Mausam, (1986), 37, 3, 377-384

632.116 : 633

An analysis of droughts in Maharashtra by a modified Palmer's approach

A. SAMBASIVA RAO* and A. R. SUBRAMANIAM
Dep. of Met. and Oceanography, Andhra University, Waltair

(*Received 23 December 1983*)

सार — महाराष्ट्र का वर्षा आधारित कृषि के सामने अनावृष्टि एक गंभीर समस्या उत्पन्न कर देता है। 1934 से '77 की अवधि में राज्य के 23 स्थानों में मौसम विज्ञान अनावृष्टियों की विभिन्न प्रबलताओं के प्रारम्भ और उनके अन्त का पता पामर विधि द्वारा लगाया गया। पामर विधि अपनाते समय विभव वाह की परिभाषा तथा मूल रूप से पामर द्वारा दिए गए भारण गुणांकों को महाराष्ट्र की जलवायु के अनुसार परिवर्तित किया गया है। इस क्षेत्र में अनावृष्टि की विभिन्न श्रेणियों के निर्धारण के लिए परिष्कृत अनावृष्टि सूचकांकों ने बहुत अच्छा काम किया। विश्लेषण से पता चलता है कि इस क्षेत्र में अनावृष्टि सम्भाव्य क्षेत्रों का स्थानिक वितरण खरीफ के मौसम (जून से सितम्बर) में भी वही होता है जो रबी के मौसम (अक्तूबर से फरवरी) में होता है। केवल खरीफ के ही मौसम में राज्य में इन 44 में से 28 साल भयंकर भीषण अनावृष्टि की हालत रही किन्तु कोल्हापुर और सिरोंच जैसे कुछ ही अल्पार्द्र स्थान हैं जहां अनावृष्टि की स्थिति कभी भी भयंकर/अत्यधिक नहीं हुई।

ABSTRACT. Droughts pose a serious problem in rainfed agriculture of Maharashtra. The commencement and cessation of different intensities of meteorological droughts during 1934-77 at 23 locations of the State are identified by using the Palmer's approach. While adopting Palmer's approach, the definition of potential runoff and the weighting factors originally given by him are suitably modified for the climatic conditions of Maharashtra. The modified drought indices performed well for identification of various classes of droughts in the region. The analysis shows that the spatial distribution of drought prone areas during kharif (June-September) is similar to that of rabi season (October-February) in the region. During kharif season alone severe/extreme drought conditions prevailed for 28 out of 44 years in the State. But there are few stations like Kolhapur and Sironcha (Sub-humid) where the drought situation never touched the extreme conditions.

1. Introduction

With an average annual rainfall of less than 1100 mm, the State of Maharashtra is generally drought-prone. Irrigation facilities are available for less than 10 per cent of the net sown area and the rainfed agriculture is mostly under the influence of the vagaries of southwest monsoon rainfall. Therefore, the study of droughts in the State by climatic approaches will be helpful in planning short and long term operations such as water distribution for irrigation, food distribution policies for anticipated famines etc.

A number of workers gave definitions for delineating and quantifying the droughts based on soil, crop and climatic parameters. The various approaches for quantification of drought effect have been summarized by Hounam *et al.* (1975) in their report on '*Drought and Agriculture*'.

Subrahmanyam and Subramaniam (1964) identified that the droughts in India are due to failures of monsoon, the main source of rainfall and hence these droughts are the root cause of many famines. They recommended the water balance method for identifying and predicting drought conditions at a place. Drought studies by climatic approach for Maharashtra region have been reported by Ramdas (1950), Subrahmanyam and Subramaniam (1964), Subrahmanyam *et al.* (1965), Subrahmanyam (1972), Borkar and Nadkarni (1975), Subramaniam and Rao (1981), Chowdhury *et al.* (1979) etc.

George *et al.* (1973) and George and Ramasastri (1975) have analysed the meteorological droughts in different met-subdivisions of India using the Palmer's (1965) approach. Because of the expected large spatial variations of rainfall, drought analysis based on divisional average rainfall has limited value in drought quantification. Later, Bhalme and Mooley (1979) modified Palmer's (1965) drought severity equations to suit the Indian region. In the present paper, the drought classification at 23 locations (Table 1) of Maharashtra is attempted using Palmer's approach with suitable modifications.

2. Methodology

The procedure given by Palmer (1965) is followed for computing drought severity indices at 23 locations spread in Madhya Maharashtra, Marathwada and Vidarbha. To avoid the complexity of biological factors that involve while defining a drought, Palmer (1965) considered drought strictly as a meteorological

*Centre for Water Resources Development and Management, Calicut-673 571.

TABLE 1

Station	Lat. (°N)	Long. (°E)	Height above m.s.l. (m)	Data used
Madhya Maharashtra				
Ahmednagar	19° 05′	74° 55′	657	1938-77
Baramati	18° 09′	74° 35′	550	1955-77
Jalgaon	21° 03′	75° 34′	201	1943-77
Jeur	18° 12′	75° 12′	521	1951-75
Kolhapur	16° 42′	74° 14′	570	1948-77
Malegaon	20° 33′	74° 32′	437	1933-77
Miraj	16° 40′	74° 41′	554	1938-69
Nandurbar	21° 22′	74° 15′	259	1957-75
Poona	18° 32′	73° 51′	559	1933-77
Sholapur	17° 40	75° 54′	479	1938-77
Marathawada				
Aurangabad	19° 53′	75° 20′	481	1938-77
Nanded	19° 08′	77° 20′	358	1960-65
Parbhani	19° 08′	76° 50′	423	1944-77
Vidarbha				
Akola	20° 42′	77° 02′	282	1933-77
Amraoti	20° 56′	77° 47′	370	1943-76
Brahmapuri	20° 36′	79° 52′	227	1957-76
Buldana	20° 32′	76° 11′	646	1949-77
Chandrapur	19° 57′	79° 18′	190	1933-77
Gondia	21° 27′	80° 12′	313	1947-76
Nagpur	21° 09′	79° 07′	310	1933-77
Pusad	19° 55′	77° 35′	332	1961-76
Sironcha	18° 50′	79° 58′	200	1951-77
Yeotmal	20° 23′	78° 08′	451	1950-77

TABLE 2

Monthly weighting factor, K, for selected places in Maharashtra

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Madhya Maharashtra												
Ahmednagar	1.460	1.909	2.303	2.912	2.182	0.721	0.773	0.673	0.544	0.638	0.790	1.161
Baramati	2.815	4.877	5.955	4.591	1.878	1.392	1.524	1.072	0.705	0.735	1.208	2.180
Jalgaon	1.587	2.082	2.985	4.573	2.396	0.740	0.628	0.613	0.302	0.751	1.017	1.291
Jeur	2.487	3.189	4.068	3.198	1.648	1.119	0.875	0.773	0.625	0.695	1.059	1.692
Kolhapur	1.556	2.760	2.894	2.269	1.000	0.514	0.356	0.403	0.582	0.606	0.759	1.311
Malegaon	1.406	1.845	2.706	3.575	2.466	0.634	0.404	0.389	0.421	0.558	0.688	1.219
Miraj	2.174	2.576	4.213	2.798	1.561	1.271	0.908	0.779	0.735	0.655	0.920	1.272
Nandurbar	1.345	1.849	2.277	3.225	3.546	0.672	0.374	0.405	0.420	0.527	0.749	0.703
Poona	1.484	2.087	2.942	2.756	1.886	0.806	0.632	0.699	0.622	0.678	0.835	1.121
Sholapur	2.440	3.043	3.839	3.521	2.217	1.009	0.758	0.557	0.519	0.797	1.000	1.510
Marathwada												
Aurangabad	2.902	3.886	4.779	5.217	3.475	0.801	0.727	0.704	0.623	0.776	0.980	1.630
Nanded	1.748	2.239	1.910	1.838	2.283	0.465	0.317	0.257	0.283	0.650	1.592	1.101
Parbhani	1.167	1.466	2.088	2.524	2.501	0.661	0.514	0.481	0.478	0.597	0.843	0.956
Vidarbha												
Akola	1.455	1.792	2.547	3.635	3.491	0.678	0.561	0.567	0.551	0.699	0.811	1.180
Amraoti	1.408	2.069	2.616	3.628	3.835	0.719	0.542	0.518	0.548	0.724	0.865	1.238
Brahmapuri	1.860	2.627	1.734	3.039	2.929	0.497	0.328	0.301	0.319	0.829	1.857	1.986
Buldana	1.253	2.112	2.609	3.622	3.324	0.681	0.546	0.549	0.481	0.681	0.938	1.886
Chandrapur	1.802	1.784	1.905	2.521	3.517	0.613	0.526	0.530	0.529	0.656	1.010	1.439
Gondia	1.161	1.627	1.834	2.830	3.867	0.659	0.880	0.634	0.530	0.594	1.047	1.150
Nagpur	0.914	1.587	1.510	1.740	3.111	0.533	0.439	0.433	0.514	0.554	0.857	1.345
Pusad	1.936	2.985	2.011	3.000	2.575	0.449	0.461	0.294	0.421	0.828	0.711	1.079
Sironcha	1.775	2.169	2.199	2.419	2.814	0.577	0.531	0.476	0.671	0.656	1.092	1.317
Yeotmal	1.453	2.510	2.362	3.019	3.056	0.539	0.468	0.423	0.489	0.669	1.081	1.231

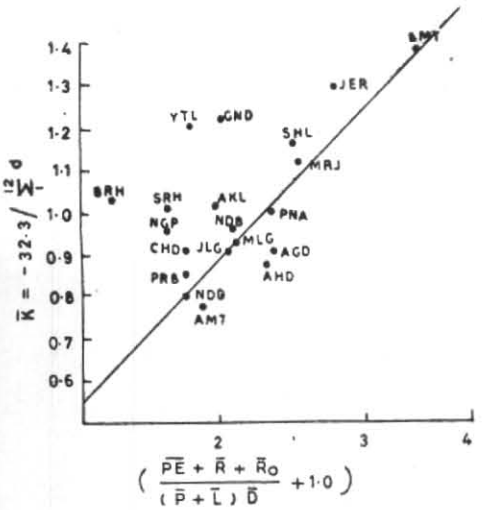


Fig. 1. Mean annual weighting factor as related to average moisture demand, average moisture supply and average absolute moisture departure

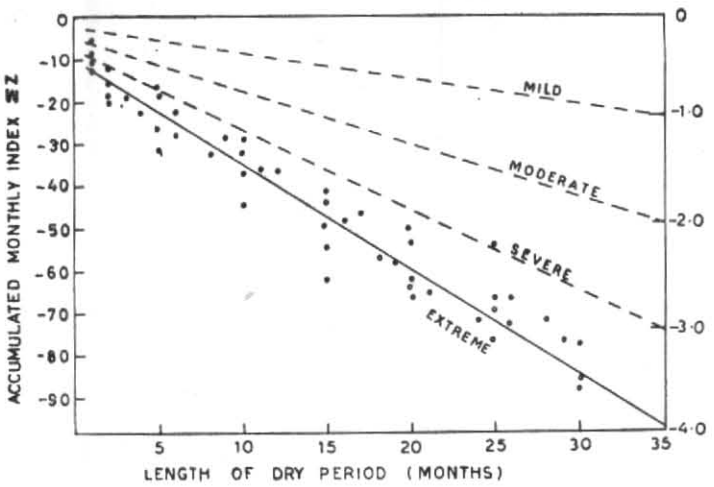


Fig. 2. Accumulated moisture anomaly index during driest period of various lengths

phenomenon, characterized by a prolonged and abnormal moisture deficiency. Palmer compares actual rainfall (P) with a well defined normal rainfall ($\hat{P}$) to obtain a rainfall anomaly for computing the severity of drought and wet spells. The well defined rainfall is called by him as CAFEC (Climatically Appropriate For Existing Conditions) precipitation, which is the amount of rainfall for the near normal operation of the established economy of the area. Its value depends on the average climate of the area and on the prevailing and antecedent meteorological conditions of the period. The following modifications are made to the original procedure given by Palmer (1965) during the analysis.

The monthly potential evapotranspiration (PE) values in different years during 1935-77 have been computed (Sambasiva Rao 1983) using a modified Penman's formula suggested by Rao *et al.* (1971) and Brown and Cocheme (1973).

The available water capacity values for each location have been taken from the table for different soil and vegetation types given by Thornthwaite and Mather (1957). The soil types have been obtained from the soil map of India published by the National Atlas Organization of the Government of India in 1957. The values for the region ranged from 150 to 300 mm.

Palmer defined the potential runoff (PRO) as the difference between available water capacity (AWC) and potential recharge (PR), but this definition was found unsatisfactory in many of the cases examine for Maharashtra. When precipitation exceeds the total amount of AWC and PE, in such cases runoff will be higher than potential runoff (PRO). Hence, the definition PRO=AWC—PR, should be modified as it does not performed well when $P > (AWC+PE)$. In the second definition of Palmer, to subtract the PR values of individual years from three times of normal rainfall to get PRO values of those years was also unsatisfactory. Therefore, it is assumed in the present computations that PRO could go as high as precipitation *plus* the available soil moisture, which gave a satisfactory results in the present analysis.

Bhalme and Mooley (1979) reported that Palmer' index failed to explain the well known 1918 drought in the Indian sub-continent. They also observed that the weighting factor for July in respect of Chanda district was even negative and the defective weighting factor changed the sign of the moisture departure. Therefore, they have suggested suitable modifications for Indian climatic conditions.

While using the weighting factor modified by Bhalme and Mooley, two points should be mentioned : (*i*) Palmer and Bhalme and Mooley have used Thornthwaite (1955) equation for computing the potential evapotranspiration. So the weighting factor given by Palmer or Bhalme & Mooley may not be suitable for Maharashtra because the estimates of PE for the present study have been made with Penman's equation, and (*ii*) only three

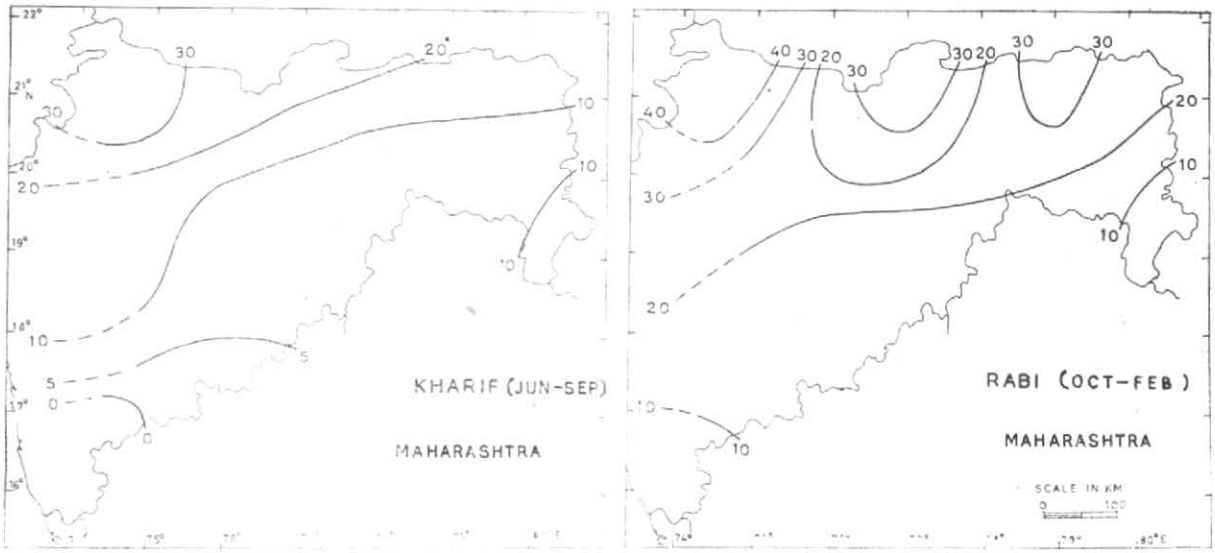
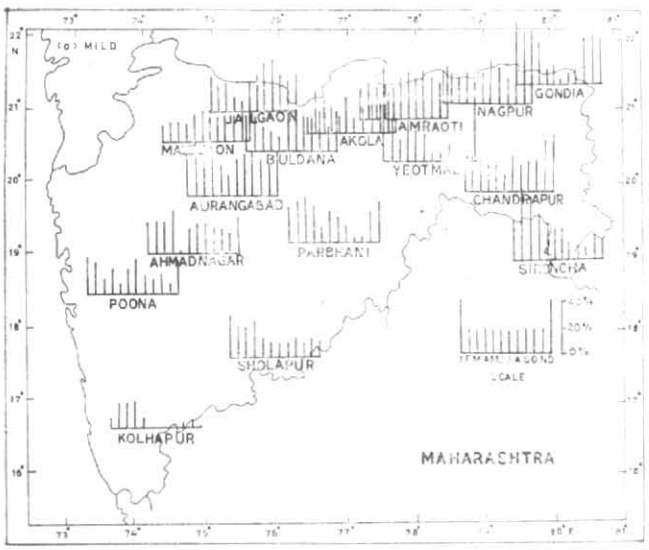


Fig. 3. Number of droughty months during 1952-76 (Maximum possible droughty months = 125)



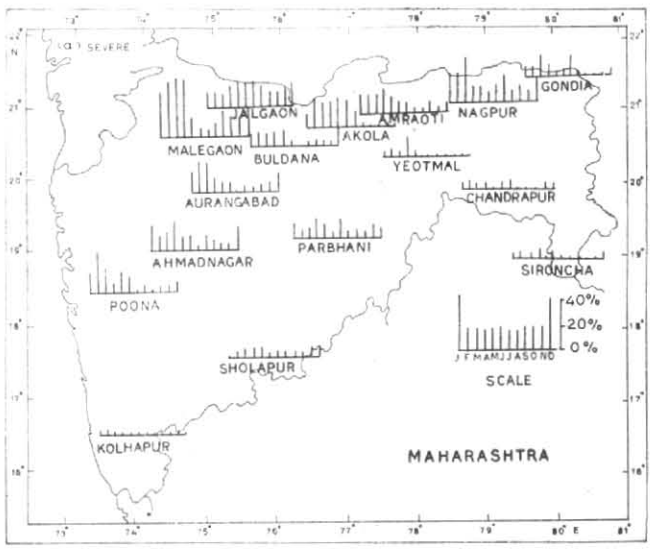


Fig. 4. Percentage occurrences of (a) mild and (b) moderate droughts during 1952-76

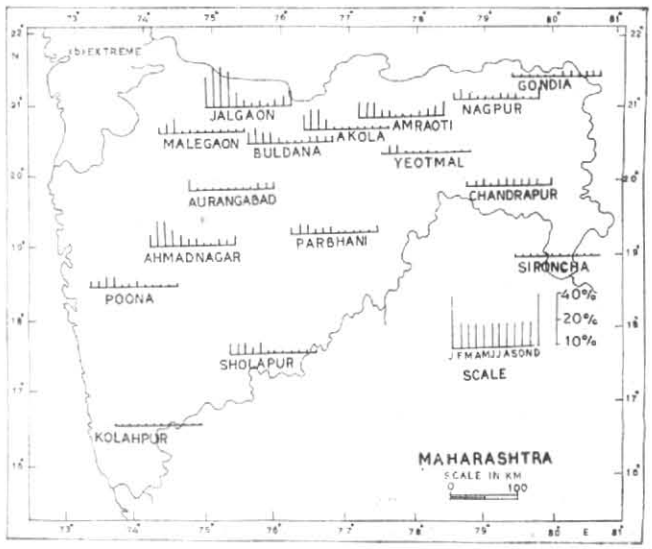


Fig. 5. Percentage occurrences of (a) severe and (b) extreme droughts during 1952-76

stations from Maharashtra were used by Bhalme & Mooley while developing the weighting factor. In view of the above, the weighting factor for Maharashtra conditions is modified as follows :

The mean of the extreme 12 monthly moisture anomaly index for 23 stations of Maharashtra is as high as 32.3. The reason being the PE estimates given by Penman's formulation are higher than that of Thornthwaite especially in semi-arid and arid regions. Keeping the suggestions given by Bhalme & Mooley, the semi-logarithmic plot of $\left[\frac{\overline{PE}+\overline{R}+\overline{RO}}{(\overline{P}+\overline{L})\overline{D}}+1.0\right]$ is plotted against $\overline{K}\,(K=-32.3/\sum_{1}^{12} d)$ as shown in Fig. 1, where,

$\overline{PE}$ mean monthly potential evapotranspiration
$\overline{R}$ mean monthly moisture gain
$\overline{RO}$ mean monthly runoff
$\overline{P}$ mean monthly precipitation
$\overline{L}$ mean monthly loss
$\overline{D}$ mean of absolute values of anomaly d
$\overline{K}$ mean monthly weighting factor

and $\sum_{1}^{12} d$ sum of the anomaly of the driest 12 months period.

The weighting factor K' for a given month is approximated from the graph as

$$K' = 2.06 \log_{10}\left[\frac{\overline{PE}+\overline{R}+\overline{RO}}{(\overline{P}+\overline{L})\overline{D}}+1.0\right]_m+0.26 \quad (1)$$

where suffix m denotes the monthly mean values of the parameter PE, R, RO, P, L and D. The monthly weighting factor is further adjusted for spatial variability as

$$K = \frac{22.108}{\sum_{1}^{12} \overline{D}K'} \quad (2)$$

where K is the final adjusted monthly weighting factor. The mean annual sum of $\overline{D}K'$ for 23 stations of Maharashtra is 22.108. Eqn. (2) is used for adjusting the monthly anomaly $(P-\hat{P})$ for 23 stations of the State. The adjusted weighting factor, K, for selected places in Maharashtra are given in Table 2.

Consequent to the modification of weighting factor, it is necessary to modify the drought severity equation given by Palmer to suit the climatic conditions of Maharashtra. The highest accumulated values of negative *moisture anomaly index* are plotted against the duration in months in which they are accumulated (Fig. 2). A straight line is fitted to represent extreme drought and a numerical value of —4.0 is assigned to it. Following the procedure laid out by Palmer, the following drought severity equation is developed (Sambasiva Rao 1983) :

$$X_i = X_{i-1} + \frac{Z_i}{3.025} - 0.209\ X_{i-1} \quad (3)$$

where X_i, and X_{i-1} are drought severity indices of the ith month and i—1 month, Z_i is the accumulated moisture anomaly index over duration i months. The main difference between Eqn. (3) and Palmer's equation is higher weightage to the current moistute anomaly on the modified severity equation. The index limits for drought spell categorization given by Palmer are taken as such for the present study.

The identification of the actual beginning and ending of the drought spell is carried out by the procedure given by Palmer himself. The computed indices for individual locations are compared with the values on divisional basis earlier reported by George *et al.* (1973).

3. Results and discussion

(a) *Performance of the modified Palmer's drought severity index*

The lowest drought severity indices obtained in the present analysis with the modified Palmer's approach have been examined. During the analysis, the lowest value obtained is —7.06 at Miraj when the drought conditions prevailed for 64 months duration. The index values are within the limits expected and responded for variation in accordance with the rainfall and moisture conditions. It could also explain and categorize properly the well known drought conditions of the State in 1972-73 into the extreme category.

The indices obtained for individual locations are compared with indices based on divisional means (George *et al.* 1973). The divisional analysis shows that the drought spells have occurred for only 10 times during 1934-71 in Madhya Maharashtra, whereas the location analysis in the area at Poona and Malegaon identified 28 and 25 drought spells during the same period. Similarly, the divisional analysis of Marathwada could identify only 11 out of the 26 drought spells at Parbhani and 22 at Aurangabad. The divisional analysis for Vidarbha could identify only 15 drought spells out of 32 at Chandrapur and 27 at Akola during 1935-77. Thus the locationwise analysis could identify properly the various intensities of droughts occurred in Maharashtra.

TABLE 3

Meteorological droughts during kharif (Jun-Sep) season in Maharashtra

Station	Period considered	Years of severe and extreme droughts occurred
		Madhya Maharashtra
Ahmednagar	1939-77	1939-41, 1944-45, 1951-53, 1961, 1963-64, 1965-67, 1972-73, 1976-77
Baramati	1959-77	1961, 1963, 1965, 1970-72, 1976
Jalgaon	1944-77	1951-54, 1957, 1963, 1965-69, 1971-73, 1975-76
Jeur	1952-75	1952-53, 1965-68, 1971-73
Kolhapur	1949-77	1972
Malegaon	1934-77	1934-35, 1939-45, 1951-52, 1957, 1959,1960-61, 1963-64, 1966-68, 1970-74, 1976
Miraj	1939-69	1939-43, 1945, 1948-49, 1951-52, 1954
Nandurbar	1958-75	1960, 1963-64, 1966, 1971-72, 1975
Poona	1934-77	1934-36, 1939-41, 1950, 1953, 1957, 1966-67, 1968, 1970-72
Sholapur	1939-77	1939, 1945, 1952, 1972, 1976-77
		Marathwada
Aurangabad	1939-77	1940-41, 1945, 1951, 1960, 1964-65, 1971-73, 1975-77
Nanded	1961-75	1964, 1966-69, 1971-74
Parbhani	1945-77	1945-47, 1950-52, 1966, 1971-72, 1977
		Vidarbha
Akola	1934-77	1939, 1941, 1950-51, 1953-54, 1958, 1963, 1966, 1969, 1971-72, 1977
Amraoti	1944-76	1950-53, 1963-65, 1968-69, 1971-72, 1974-75
Brahmapuri	1958-76	1965, 1972-73
Buldana	1950-77	1950-54, 1958, 1964-67, 1972-73, 1976-77
Chandrapur	1934-77	1939, 1941, 1943, 1953, 1963, 1971-72
Gondia	1948-76	1950, 1952-54, 1965, 1972-73, 1976
Nagpur	1934-77	1940-41, 1950, 1953-54, 1957-58, 1960, 1963-65, 1969, 1972-73, 1977
Pusad	1962-76	1965-67, 1969, 1971-73
Sironcha	1952-77	1974
Yeotmal	1951-77	

(b) *Drought spells of different classes and duration*

The longest spell of drought occurred at Miraj beginning in January 1939 and ending in April 1944 with a duration of 64 months. This station is situated in a low rainfall area. The dry sub-humid climatic location of Nagpur has experienced drought conditions for 32 consecutive months during December 1951 to July 1954, while Chandrapur has 26 months of drought period during September 1946 to October 1948. This shows that drought conditions prevail for longer periods in semi-arid regions compared to the dry sub-humid regions.

The total number of months with drought conditions when the index value reaches —2.00 or lower during 1952-76 kharif (June-September) and rabi (October-February) seasons are shown in Fig. 3. The number of drought months during kharif season ranged from 30 in the extreme north to 0 in the extreme south of Madhya Maharashtra. The Marathwada region experienced drought for about 10 months during the period. The northwestern parts of Vidarbha experienced drought for 10-20 months whereas the southeastern parts for 5-10 months. The pattern of drought prone areas for rabi season was similar to that of kharif season. The north Madhya Maharashtra experienced 40 months of drought in the rabi season, whereas the south Madhya Maharashtra 5-10 months, Vidarbha 10-30 months and Marathwada 15-20 months of drought.

Years of severe/extreme drought conditions occurred during (June-September) are also examined at different locations (Table 3). Severe and extreme conditions prevailed in 28 out of the 44 years during 1934-77 at

some location or the other. At half of the locations, severe/extreme drought conditions prevailed during June to September in 1972-73 alone. At few stations like Yeotmal drought situation (1951-77) never touched the extreme conditions during the period. The severe/extreme drought situations also prevailed in the region for two to three consecutive years. Because of spatial and temporal variability of rainfall, the dates of beginning and ending of different classes of droughts are differing from location to location.

(c) *Percentage occurrence of droughts of various classes*

The percentage occurrence of various classes of droughts during the period 1952-76 are shown in Figs. 4 & 5. The observations from the figures could be summarized as follows.

(1) The percentage occurrence of mild drought (index values from —1.00 to —1.99) was highest in the northern parts and lowest in the southern parts of Madhya Maharashtra. Mild drought prevailed on 30% of the occasions at Aurangabad, 7% at Kolhapur, 21% at Parbhani and 26% at Chandrapur.

(2) The percentage occurrence of moderate droughts (index values from —2.00 to —2.99) was low compared to mild droughts in all locations except in the north Madhya Maharashtra where it was high. Kolhapur in south Madhya Maharashtra was free from moderate droughts during May to November. Yeotmal was free from moderate droughts from June to September. The percentage occurrence of droughts are maximum at Malegaon (32%) and minimum at Kolhapur (2%).

(3) The percentage occurrence of severe droughts (index value —3.00 to —3.99) was highest in the northern parts of Madhya Maharashtra, northwestern parts of Vidarbha compared to other parts of the State. But the percentage occurrence of severe droughts was less than that of moderate droughts.

(4) Severe droughts occurred for about 2% at Yeotmal, 3% at Sironcha, 24% at Malegaon and 16% at Nagpur. The areas were free from droughts throughtout the year at Kolhapur, August-October at Chandrapur, June-December at Yeotmal, September-October at Chandrapur, June-December at Yeotmal and September-October at Akola.

(5) The southern parts of Madhya Maharashtra, Marathwada and Vidarbha were almost free from extreme drougbt (index value —4.00 and below). The frequency of extreme droughts was zero at Kolhapur in Madhya Maharashtra and Sironcha in Vidarbha. Yeotmal in west Vidarbha has 4% of severe drought in February-March. The stations Jalgaon, Ahmednagar, Amraoti have experienced severe droughts for 13, 8 and 6% of the total period. The stations Nagpur, Buldana and Akola experienced extreme droughts for 4% of the total period. The maximum number of extreme droughts in the region were in January-April.

4. Summary and conclusions

The incidence and spread of meteorological droughts in Maharashtra during 1934-77 are studied following Palmer's approach for drought evaluation. The analysis is based on monthly rainfall and monthly potential evapotranspiration values in different years at 23 locations in the State. The definition of potential runoff and the weighting factor for drought severity indices given by Palmer are modified for the climatic conditions of the region. The locationwise study brought out more details about the beginning and ending of various dry spells occurred in the region than the divisionwise analysis reported earlier. The percentage frequency of droughts of various classes occurred in Maharashtra have also been reported.

Acknowledgements

The authors are thankful to the India Met. Dep., Pune for kindly supplying the meteorological data and to the Computer Centre, Andhra University, Waltair for providing the facilities. Thanks are also due to Dr. (Mrs.) A.M. Selvam, Indian Institute of Tropical Meteorology, Pune for her guidance given to prepare the computer program. Senior author duly acknowledges the Chairman, University Grants Commission, New Delhi for the financial support. The authors are also thankful to the referees for offering suggestions.

References

Bhalme, H.N. and Mooley, D.A., 1979, On the performance of modified Palmer index, Intl. Symp. Hydr. Aspects of Droughts, I.I.T., New Delhi, Vol. **1&2**, pp. 373-382.

Borkar, V.V. and Nadkarni, M.V., 1975, *'Impact of drought on rural life,'* Popular Prakashan Pvt., Bombay, pp. 1-40.

Brown, L.H. and Cocheme, J., 1973, 'A study of the agroclimatology of the Highlands of Eastern Africa WMO, Geneva Tech. Note No. 125.

Chowdhury, A., (Km.) Gokhale, S.S. and Rentala, G.S., 1979, Spells of dry days related to agricultural drought in India, *Mausam*, **30**, 4, pp. 501-510.

George, C.J., Ramasastri, K.S. and Rentala, G.S., 1973, Incidence of Droughts in India, Met. Monogr, Agrimet. No. 5., India Met. Dep., Poona, pp. 1-25.

George, C.J. and Ramasastri, 1975, K.S., 'Agricultural drought of 1972 kharif season', *Indian J. Met. Hydrol. Geophys.*, **26**, 1, pp. 89-96.

Hounam, C.E., Burgos, J.J., Kalik, M.S., Palmer, W.C. and Rodda, J., 1975, Drought and Agriculture, W.M.O. Tech. Note No. 138.

Palmer, Wayne C., 1965, 'Meteorological drought,' U.S. Dept. of Commerce, Weather Bureau paper 45, pp. 1-58.

Ramdas, L.A., 1950, 'Rainfall and Agriculture use of routine reports for crops outlook, *Indian J. Met. Geophys.*, **1**, 4, pp. 262-274.

Rao, K.N., George, C.J. and Ramasastri, K.S., 1971, 'Potential evapotranspiration (PE) over India', Sci. Rep. No. 136, India Met. Dep., Poona.

Sambasiva Rao, A., 1983, 'Some agroclimatic studies of Maharashtra,' Unpublished Ph. D. thesis submitted to Andhra University, Waltair.

Subrahmanyam, V.P. and Subramaniam, A.R., 1964, 'Application of water balance concepts for a climatic study of droughts in south India', *Indian J. Met. Geophys.*, **15**, pp. 393-402.

Subrahmanyam, V.P. and Subramaniam, A.R., 1965, Some characteristics and frequencies of occurrences of droughts in the dry climatic zone of India, *Bull. Inter. Assoc. Sci. Hyd. Xenee*, No. 3, pp. 31-37.

Subrahmanyam, V.P., 1967, Incidence and spread of continental drought, W.M.O/I.H.D. Project report No. 2, Secretariat of W.M.O., Geneva,

Subrahmanyam, V.P., 1972, The concept and use of water balance in Ecoclimatic planning, Publ. In *climatology*, Vol. XXV, No. 2, Thornthwaite Associates, Lab. of Climatology, Elmer, N.J., pp. 46-57.

Subramaniam, A.R. and Sambasiva Rao, A., 1981, Water balance and its applications to Maharashtra, *Natl. Geogr. J. Indi.*, **XXVII**, Part 3&4, pp. 134-145.

Thornthwaite, C.W. and Mather, J.R., 1957, Instructions and Tables for computing potential evapotranspiration and the water balance, Publ. in *climatology*, **X**, 3, Lab. of Climatology, N.J.