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Models for Agricultural Drought Investigations at Koraput (Orissa)

Susama Sudhishri*, R.K.Panda and U.S. Patnaik*****

ABSTRACT

Rainfall and maximum and minimum temperature data of 32 years (1970- 2001) at Semiliguda, Koraput (Orissa) were analysed to study the weekly, monthly and yearly drought and comparing the different models for finding a suitable method for drought investigation by studying the water balance. The IMD method was adjudged more suitable for drought identification than the revised IMD method. Frequency analysis was done to predict weekly, monthly, seasonal and annual rainfall at different per cent chances.

INTRODUCTION

Frequent occurrence of drought despite a good annual rainfall of about 1522 mm (Anonymous, 2001) is a bane for agricultural development of the tribal district of Koraput in Orissa. For regional planning in terms of development of water resources for agriculture, knowledge of annual drought frequency is more relevant. For the development of crop plan and irrigation strategy to meet the crop water requirement, one needs to know the adequacy of rainfall and occurrence of short period drought condition lasting for a week or a month. In this paper, drought was investigated on annual, monthly and weekly basis; a suitable method of drought analysis was identified and water deficit or surplus was investigated through water balance computation.

MATERIALS AND METHODS

The daily rainfall, maximum and minimum temperature data of 32 years (1970-2001) were obtained from Agricultural Meteorological Observatory, Mixed farm, Govt. of Orissa and the Research Center of the Central Soil and Water Conservation Research and Training Institute, Semiliguda in the Koraput district of Orissa. These data were the basis of all subsequent analysis.

Determination of drought condition

The following definitions given by Sharma *et.al.* (1979) for monthly and yearly droughts and by Ramdas and Mallik (1948) for weekly drought were the basis for drought identification in the present study.

a) Drought weeks/ months - any week/ month receiving precipitation less than 50% of the average weekly/monthly rainfall.

b) Abnormal week/month - any week/ month receiving precipitation more than twice the average weekly/monthly rainfall.

*Scientists, ** Senior Scientist, *** Principal Scientist and Head of the Center, CSWCRTI, Research Centre, P B 12, Sunabeda-763 002, Koraput, Orissa.

c) Normal week/month - any week/month receiving precipitation in between 50% and 200% of the average weekly/monthly rainfall.

d) Drought year - any year receiving rainfall less than or equal to P_{av} - S

e) Abnormal year - any year receiving rainfall more than or equal to P_{av} + S

f) Normal year - any year receiving rainfall in between (P_{av} + S) and (P_{av} – S)

where, P_{av} is the mean yearly rainfall and S is the standard deviation of annual rainfall.

Determination of drought intensity/ severity

The method used by IMD and revised IMD (Ravikumar and Karmegam, 1996) was used for the present drought intensity study and a comparison was made between the two.

A. IMD method

Following this method, drought was assessed on the basis of percentage deviation D_i of rainfall from the long-term mean rainfall.

$$D_i = \{(P_i - PM)/PM\}*100 \quad \ldots (1)$$

where, P_i is the rainfall in the time period i (i.e. may be week, month or year) and PM is the long-term mean rainfall. The percentage deviation of rainfall and the category of drought assessment as used by IMD are shown in Table 1.

B. Revised IMD method

In this method, drought is assessed on the basis of percentage deviation of cumulative rainfall from the cumulative long-term mean rainfall. The percentage deviation is given by:

$$CD_i = \{(Pc_i - PCM_i)/PM\}*100 \quad \ldots (2)$$

Where, Pc_i = cumulative actual rainfall up to the time period i,

Table 1. IMD classification of drought.

Percentage deviation (D_i)	Class	Category
>0	M0	No drought
0 to -25	M1	Mild
-25 to -50	M2	Moderate
<-50	M3	Severe

PCM_i = cumulative long term mean rainfall up to the time period i,

PM = long term mean rainfall for the entire duration of data

The procedure is such that the excess or deficit of rainfall of the preceding time periods will be influencing the adequacy of present time period's rainfall in meeting the requirement for the cumulative long-term mean rainfall.

Probability analysis of drought and monthly rainfall

The rainfall frequency analysis was computed using Weibull' method (Chow, 1964). The probability p in per cent was expressed as:

$$p = m/(n+1) *100 \quad \ldots (3)$$

Where, m = rank number of the data arranged in descending order and n = total number of years of data.

Water balance study

Crop coefficient and crop evapotranspiration. Hargreaves *et.al.*(1985) and Hargreaves (1994) presented a procedure for estimating reference crop evapotranpiration ET_0 (mm/day) requiring the measured data of only the maximum and minimum temperature.

$$ET_0 = 0.0022*RA*(Tc+17.8)*TD^{0.5} \quad \ldots (4)$$

where, RA = extra terrestrial radiation,

mm/day (vide Table of Doorenboos and Pruitt, 1977.

Tc = mean temperature. ^{0}C

TD = Difference between maximum and minimum temperature, ^{0}C

Penman-Monteith equation, recommended by FAO has been accepted world wide for computation of ET crop. Jensen *et.al.* (1997), however, opined that when fewer weather parameters are available, the Hargreaves method may be the natural choice for estimating actual crop evapotranspiration, as it gives results comparable to those obtained by using the FAO version of the Penman-Monteith method.

In order to generate daily crop coefiicient (Kc) values for the crop growing period, Mishra et. al. (2000) fitted the following polynomial equation for Kc value for paddy

$$Kc= a_0 + a_1(DAT) + a_2(DAT)^2 + a_3(DAT)^3 \quad \ldots (5)$$

Where, DAT = the days after transplanting of the paddy crop and the values of the polynomial constants were: a_0= 5.31844* 10^{-2}; a_1= 4.18136*10^{-2}; a_2= -4.74297*10^{-4}; a_3 = 1.61472*10^{-6}.

Actual crop Evapotranspiration, ETc is given by:

$$Etc = ET_0 * Kc \quad \ldots (6)$$

Deep percolation loss

An empirical relationship (Srivastava, 1998) was adopted to determine seepage and percolation loss. The relation is:

$$SP= 2.0786+(0.0388*D) \quad \ldots (7)$$

Where, D = depth of ponding, cm and and SP = deep percolation, mm/day. Various numerical values of depth of ponding for different paddy crop growing period has been assumed as mentioned below:

D = 2cm for first 30 day for paddy crop i.e. for transplanting.

= 3cm for next 20 days i.e. for tillering stage.

= 5cm for next 35 days i.e. panicle initiation stage.

= 5 cm for next 45 days i.e. for flowering and grain formation stage.

= 1 cm for next 25 days i.e. for grain growth and maturity stage.

Comparison between IMD and revised IMD method

One graph was prepared between standard meteorological weeks for *kharif* season i.e. 24th to 46th week giving weightage factor of 10 and this was superimposed with water balance curve between rainfall and ETc + SP for comparing the above two methods.

RESULTS AND DISCUSSION

On the basis of the definitions described earlier, the rainfall values for normal (N), abnormal (A) and drought (D) conditions with average values are given in Table 2.

Normal, abnormal and drought months

Normal months. The analysis reveals that during 32 years, about 53.38% of the months were normal. Thus in a particular year, the expected number of normal month would be 6.4. The rainfall-based criteria for normal, abnormal and drought months and the distribution of such months are given in Tables 2 and 3, respectively. About 45.38% normal months occur between October to May and rest during monsoon. During 32 years, maximum 9 months were normal.

Abnormal months. About 11.46% of the total number of months are abnormal and

Table 2. The rainfall for a month to be normal, abnormal or drought and the average rainfall

Month	CV (%)	Average rainfall (mm)	Standard deviation (mm)	For normal months (mm)	For abnormal months (mm)	For drought months (mm)
January	195.2	4.4	8.5	2.2-8.7	≥ 8.7	< 2.2
February	195.7	10.2	20.0	5.1-20.5	≥ 20.5	< 5.1
March	121.9	26.1	31.8	13.0-52.1	≥ 52.1	< 13.0
April	68.8	50.2	34.5	25.1-100.3	≥ 100.3	< 25.1
May	87.2	94.0	81.9	47.0-188.0	≥ 188.0	< 47.0
June	55.3	184.4	101.9	92.2-368.8	≥ 368.8	< 92.2
July	35.0	352.8	123.4	176.4-705.6	≥ 705.6	< 176.4
August	34.1	322.9	110.1	161.4-645.7	≥ 645.7	< 161.4
September	49.0	212.2	104.1	106.1-424.4	≥ 424.4	< 106.1
October	70.0	89.2	62.5	44.6-178.3	≥ 178.3	< 44.6
November	139.1	30.1	41.9	15.1-60.2	≥ 60.2	< 15.1
December	227.6	3.3	7.5	1.7-6.6	≥ 6.6	< 1.7
Annual	18.5	1373.2	254.5	1118.7-1627.7	≥ 1627.7	< 1118.7

Table 3. Distribution of normal (N), abnormal (A) and drought (D) months

Month	Percentage of months falling in the given month as			Percentage of total years having the given month as		
	N	A	D	N	A	D
January	1.95	15.91	15.56	12.5	21.88	65.62
February	2.93	13.64	14.81	18.75	18.75	62.5
March	6.83	9.09	10.37	43.75	12.5	43.75
April	9.76	9.09	5.93	62.5	12.5	25
May	9.27	9.09	6.67	59.38	12.5	28.12
June	11.71	6.82	3.7	75	9.37	15.63
July	14.14	0	2.22	90.63	0	9.37
August	14.63	0	1.48	93.75	0	6.25
September	14.14	2.27	1.48	90.63	3.12	6.25
October	9.76	4.54	7.41	62.5	6.25	31.25
November	4.88	13.64	11.85	31.25	18.75	50
December	0	15.91	18.52	0	21.88	78.12

about 90.91% of them occur between October to May and rest during monsoon. About 15.91%, which is the largest of the total abnormal months coincide with December-January. Per cent of total years having a given number of abnormal months and probability distribution of abnormal months in a year are shown in Tables 3 and 4, respectively. During 32 years maximum 4 months were abnormal.

Drought months. About 35.16% of the total number of months are drought months. The per cent of total years with a given number of drought months and the probability distribution of drought months in a year are shown in Tables 3 and 4, respectively. During 32 years maximum 8 were drought months.

Of the total drought months, 16.29% occur between June and October and the

Table 4. probability distribution of drought, normal and abnormal months

Drought months(Dm)			Normal months (Nm)			Abnormal months(Am)		
No.	Probability	% of Dm	No.	Probability	% of Nm	No.	Probability	% of Am
8	0.03	3	9	0.06	6	4	0.03	3
7	0.03	0	8	0.18	12	3	0.15	12
6	0.21	18	7	0.48	30	2	0.45	30
5	0.42	21	6	0.76	28	1	0.76	31
4	0.7	28	5	0.85	9	0	0.97	21
3	0.79	9	4	0.97	12			
2	0.94	15						
1	0.97	3						

Table 5. Probability distribution of M3, M2, M1 & M0 months (IMD method)

Severe drought			Moderate drought			Mild drought			No drought		
No.	Probability	%	No.	Probability	%	No.	Probability	%	No.	Probability	%
7	0.24	24	2	0.24	24	4	0.03	3	6	0.06	6
6	0.85	61	1	0.39	15	3	0.03	0	5	0.45	39
5	0.88	3	0	0.97	58	2	0.15	12	4	0.79	34
4	0.97	9				1	0.55	40	3	0.94	15
						0	0.97	42	2	0.97	3

percentage distribution of drought months during June, July, August, September and October are 22.71, 13.63, 9.08, 9.08 and 45.5 respectively. Similarly, during *rabi* season (November to March), 71.11% of the total months are drought months. This shows the likelihood of failure of *rabi* crops under rainfed conditions in most of the years. The percentage distribution of drought months in *rabi* season are 16.66, 26.04, 21.88, 20.83 and 14.58 during November, December, January, February and March, respectively.

Monthly drought intensity

a) IMD method

About 50.52%, 7.03% and 6.25% of the total months were severe, moderate and mild drought months, respectively. The probability distribution of the months of different drought categories and the percentage of months and years falling under different drought categories are given in Tables 5 and 6, respectively. Maximum 7, 2 and 4 months were severe, moderate and mild drought months, respectively. Also, 7.73%, 18.52 and 70.84% of the total severe, moderate and mild drought months, respectively, are falling between June and October. During *rabi* season 77.31%, 22,22% and 4.17% of the total months were under the categories of M3, M2 and M1. Maximum severe drought occurred in December and January, moderate drought in May and mild in September.

b) Revised IMD method

About 52.86%, 1.3% and 3.91% of the total months were under severe, moderate and mild drought categories, respectively. Probability distribution and percentage of total

Table 6. Month wise distribution of M3, M2, M1 and M0 months (IMD method)

Month	Percentage of months falling in the given month as				Percentage of total years having the given month as			
	M3	M2	M1	M0	M3	M2	M1	M0
January	16.49	0	0	0	100	0	0	0
February	15.98	0	4.17	0	96.88	0	3.12	0
March	14.95	7.41	0	0.72	90.63	6.25	0	3.12
April	9.79	25.93	16.67	1.44	59.37	21.88	12.5	6.25
May	5.15	33.33	2.78	7.91	31.25	28.13	6.25	34.37
June	1.03	7.41	16.67	17.27	6.25	6.25	12.5	75
July	0	0	4.17	22.3	0	0	3.12	96.88
August	0	0	4.17	22.3	0	0	3.12	96.88
September	0	0	25	4.68	0	0	18.75	81.25
October	6.7	11.11	20.83	7.91	40.63	9.38	15.63	34.36
November	13.4	14.81	0	1.44	81.25	12.5	0	6.25
December	16.49	0	0	0	100	0	0	0

Table 7. Probability distribution of M3, M2, M1 & M0 months (revised IMD method)

Severe drought (M3)			No drought (M0)		
No.	Probability	%	No.	Probability	%
12	0.18	18	12	0.06	6
11	0.18	0	11	0.09	3
10	0.21	3	10	0.09	0
9	0.24	3	9	0.15	6
8	0.33	9	8	0.21	6
7	0.42	9	7	0.3	9
6	0.61	19	6	0.45	15
5	0.7	9	5	0.58	13
4	0.79	09	4	0.67	9
3	0.82	3	3	0.73	6
2	0.88	6	2	0.76	3
1	0.88	0	1	0.79	3
0	0.97	9	0	0.97	18

Note: M2 occurred once and M1 occurred twice only and are not shown in the above Table.

years having the drought intensity are shown in Tables 7 and 8. During the same period, maximum 12, 1 and 2 months were under severe, moderate and mild drought categoroes, respectively. Also, 29.57%, 40% and 59.99% of the total sever, moderate and mold drought months, respectively, occurred between June and October. During *rabi* season 42.36%, 20% and 40% of the total months are observed to be M3, M2 and M1 categories. Maximum severe drought occurred in May.

WEEKLY DROUGHT ANALYSIS

Normal, abnormal and drought weeks. The average rainfall of different weeks varied from 6.03mm in 45th week to 82.63 mm in 27th week. The weekly drought events varied

Table 8. Month wise distribution of M3, M2, M1&M0 (Revised IMD method)

Month	Percentage of months falling in the given month as having				Percentage of total years the given month as			
	M3	M2	M1	M0	M3	M2	M1	M0
January	9.36	0	0	8.07	59.38	0	0	40.62
February	10.34	0	13.33	5.59	65.63	0	6.25	28.12
March	12.81	0	6.67	3.11	81.25	0	3.13	15.62
April	13.79	20	0	1.86	87.5	3.13	0	9.37
May	14.29	20	0	1.24	90.62	3.13	0	6.25
June	13.3	20	0	2.48	84.37	3.13	0	12.5
July	6.9	0	33.33	8.07	43.75	0	15.62	40.63
August	3.45	20	13.33	13.66	21.87	3.13	6.25	68.75
September	2.96	0	13.33	14.91	18.75	0	6.25	75
October	2.96	0	0	16.15	18.75	0	0	81.25
November	4.43	0	6.67	13.66	28.12	0	3.13	68.75
December	5.42	20	13.33	11.18	34.37	3.13	6.25	56.25

from a minimum of 7 in the 28th week to a maximum of 27 in the 46th week during the 32 years period. There is a 97% probability of getting 20 drought, 9 normal and 2 abnormal weeks in a year (Table 9) and 30.94% of the drought weeks occurred between 24th to 46th week.

IMD method. During 32 years of record, 22.65% of the severe drought weeks fall between 24th to 46th weeks. There is a 97% probability of getting 24 severe, zero moderate, zero mild and 10 drought weeks in a year (Table 10)

Revised IMD method. In this method 50.24%, 0.54%, 0.48% and 48.73% are under M3, M2, M1 and M0 years respectively. It was found that 34.12% of the total severe drought weeks are falling between 24th to 46th week and maximum in 24th week.(Table 11).

Yearly drought analysis

Normal, abnormal and drought years. The mean and the standard deviation of annual precipitation of the study area are 1373.23mm and 254.51mm, respectively. Thus, any year receiving rainfall less or equal to 1118.72 mm will be a drought year. Any year receiving rainfall equal to or more than 1627.74mm will be abnormal year and between 1118.72 and 1627.74mm will be normal year. During the 32 years period 6.25%, 81.25% and 12.5% were drought, normal and abnormal years, respectively. Therefore, on an average, there will be one drought year in every sixteen-years.

IMD method. Of the total number of years, 40.63%, 56.25% and 3.12% were no drought, mild drought and moderate drought years, respectively i.e. there will be one mild drought year in every two years and one moderate drought year in every thirty-two year period.

Revised IMD method. Of the total number of years, 56.25%, 25%, 9.38 and 9.38% were no drought, mild drought, moderate and severe drought years, respectively i.e. there will be one mild drought years in every four years period, one moderate drought year in every eleven years period and

Table 9. Probability analysis of normal, abnormal and drought weeks.

Drought			Normal			Abnormal		
No.	Probability	%	No.	Probability	%	No.	Probability	%
37	0.03	3	20	0.06	6	13	0.06	6
36	0.09	6	19	0.09	3	12	0.09	3
35	0.09	0	18	0.18	9	11	0.12	3
34	0.21	12	17	0.3	12	19	0.15	3
33	0.27	6	16	0.36	6	9	0.24	9
32	0.36	9	15	0.42	6	8	0.36	12
31	0.42	6	14	0.61	19	7	0.55	19
30	0.58	6	13	0.7	9	6	0.79	24
29	0.73	15	12	0.91	21	5	0.85	6
28	0.76	3	11	0.91	0	4	0.88	3
27	0.85	9	10	0.91	0	3	0.91	3
26	0.88	3	9	0.97	6	2	0.97	6
25	0.91	3						
24	0.91	0						
23	0.94	3						
22	0.94	0						
21	0.94	0						
20	0.97	3						

one severe drought year in every eleven years period.

Monthly rainfall analysis

The analysis of monthly rainfall data shows that minimum average rainfall of 3.31mm was received during December and the maximum average rainfall of 352.78 mm was received during July. Drought was observed in 2 out of 32 years during august while in 25 out of 32 years in the month of December. From Table 12, it is observed that at 90% probability, only 1236 mm of rainfall could be expected per annum and this value remains below the drought definition level. A rainfall of 15.6mm may be expected in December once in 10 years and for the entire *rabi* season, a rainfall of 68.7mm is expected every 2 years. This shows the inadequacy of rainfall during the *rabi* season, thereby preventing the farmers to go for *rabi* crops.

Water balance study and comparison of models

From 24th to 46th week evapotranspiration and deep percolation were calculated and water balance diagram was superimposed on the weightage map of the drought intensity (Fig.1). It was observed that total surplus was 363.38 mm and the deficit was 212.68 mm. It was also observed that IMD method and Sharma *et.al.* methods gave results very close to each other with a greater variation with revised IMD method. Therefore, IMD method of estimation of drought is accepted for the region.

Table 10. Probability analysis of M3, M2, M1&M0 (IMD method).

Severe drought			Moderate drought			Mild drought			No drought		
No.	Probability	%	No.	Probability	%	No.	Probability	%	No.	Probability	%
37	0.03	3	6	0.03	3	6	0.03	3	20	0.03	3
36	0.06	6	5	0.09	6	5	0.12	9	19	0.15	12
35	0.15	9	4	0.39	30	4	0.3	18	18	0.3	15
34	0.15	0	3	0.64	25	3	0.45	15	17	0.42	12
33	0.21	6	2	0.82	18	2	0.73	28	16	0.45	3
32	0.36	15	1	0.94	12	1	0.94	21	15	0.61	16
31	0.55	19	0	0.97	3	0	0.97	3	14	0.82	21
30	0.61	16							13	0.91	9
29	0.76	15							12	0.94	3
28	0.82	6							11	0.94	0
27	0.88	6							10	0.97	3
26	0.88	0									
25	0.94	6									
24	0.97	3									

Table 11. Probability analysis of M3, M2, M1 &M0 weeks (Revised IMD method)

Severe drought			No drought		
No.	Probability	%	No.	Probability	%
52	0.15	15	52	0.15	15
48	0.18	3	51	0.18	3
46	0.21	3	49	0.21	3
44	0.24	3	44	0.24	3
41	0.27	3	37	0.27	3
36	0.3	3	32	0.3	3
35	0.33	3	31	0.36	6
33	0.36	3	30	0.39	3
30	0.39	3	29	0.42	3
29	0.42	3	28	0.45	3
28	0.45	3	26	0.51	6
26	0.51	6	24	0.54	3
24	0.54	3	22	0.57	3
23	0.57	3	21	0.61	4
21	0.61	4	19	0.64	3
20	0.64	3	16	0.67	3
19	0.7	6	14	0.7	3
14	0.73	3	11	0.73	3
7	0.76	3	6	0.76	3
2	0.79	3	5	0.79	3
0	0.97	18	4	0.82	3
			0	0.97	15

Note: The number of moderate droughts were 3, 2 and 1 in the 52nd, 48th and 46th weeks and zero in all the other weeks. The number of mild droughst were 1 in the 52nd week and zero in all the other weeks.

Table 12. Expected rainfall (mm) of Semiliguda with different percent chances.

Month/ season	10%	30%	50%	70%	90%
January	21.3	3.4	0.8	0.4	0.1
Frbruary	30.6	10.1	1.1	0.6	0.2
March	65.2	31.8	18.4	5.5	0.4
April	107.3	61.9	48.9	28.3	8.0
May	235.9	116.4	65.0	56.3	16.2
June	311.7	205.4	171.6	1331	84.3
July	499.8	424.2	352.3	272..4	195.6
August	477.7	363.5	314.7	255.6	170.3
September	388.0	273.2	180.0	136.6	111.4
October	170.5	115.9	81.5	41.5	21.7
November	66.4	41.1	15.8	3.0	0.8
December	13.5	8.0	5.6	3.2	0.8
Rabi(Nov.-Mar.)	124.1	98.8	68.7	45.5	20.0
Annual	1763.9	1537.4	1310.4	1208.8	1135.6

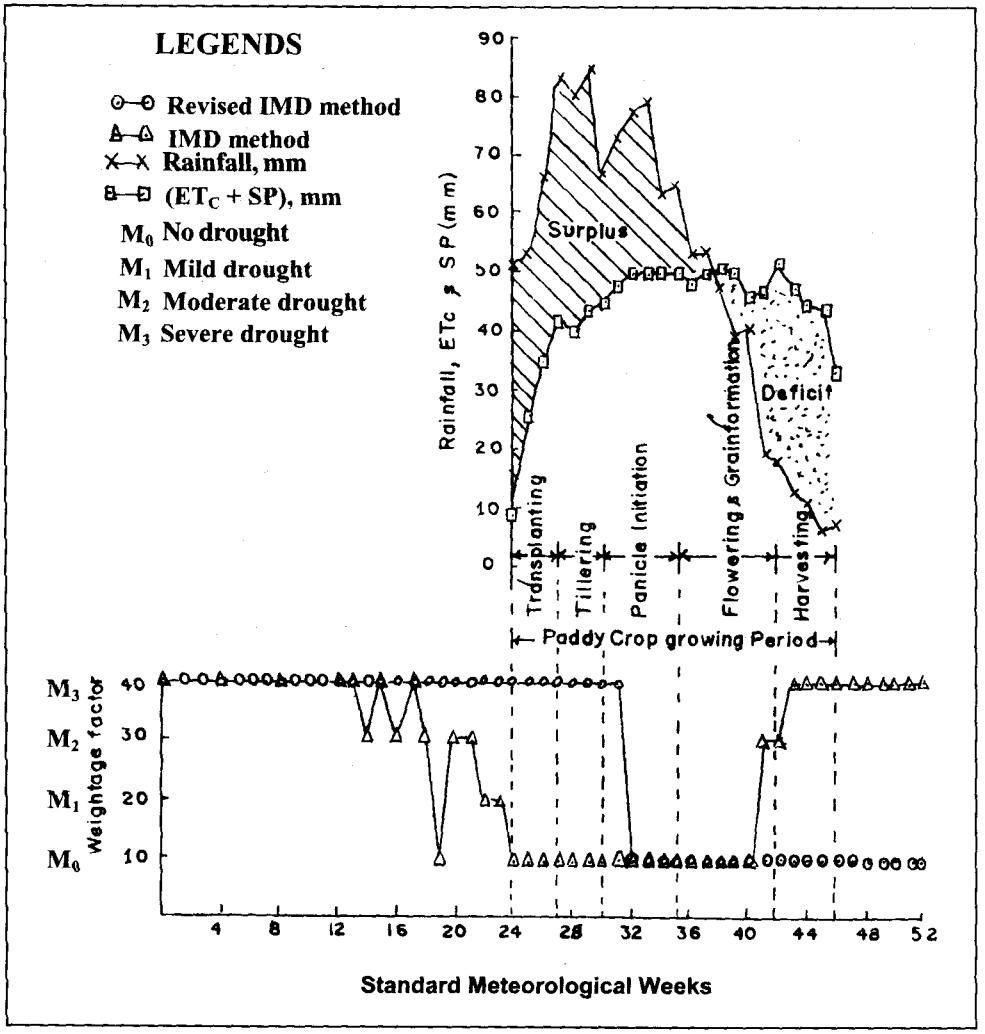

Fig. 1. Water balance study at Koraput, Orissa

CONCLUSION

Drought analysis for Semiliguda (Orissa) was done using rainfall, maximum and minimum temperature data of 32 years (1970-2001). It was observed that in any one year the expected number of drought month is 4.2 and one drought year in every sixteen-year period. IMD method was adjudged better than the revised IMD method for the region to find out the drought intensity. It was also found that maximum number of severe drought occurs in December and January, moderate drought in May and mild drought in September. The 46th week has maximum frequency of drought while minimum is in case of 28th week. Analysis also revealed erratic distribution of precipitation during *rabi* season thereby preventing the farmers to go for *rabi* crops. Therefore, the irrigation must be assured for sowing *rabi* crops.

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