many times leading to the total failure in crop production. To stabilize rainfed agriculture, it is necessary to build up an adequate rainfall climatology. Characterisation of rainfall with respect to amount, distribution, extreme values and its dependability forms an important parameter to evolve suitable cropping patterns for stabilizing crop yields and increasing productivity. The widespread deforestation, large-scale industrialisation, and extensive urban constructions resulted possibly in modifying climate in general and this situation warrants such studies afresh. Keeping this in view, studies were undertaken to characterise the rainfall of Nagpur region for dependability, variability, distribution and degree of satisfaction of monsoon.

2. Materials and methods

The daily meteorological data of 29 years (1961-1989) of Nagpur (21° 9′N, 79° 8′E, 321 m.a.m.s.l.) district were used for analysis in this work. The daily rainfall was analysed statistically for annual, seasonal, 4-weekly and weekly periods. In order to assess the variability of rainfall for a given period, the coefficient of variability in per cent was worked out. To work out rainfall probability, rainfall data for a given period was arranged in descending magnitude and was ranked (Doorenbos & Pruitt 1975). The plotting positions (Fa) were obtained and plotted on log-normal probability paper (Ven Te Chow 1964). The dependability of rainfall was then determined from the probability curves. Relative Degree of Monsoon Satisfaction (RDMS) as explained and defined in a later paragraph was worked out. The suitability of the crops with respect to water requirement was also worked out.

3. Results and discussion

For better understanding of the distribution patterns, the rainfall data on annual, seasonal, 4-weekly and weekly basis were analysed. Some of the important characteristics of rainfall (Tables 1, 2 & 3) are as follows. The mean annual rainfall (1961-1989) at Nagpur was 1048.7 mm with 68.4 rainy days (*i.e.*, days with rainfall

TABLE 1

Mean annual and seasonal rainfall, rainy days and CV (%) for 1961-1989

	Kharif (25-41 MW)		Rabi (42-7 MW)		Summer (8-24 MW)		Annual (1-52 MW)	
	RF	RD	RF	RD	RF	RD	RF	RD
Mean	861.5	52.3	87.4	6.3	99.8	9.8	1048.7	68.4
CV %	20.8	17.3	77.2	66.9	73.4	57.8	17.6	13.4
% of mean annual rainfall	82.1	76.5	8.3	9.2	9.5	14.3	100	100

TABLE 2

Mean rainfall and mean CV (%) for 4-weekly period (1961-1989)

Four weekly period	MW	RF	CV(%)	RD	CV (%)
1 Jan-28 Jan	1-4	13.1	302.7	1.8	214.3
29 Jan-25 Feb	5-8	18.2	278.9	1.5	210.3
26 Feb-25 Mar	9-12	17.2	293.2	1.7	209.2
26 Mar-22 Apr	13-16	6.2	248.0	1.4	209.2
23 Apr-20 May	17-20	9.9	324.1	1.0	234.9
21 May-17 Jun	21-24	63.3	161.5	5.2	116.6
18 Jun-15 Jul	25-28	255.0	83.3	13.6	51.1
16 Jul-12 Aug	29-32	263.5	89.4	16.0	50.0
13 Aug-9 Sep	33-36	214.9	101.7	13.0	56.5
10 Sep-7 Oct	37-40	115.0	135.9	7.8	93.2
8 Oct-4 Nov	41-44	35.8	237.9	2.1	214.0
5 Nov-2 Dec	45-48	16.8	378.2	1.0	324.2
3 Dec-31 Dec	49-52	19.7	342.1	0.9	295.1
Annual		1048.7	17.6	68.4	13.4

$\geqslant$2.5 mm) and this showed a declination from the established normal rainfall (1901-1950) 1242.2 mm and 74.4 rainy days at Nagpur (Anonymous 1980). Out of 29 years, the rainfall was normal (+19 to —19%) in 18 years, excess (+20 to 59%) in 8 years and deficient (—20 to —59%) in only 3 years. The highest rainfall 1364.3 mm with 84 rainy days was received in 1970; however, highest number of rainy days (116.0) with 1281.2 mm rainfall was in 1961. The lowest annual rainfall (RF) was only 590.0 mm (54 rainy days, RD) in 1972. The annual rainfall and rainy days showed a low variation with coefficient of variation (CV) 17.6% (for RF) and 13.4% (for RD).

Kharif season (25-41 MW) under SW monsoon received mean rainfall 861.5 mm (52.3 RD) with lowest 425.1 mm (1982) and highest 1143.8 mm (1961). Kharif season contributed 82.1% of total annual rainfall with 8.3% (87.4 mm) and 9.5% (99.8 mm), as contributions of winter (rabi) (42-7 MW) and summer (8-24 MW) seasons respectively. Kharif season showed the lowest variability (CV 20.8%) followed by summer (CV 57.8%) and rabi (77.2%) seasons. Probability during kharif for normal rainfall was highest 62.1%, for excessive rainfall 20.7%, for deficient 13.7% and for large deficient was lowest 3.4%. These probabilities together with lowest CV 20.8%, indicated the assured and uniform rainfall during kharif.

From the Table 2, it is seen that the rainfall was highest (263.5 mm) for (16 July-12 August) 4-weekly period. The rainfall and CV for 18 June-15 July, 16 July-12 August, 13 August-9 September, 4 week periods showed little difference; however, for 10 September-7 October period rainfall declined to 115.0 mm and CV increased to 135.9%. Highest CV of 378.2% was observed for 5 November-2 December period.

The mean weekly rainfall, rainy days and CV were computed and are given in Table 3. 28 meteorological week (MW) had highest mean rainfall of 73.7 mm (CV 85.7%) followed by 31, 30, 27 and 32 MW. The mean weekly rainfall during kharif (15 June-15 October) is observed to be greater than 20 mm except for 40 (16.0 mm) and 41 (13.2 mm) MW. The CV ranged between 74.3% & 219.0% but it appeared that the rainfall declined and SW monsoon weakened from 37 MW (10-16 September) with increase in CV from 123% to 219% (41 MW) indicating weakening withdrawal of monsoon. The period of 15 weeks from 25 MW to 39 MW with rains greater than 20 mm and moderate CV value is the most risk-free period during which crop grows and matures later. The rainy days also followed very much similar trend. No week with RF $<$ 20 mm except 23 and 24 MW was observed indicating favourable period. For all remaining weeks on

TABLE 3

Mean weekly rainfall, rainy days and CV (%) for 29 years (1961-1989)

MW	Weekly period	RF	CV(%)	RD	CV (%)
1	1 Jan-7 Jan	3.9	267.1	0.4	264.8
2	8 Jan-14 Jan	3.7	207.3	0.6	175.8
3	15 Jan-21 Jan	3.5	347.2	0.5	258.5
4	22 Jan-28 Jan	2.0	389.4	0.3	158.1
5	29 Jan-4 Feb	4.5	357.8	0.3	231.5
6	5 Feb-11 Feb	4.9	228.8	0.4	198.4
7	12 Feb-18 Feb	5.7	205.6	0.4	165.4
8	19 Feb-25 Feb	3.1	323.5	0.3	245.7
9	26 Feb-4 Mar	5.8	240.3	0.5	191.1
10	5 Mar-11 Mar	2.8	289.0	0.3	231.5
11	12 Mar-18 Mar	6.2	268.0	0.5	158.8
12	19 Mar-25 Mar	2.4	375.4	0.4	255.5
13	26 Mar-1 Apr	1.4	315.5	0.2	282.6
14	2 Apr-8 Apr	0.8	236.6	0.2	200.0
15	9 Apr-15 Apr	1.7	213.7	0.5	158.8
16	16 Apr-22 Apr	2.3	226.2	0.4	195.4
17	23 Apr-29 Apr	3.8	265.9	0.3	162.4
18	30 Apr-6 May	3.3	425.4	0.2	338.3
19	7 May-13 May	0.1	381.0	0.1	282.6
20	14 May-20 May	2.6	224.0	0.4	156.5
21	21 May-27 May	4.4	205.1	0.6	164.8
22	28 May-3 Jun	2.5	174.8	0.5	131.8
23	4 Jun-10 Jun	19.5	145.8	1.9	93.0
24	11 Jun-17 Jun	36.8	120.5	2.1	76.9
25	18 Jun-24 Jun	58.9	74.3	3.4	53.8
26	25 Jun-1 Jul	58.3	81.3	3.4	52.8
27	2 Jul-8 Jul	64.0	91.9	3.8	48.8
28	9 Jul-15 Jul	73.7	85.7	3.9	49.0
29	16 Jul-22 Jul	63.7	85.6	3.8	52.8
30	23 Jul-29 Jul	66.8	95.9	3.8	52.7
31	30 Jul-5 Aug	67.1	83.8	4.0	50.3
32	6 Aug-12 Aug	66.0	92.2	4.4	44.3
33	13 Aug-19 Aug	55.0	84.6	3.4	39.5
34	20 Aug-26 Aug	45.7	107.2	3.2	72.6
35	27 Aug-2 Sep	63.4	110.0	3.2	61.1
36	3 Sep-9 Sep	50.8	105.2	3.2	52.7
37	10 Sep-16 Sep	30.9	123.1	2.2	66.3
38	17 Sep-23 Sep	44.3	125.3	2.2	91.1
39	24 Sep-30 Sep	23.7	144.7	2.0	96.6
40	1 Oct-7 Oct	16.0	150.5	1.4	118.9
41	8 Oct-14 Oct	13.2	219.1	0.7	168.6
42	15 Oct-21 Oct	3.5	236.6	0.4	207.0
43	22 Oct-28 Oct	16.3	237.2	0.7	219.3
44	29 Oct-4 Nov	2.7	258.6	0.3	261.4
45	5 Nov-11 Nov	2.9	398.5	0.2	308.5
46	12 Nov-18 Nov	0.9	512.0	0.1	530.3
47	19 Nov-25 Nov	5.9	294.0	0.2	232.5
48	26 Nov-2 Dec	7.1	308.3	0.4	225.4
49	3 Dec-9 Dec	7.5	343.0	0.2	308.5
50	10 Dec-16 Dec	7.6	413.5	0.3	335.2
51	17 Dec-23 Dec	1.7	360.8	0.2	282.6
52	24 Dec-31 Dec	2.9	251.1	0.2	254.1

TABLE 4

Highest, lowest rainfall (mm) with their frequencies, normal rainfall and rainfall at various dependability levels during different MW

Met. week	Rainfall			Various probability levels of rainfall				
	Highest	Lowest	Normal	50%	75%	80%	85%	90%
				Kharif season				
25	151.8	0(2)	58.9	44.5	18.0	14.1	7.2	5.0
26	179.4	0(2)	38.3	47.3	14.9	11.8	6.2	4.4
27	243.3	0(2)	64.0	40.6	26.6	21.8	16.3	9.9
28	246.3	0(Nil)	73.7	64.0	18.7	14.4	10.2	4.3
29	206.4	0(3)	63.7	44.5	28.1	21.4	12.5	5.5
30	301.7	0(3)	66.8	53.4	31.8	18.6	12.0	6.8
31	207.8	0(1)	67.1	51.2	18.8	16.4	13.6	11.9
32	252.5	0(1)	66.0	45.2	23.3	17.2	14.4	9.1
33	175.4	0(Nil)	55.0	44.7	11.2	9.2	6.6	5.0
34	234.4	0(6)	45.7	26.5	4.6	1.3	0.0	0.0
35	353.3	0(3)	63.4	50.0	26.6	14.6	4.7	2.4
36	228.0	0(1)	50.8	36.3	15.2	13.0	6.5	3.0
37	162.8	0(3)	30.9	20.2	8.2	7.6	4.5	1.6
38	200.2	0(7)	44.3	13.7	2.0	0.0	0.0	0.0
39	141.0	0(7)	23.7	8.0	1.0	0.0	0.0	0.0
40	90.4	0(15)	16.0	6.5	0.0	0.0	0.0	0.0
41	118.6	0(17)	13.2	0.0	0.0	0.0	0.0	0.0
				Rabi season				
42	33.4	0(22)	3.5	0	0	0	0	0
43	137.6	0(22)	16.3	0	0	0	0	0
44	27.3	0(24)	2.7	0	0	0	0	0
45	60.2	0(25)	2.9	0	0	0	0	0
46	24.4	0(26)	0.9	0	0	0	0	0
47	70.0	0(22)	5.9	0	0	0	0	0
48	109.3	0(23)	7.1	0	0	0	0	0
49	102.4	0(25)	7.5	0	0	0	0	0
50	165.0	0(23)	7.6	0	0	0	0	0
51	31.2	0(24)	1.7	0	0	0	0	0
52	29.2	0(24)	2.9	0	0	0	0	0
1	44.9	0(24)	3.9	0	0	0	0	0
2	34.7	0(20)	3.7	0	0	0	0	0
3	63.6	0(22)	3.5	0	0	0	0	0
4	39.5	0(23)	2.0	0	0	0	0	0
5	67.8	0(23)	4.5	0	0	0	0	0
6	43.0	0(23)	4.9	0	0	0	0	0
7	46.0	0(20)	5.7	0	0	0	0	0
				Summer season				
8	49.6	0(23)	3.1	0	0	0	0	0
9	50.9	0(21)	5.9	0	0	0	0	0
10	38.4	0(23)	2.8	0	0	0	0	0
11	73.0	0(19)	6.2	0	0	0	0	0
12	47.0	0(23)	2.4	0	0	0	0	0
13	16.6	0(23)	1.4	0	0	0	0	0
14	6.6	0(22)	0.8	0	0	0	0	0
15	17.6	0(10)	1.7	0	0	0	0	0
16	19.0	0(21)	2.3	0	0	0	0	0
17	41.1	0(20)	3.8	0	0	0	0	0
18	74.4	0(25)	3.3	0	0	0	0	0
19	3.2	0(24)	0.1	0	0	0	0	0
20	23.0	0(18)	2.7	0	0	0	0	0
21	40.4	0(11)	4.4	0	0	0	0	0
22	16.0	0(12)	2.5	0	0	0	0	0
23	94.5	0(6)	19.5	5.5	1.4	0	0	0
24	138.0	0(6)	36.8	21.35	1.0	0	0	0

TABLE 5

Gradation and weightages of the parameters accounting for RDMS

(i) Start of monsoon					
Gradation	Very early 4-10 Jun 23 (MW)	Early 11-17 Jun (24 MW)	Normal 18-24 Jun (25 MW)	Late 25-1 Jul (26 MW)	Very late 2-8 Jul (27 MW)
Weightage	5	4	3	2	1
(ii) Continuous dry and stress weeks					
Gradation	No dry week	Continuous 1 week	Continuous 2 week	Continuous 3-4 week	Continuous 5 or more week
Weightage	5	4	3	2	1
(iii) Cessation of monsoon					
Gradation	Very early 38 MW and before	Early 39 MW	Normal 40 MW	Late 41 MW	Very late 42 MW and later
Weightage	1	2	3	4	5
(iv) Duration of monsoon					
Gradation	Longest >18 weeks	Long 16-18 weeks	Normal 14-16 weeks	Short 14-12 week	Shortest <11 weeks
Weightage	5	4	3	2	1
(v) Monsoon rainfall sufficiency					
Gradation	Large excess >60%	Excess +20 to +59%	Normal +19 to −19%	Deficient −20 to −59%	Large deficient < −60%
Weightage	5	4	3	2	1

annual basis except (23-41 MW and 43 MW) the weekly rainfall ranged between 0.1 & 7.6 mm with CV from 174.1 to 512.0% indicating unfavourable period for crop growth.

Weekly highest, lowest rainfall (mm) with their frequencies alongwith the mean rainfall and the rainfall dependability at 75, 80, 85, 90% levels are given in Table 4. Rather than using mean rainfall data, a dependable level of rainfall has more significance in crop production and was computed. During rabi (42-7 MW) and summer (8-24 MW), though much difference in highest rainfall was observed, lowest rainfall in almost all the weeks was only zero with large frequencies. Similarly at 75% or above level, there was no dependable rainfall at all in any week except 23 and 24 MW during rabi and summer seasons, thus asking for irrigation only. During 25-37 MW there is rainfall at all dependable 75, 80, 85, 90% levels. This 13 weeks' duration is the period of most assured rainfall during which crops pass through various phases, *viz.*, germination, vegetative growth and reproductive phase. There is only 2.0 and 1.0 mm rainfall in 38 and 39 MW at 75% level only which help the short duration crops like sorghum for grain filling. In the later period (40 and 41 MW) no rainfall at any level was recorded and this may accelerate maturity in short duration crops, *viz.*, sorghum, groundnut etc.

4. Relative degree of monsoon satisfaction (RDMS)

Neither the total rainfall nor its distribution nor both of these parameters together are sufficient to indicate the significance and usefulness of the rainfall in crop production. Therefore, an attempt was made to develop such an index which can indicate and assess the satisfaction of rainfall degree in crop production. In crop production, the five parameters, *viz.*, start of monsoon (early, normal or late), duration of continuous dry and stress weeks during critical stages, cessation of monsoon, duration of monsoon activity and rainfal

TABLE 6

Starting of sowing rains, cessation of rains, stress and dry weeks, and relative degree of monsoon satisfaction (RDMS %) for 1961-1989

Year	Start of rains ≥20 mm (MW)	Sowing rains RF≥5*e* +10 mm (MW)	Cessation of monsoon rains (MW)	Growing period (weeks)	Stress(S) and dry (D) week (MW)	Monsoon RF (mm)	Monsoon description	Relative degree of monsoon satisfaction (%)
1961	24	24	42	18	S—*25,26*,39	1143.8 E	E/O/VL-18 E	92
1962	27	27	39	12	D—29,31,34	994.3 N	VL/V D_1 D_2/E-12 N	48
1963	23	23	39	16	D—*25,26*,29	739.3 N	VE/S $D_{1-2}VD_1$/E—16 N	60
1964	25	25	41	16	D—39	1050.9 E	N/MD_1/I—16 E	72
1965	24	24	39	14	S—37	717.0 N	E/O/E—14 N	64
1966	25	25	37	12	S—27,34 D—26	888.5 N	N/SD_1/VE—12 N	52
1967	25	25	40	15	S—28,36,38	974.3 N	N/O/N—15 N	80
1968	24	24	40	16	S—28,32, D—*34,35*	742.7 N	E/GD_{1-2}/N—15 N	64
1969	23	25	40	15	S—28,33,36	892.8 N	N/O/N—15 N	68
1970	23	23	40	17	Nil	1116.7 E	VE/O/N-17 N	80
1971	20	25	43	19	S—28,*32,33* D—*37,38*,41	907.8 N	N/G-D_{1-2},MD_1/VL—19 N	76
1972	25	27	42	14	D—30,*38,39*	522.5 D	N/SD_1,GD_{1-2}/VL—14 D	68
1973	24	27	44	17	S—37,*39,41,42* D—30	918.9 N	VL/VD_1/VL—17 N	72
1974	23	23	44	21	S—*36,37,38* D—24,*34,35*	721.4 N	VE/SD_1, GD_{1-2}/VL—21 N	84
1975	26	26	45	19	D—31,*41,42*	937.2 N	L/VD_1, MD_{1-2}/VL—19 N	76
1976	26	26	37	11	D—30,34,37	874.4 N	L/VD_1, GD_1 D_2 /VE—11 N	40
1977	24	24	41	18	S—*39,40* D—26,36,38	760.4 N	E/VD_1,GD_1 D_2/L—18 N	76
1978	24	24	40	16	Nil	801.3 N	E/O/N—16 N	76
1979	25	25	39	14	D—29,34,39	872.0 N	N/VD_1 D_2, GD_1/E—14N	60
1980	23	23	38	15	D—30,38	658.8 D	VE/VD_1,GD_1/VE—15 D	60
1981	25	25	40	15	D—*33,34*	1224.6 E	N/VD_{1-2}/N—15 E	64
1982	24	25	38	13	S—32,34,37 D—*26,27*	425.5 D	N/SD_{1-2}/VE—13 LD	44
1983	24	24	41	13	S—37,41	1040.5 E	E/O/L—13 E	76
1984	24	24	42	17	S—*34,35,36*,39 D—30,38,40	1012.3	E/VD_1, GD_1 D_2/VL—17 N	80
1985	23	23	42	19	S—38 D—34,42	997.5 N	VE/VD_1, MD_1/VL—19 N	88
1986	25	25	41	16	S—31,38,40 D—*34,35*	799.5 N	N/VD_{1-2}/L—16 N	64
1987	23	23	36	13	S—25,28,33 D—36	635.0 D	VE/VD_1/VE—13 D	56
1988	25	25	41	15	D—32	1036.3 E	N/VD_1/L—15 E	72
1989	23	26	40	14	S—28,36 D—31	593.5 D	L/VD_1/N—14 D	56

sufficiency, all contribute to make an individual season superior, normal or inferior. These parameters need to be considered in the context of crop growth, especially the critical stages, to assess the performance of monsoon and need to be weighed. Each of these parameters was graded and weighed on 5-point scale on the basis of its contribution in the crop growth assessed from the background studies in the region as indicated in Table 5.

All those parameters either singly or jointly act to decide the performance of the season. Thus, the situation posed by very early start of monsoon (VE=5), no dry week (5), very late monsoon cessation (5), longest monsoon duration (5) and large excess rainfall (5) will fetch 25 points or relative degree of monsoon satisfaction (RDMS=100%) ensuring sufficient, well-distributed rainfall, largest cropping season and no breaks suppressing any critical stage, naturally defining the best kharif. On the contrary, the situation met with very late start of monsoon (1), shortest of monsoon duration (1) and large deficient rainfall (1) bring about the situation unfavourable for sowing, vegetative growth, grain filling etc. describing droughty season, erratic and insufficient rainfall with ill distribution, shortest growing season and will be the worst season with 5 points or RDMS 20%. All other situations lie between these two extremities.

In Table 6, yearwise percentile index (RDMS) alongwith other useful parameters in crop season like, starting of rains $\geqslant$ 20 mm, starting of sowing rains, cropping period, stress and dry weeks etc are given. Starting date of rainy season is an important variable. Adequate rainfall is required initially for land preparation and sowing of the crops. A week with rains more than 20 mm in two consecutive days followed by a wet spell (Virmani 1975) is reckoned as start of rains. It is revealed from the table that there was highest probability (31.0%) of start of rains in 23 MW followed by 24 MW and 25 MW wherein there is equal probability (27.6 %). The mean week for start of rains was 24 MW. Eventhough rainfall of 20 mm is sufficient for sowing the crops in the sandy and laterite soils, in the Nagpur region with vertisols, this rainfall (20 mm) is inadequate for safe germination and establishment of the crop stand. Therefore, the criterion $R \geqslant 5e + 10$ mm (Ashok Raj 1979) for onset of effective monsoon was employed (e=evaporation in mm). Using value for normal evaporation this criterion becomes $R \geqslant 55$ mm and a week with rainfall equal to 55 mm is, therefore, reckoned as start of sowing rains. There was highest frequency (34.5%) of sowing rains in 25 MW followed by 24 MW (24.3 %) and 23 MW (20.2 %), being lowest in the 26 and 27 MW (10.3 % each). Cessation of rains decides finally the growing period and, therefore, important. The frequency of cessation of rains in 40 MW was highest (21.4 %) followed by 41 MW (17.2 %), 39 and 42 MW (14.3 %), 37 and 38 MW (7.0 %), 44 MW (7.0 %) and the lowest in 36 and 45 MW (3.6%). Longest growing season of 21 weeks in 1974 and shortest growing period of 12 weeks in 1962 were observed. Mean growing period in the Nagpur region was 15 weeks.

In Table 6, stress weeks receiving rains less than 10 mm and dry weeks with no rainfall are also shown. Two or more continuous dry weeks depending on crop phase may affect the crop differently. Thus 2 or more dry weeks during germination or after sowing, 4 or more dry weeks during vegetative growth, 2 or more dry weeks during reproductive phase and 4 or more dry weeks during grain filling or maturity are found disastrous from the past studies in the region. In Table 6 individual dry weeks are shown as D with their numbers and two or more continuous dry weeks with numbers are in italic. Stress weeks are shown by S and two or more continuous stress weeks are in italics. From Table 6, it is seen that a single dry or stress week was more frequent and common and could be easily accommodated by the crops. The frequency of 2 continuous dry weeks was 31.0 % but no dry period with 3 or 4 weeks duration was observed.

Description of monsoon can be abbreviated by the 5 parameters in sequence, namely, start of monsoon (VE-very early, E-early, N-normal, L-late, VL-very late), dry weeks alongwith the phase with which they are associated (O-no dry week, D_1-1 dry week, D_{1-2}-two continuous dry weeks, S-after sowing, V-vegetative phase, G-grain filling, M-maturity), cessation of monsoon, the length of growing season and the total rainfall (normal, deficient, excessive, large deficient etc) and is shown in Table 5. The relative degree of satisfaction of monsoon is also shown in Table 6. In the last 29 years (1961-1989), kharif season was poor (RDMS$\leqslant$50%) in three years, unsatisfactory (51-60%) in 5 years, satisfactory (61-70%) in 6 years, very satisfactory (71-80%) in 12 years and excellent (81% and above) in 3 years.

Ghadekar and Patil (1989, 1990) have studied the water requirements of the various crops in the region following a climatological approach. Considering the mean kharif rainfall of 861.5 mm, the crops of short duration and medium duration like sunflower (489.9 mm), groundnut (563.8 mm), soybean (583.1 mm), sorghum (587.1 mm), maize (636.1 mm) seem to be risk-free, however, crops of longer duration ($\geqslant$18 weeks) like cotton (939.8 mm) and rice (876.0 mm) have some marginal risk.

5. Conclusions

These studies have clearly shown that the annual rainfall (CV 17.6 %) and rainy days (CV 13.4 %) in the Nagpur region have low variation. Kharif season with mean rainfall (861.5 mm) and with CV 20.8% has assured and most risk-free cropping season of 13 weeks (25-37 MW) with dependable rainfall at 75, 80, 85 and 90 % probability levels. The cropping period at 75% probability levels, however, was found to be of 15 weeks. In rabi and summer seasons, there was no rainfall at any dependable level of probability, the situation being risky and asking for irrigation. Normally, the sowing rains started in 25 MW (34.5 %) and ceased in 40 MW (21.4 %). Strategy for stabilizing rainfed crop yield includes the adaptation of short to medium duration crops of (16-18 weeks) with water requirements 500-900 mm like groundnut, maize, soybean etc. Long duration crops like cotton, rice can be adapted with marginal risk. In the last 29 years (1961-1989), the kharif season was poor and unsatisfactory (RDMS $\leqslant$60%) in 27.9% cases while it was very satisfactory and excellent (RDMS $>$70%) in 62.0% cases.

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