*Mausam*, (1979), 30, 4, 501-510

551.577.38 (547.1)

# Spells of dry days related to agricultural drought in India

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ABSTRACT. Efficacy of dry spells in identifying drought prone areas has been advanced in the study. For this purpose, daily rainfall from 1 June to 31 October which nearly covers all growth phases of crops grown principally during kharif season for a 70-year period (1901–1970) for 26 stations in Maharashtra State have been analysed. Two types of dry days were classified, *viz.*, a day receiving less than 2.5 mm of rainfall and receiving less than 6.3 mm of rainfall. Dry spells for both the categories have been computed and analysed. Similarly, probabilities of occurrence of dry spells of different lengths have been analysed. A theoretical distribution is also fitted to dry spells.

The study revealed that logarithmic distribution nearly represents both categories of dry days. Analysis of dry spells and the probabilities confirmed that the hard-core of the drought in Maharashtra State is located over Ahmednagar district. Other areas which possess high degree of drought proneness are eastern parts of Pune, Satara and Sangli districts and western parts of Sholapur, Aurangabad and Bhir districts. In coastal belt of Konkan and eastern parts of Vidarbha, the drought menace is comparatively less.

## 1. Introduction

An agricultural drought is a 'non-event' in sharp contrast to a distinct event such as flood. A drought has no distinct beginning and is recognisable only after a period of time. It is, as such, difficult to clearly define drought and come up with a unified treatment of the phenomenon. Different fields of study hold widely diverse views as to what constitute a drought. It is generally understood that it refers to a deficit or shortage of available moisture supply to the crops during the main rainy season and is brought about through areal and temporal variation in the synoptic situations that controls the distribution of rainfall. In short, a drought is basically a deficit of water in time, space or both. For a given region and a given period of time, the drought can be observed in various ways.

Since the number of dry days is an important parameter in the investigation of drought, it was assumed worthwhile to examine some of its important features. Statistical characteristics of the dry sequences, *i.e.*, sequences of days with less than certain threshold of precipitation have been analysed in this paper. Now agricultural drought exists as a result of depletion of soil moisture in the root zone that facilitates plant growth. It is thus possible to describe an agricultural drought through dry day sequences and measure its impact. This forms the basis of the present study.

The study has been taken up in the first instanee for Maharashtra State.

## 2. Objectives

The objectives of this paper were :

(*i*) to demonstrate the efficacy of dry day sequence as a parameter in drought delineation;

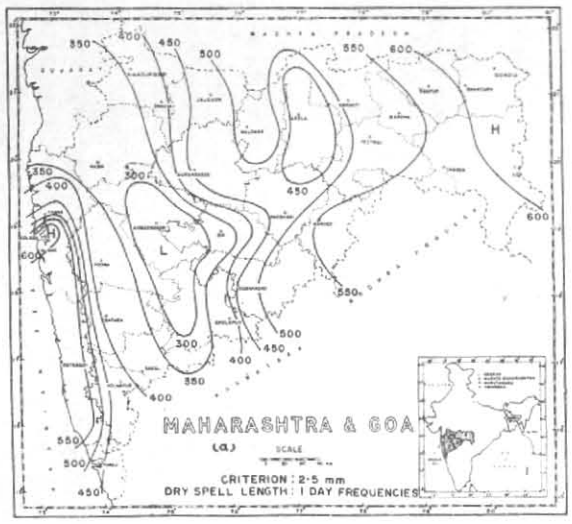
(*ii*) to establish concordance of the observed frequencies with some known theoretical distribution and estimate the un-known parameters;

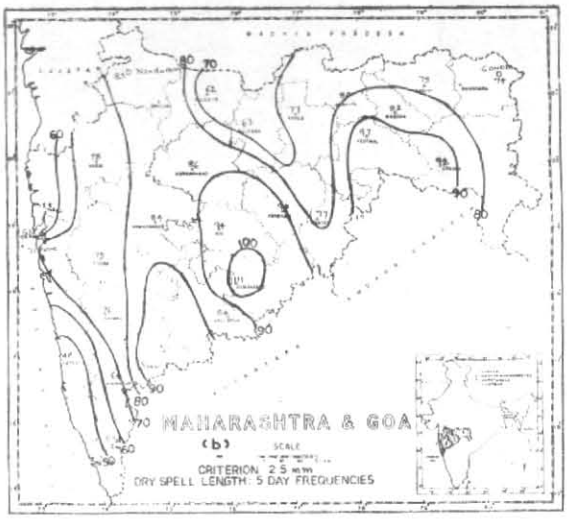
(*iii*) to determine occurrence of dry spells from mere chance, *i.e.*, from probability consideration and

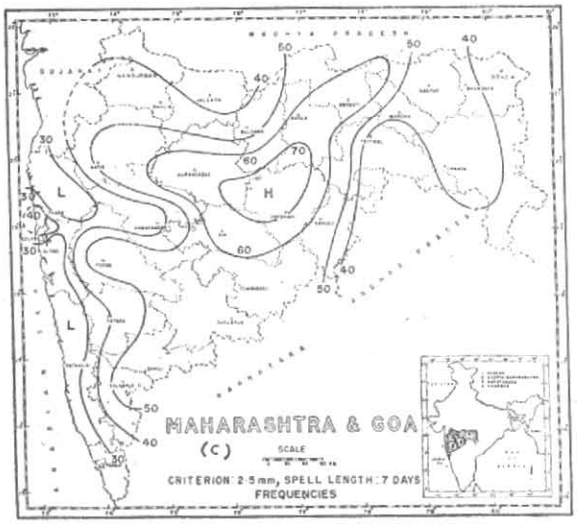
(*iv*) to compare results obtained from probability analysis with that from analysis of frequencies.

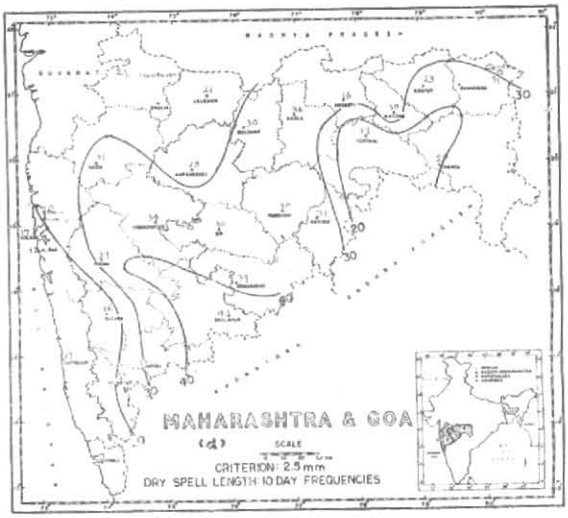
## 3. Choice of criteria

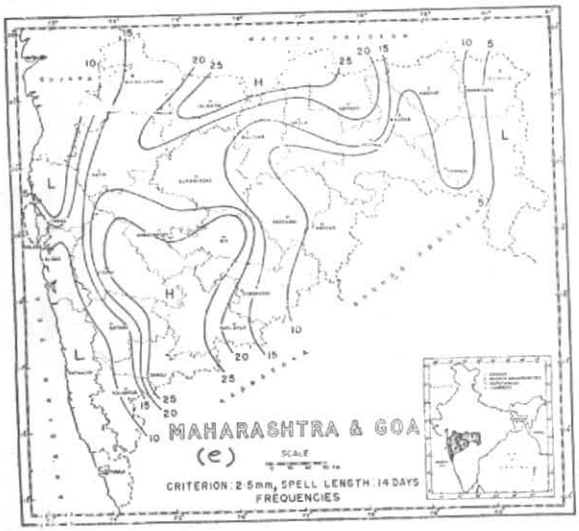
Based on agricultural considerations two different and more realistic criteria have been adopted to define a dry day. In the first criterion, a day is considered dry when it receives rainfall less than 2.5 mm (0.10″). This rainfall, it is presumed is sufficient to wet the top most soil layer. Rainfall with less than 6.3 mm (0.25″) was considered as threshold value for the second category of dry day. This threshold highlights the magnitude of a severe drought. Plant pathologists also agree that this threshold provides the crop with significant amount of moisture.

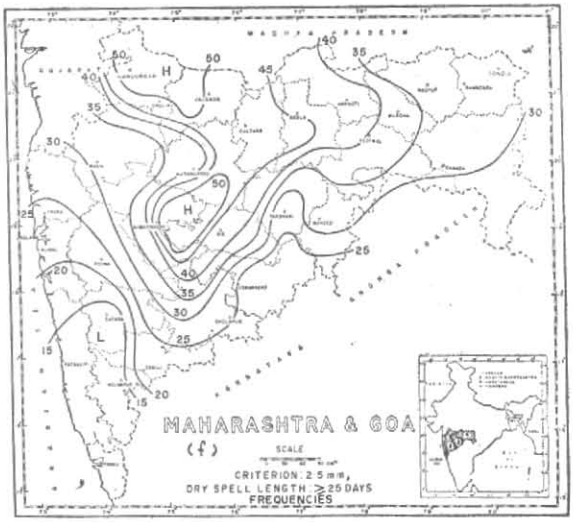

MAHARASHTRA & GOA
(a)
CRITERION : 2·5 mm
DRY SPELL LENGTH : 1 DAY FREQUENCIES


MAHARASHTRA & GOA
(b)
CRITERION: 2·5 mm
DRY SPELL LENGTH: 5 DAY FREQUENCIES

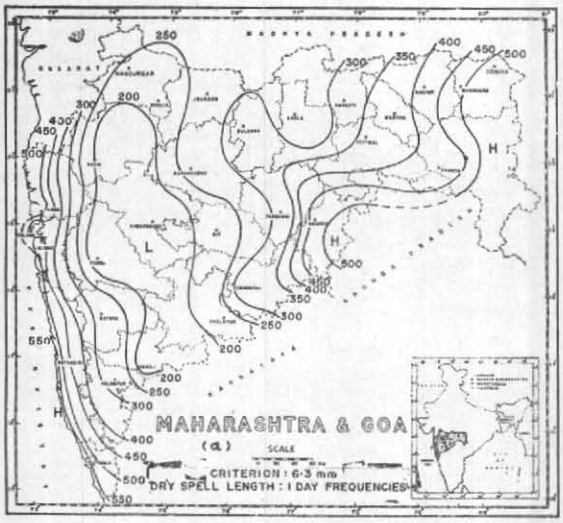

MAHARASHTRA & GOA
(c)
CRITERION: 2·5 mm, SPELL LENGTH: 7 DAYS
FREQUENCIES

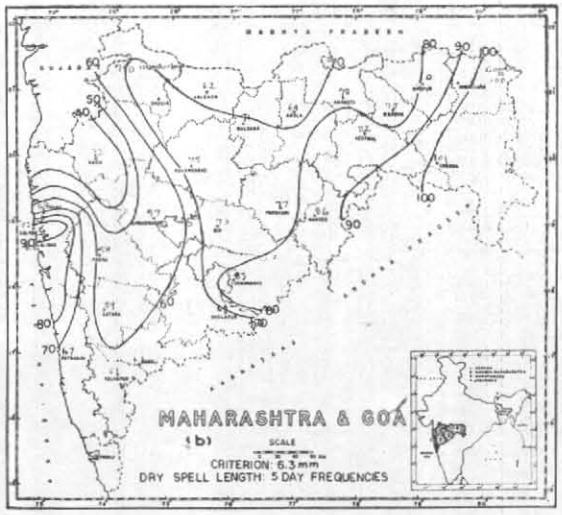

MAHARASHTRA & GOA
(d)
CRITERION: 2·5 mm
DRY SPELL LENGTH: 10 DAY FREQUENCIES

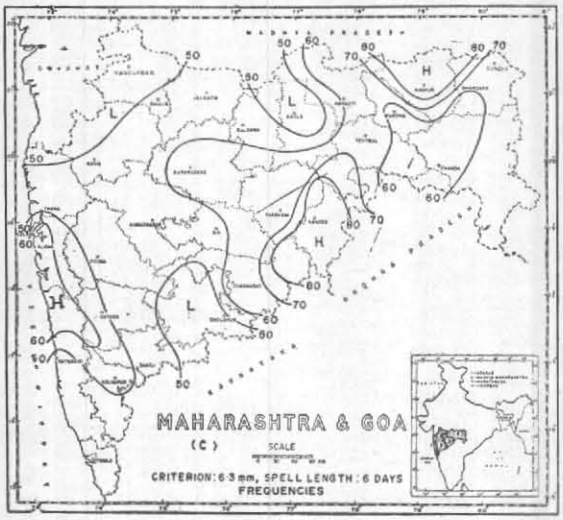

MAHARASHTRA & GOA
(e)
CRITERION: 2·5 mm, SPELL LENGTH: 14 DAYS
FREQUENCIES

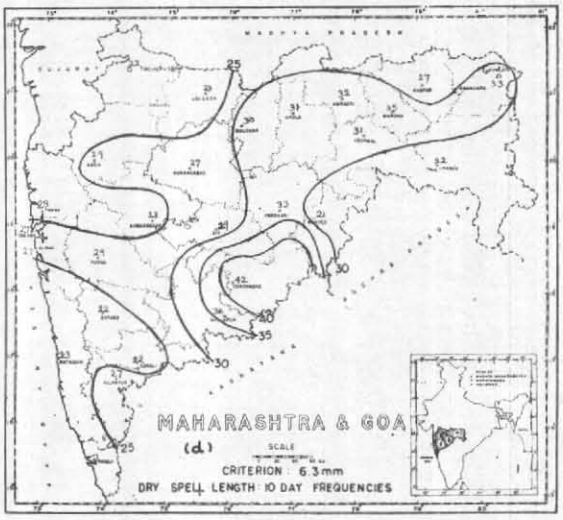

MAHARASHTRA & GOA
(f)
CRITERION: 2·5 mm,
DRY SPELL LENGTH: ≥ 25 DAYS
FREQUENCIES

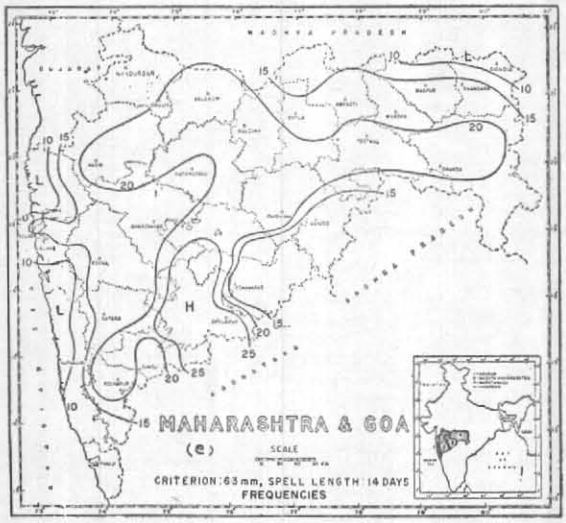
Figs. 1 (a-f)

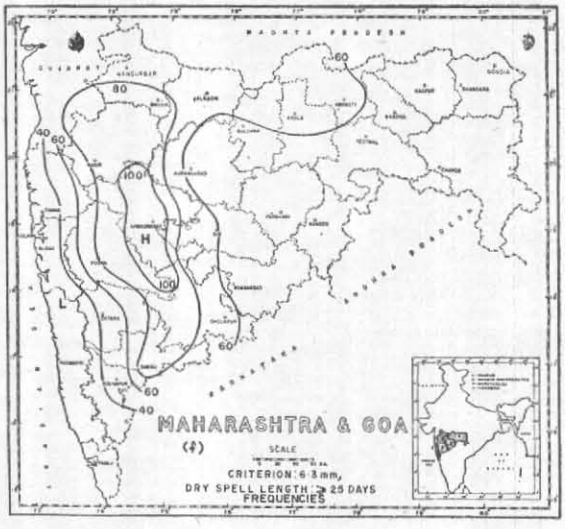

MADHYA PRADESH
MAHARASHTRA & GOA
(a)
SCALE
CRITERION : 6·3 mm
DRY SPELL LENGTH : 1 DAY FREQUENCIES


MADHYA PRADESH
MAHARASHTRA & GOA
(b)
SCALE
CRITERION: 6.3 mm
DRY SPELL LENGTH: 5 DAY FREQUENCIES


MADHYA PRADESH
MAHARASHTRA & GOA
(c)
SCALE
CRITERION: 6·3 mm, SPELL LENGTH : 6 DAYS
FREQUENCIES


MADHYA PRADESH
MAHARASHTRA & GOA
(d)
SCALE
CRITERION 6.3 mm
DRY SPELL LENGTH 10 DAY FREQUENCIES


MADHYA PRADESH
MAHARASHTRA & GOA
(e)
SCALE
CRITERION: 63 mm, SPELL LENGTH : 14 DAYS
FREQUENCIES


MADHYA PRADESH
MAHARASHTRA & GOA
(f)
SCALE
CRITERION: 6·3 mm,
DRY SPELL LENGTH : ≥ 25 DAYS
FREQUENCIES

Figs. 2 (a-f)

**TABLE 1**

**Ratio of the number of spells which last atleast $r+1$ days to thsoe which last atleast $r$ days, for both criteria**

| Dry spells | Rainfall less than | |
|---|---|---|
| | 2.5 mm per day | 6.3 mm per day |
| $r$ | $S_{r+1}/S_r$ | $S_{r+1}/S_r$ |
| 1 | .71 | .80 |
| 2 | .77 | .83 |
| 3 | .81 | .85 |
| 4 | .82 | .87 |
| 5 | .83 | .87 |
| 6 | .87 | .89 |
| 7 | .88 | .88 |
| 8 | .88 | .89 |
| 9 | .85 | .91 |
| 10 | .90 | .93 |

**4. Data used and method of analysis**

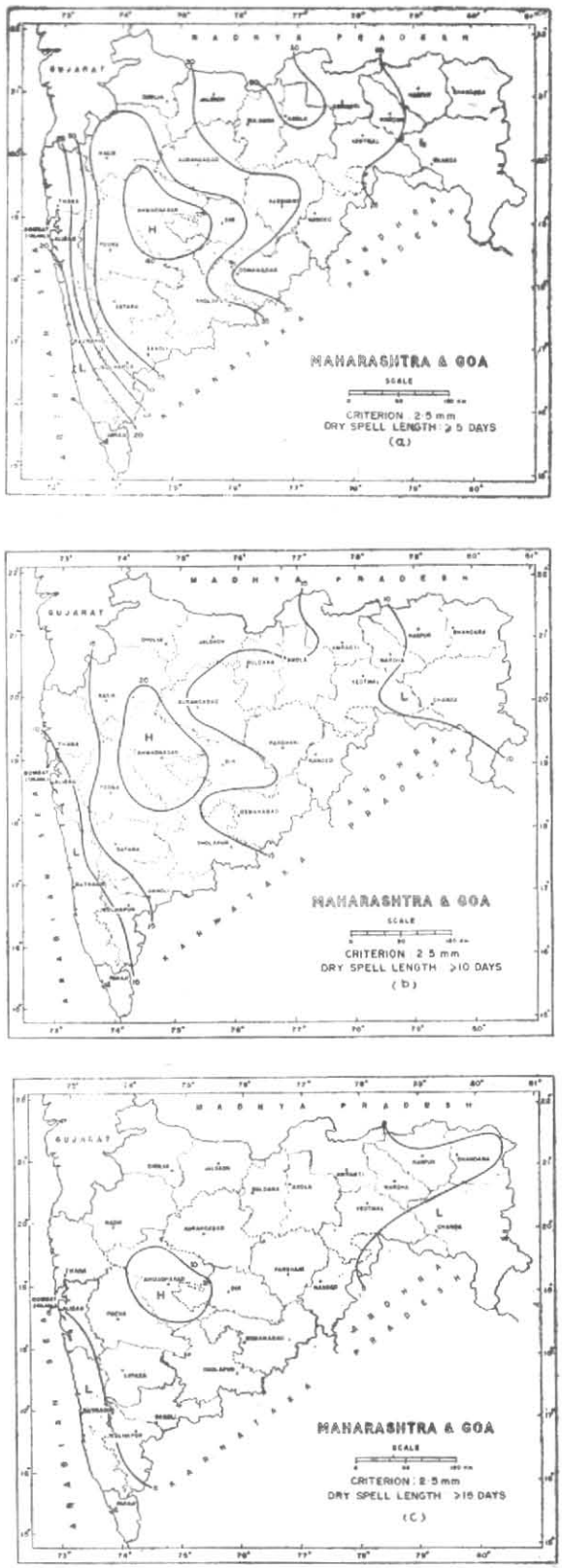
Daily rainfall data of 26 observatories for 70 years period (1901-1970) for Maharashtra were used in the study. The stations chosen represent nearly all the agroclimatic zones and soil types in the State. The data stretches from 1 June to 31 October, this being the period when over 80 per cent of the total annual rainfall occurs over the area.

The term sequence is defined as number of similar events preceded and succeeded by different events, *i.e.*, number of dry days preceded and succeeded by wet days. The sequence of daily rainfall data was examined for each individual station, year by year, according to precipitation criteria enunciated in the preceding paragraph. The frequency of the sequences computed and analysed for lengths varying from 1 to 24 and those equal to or exceeding 25 days. To facilitate easy identification of areas most probable for the drought incidence, probabilities were also worked out.

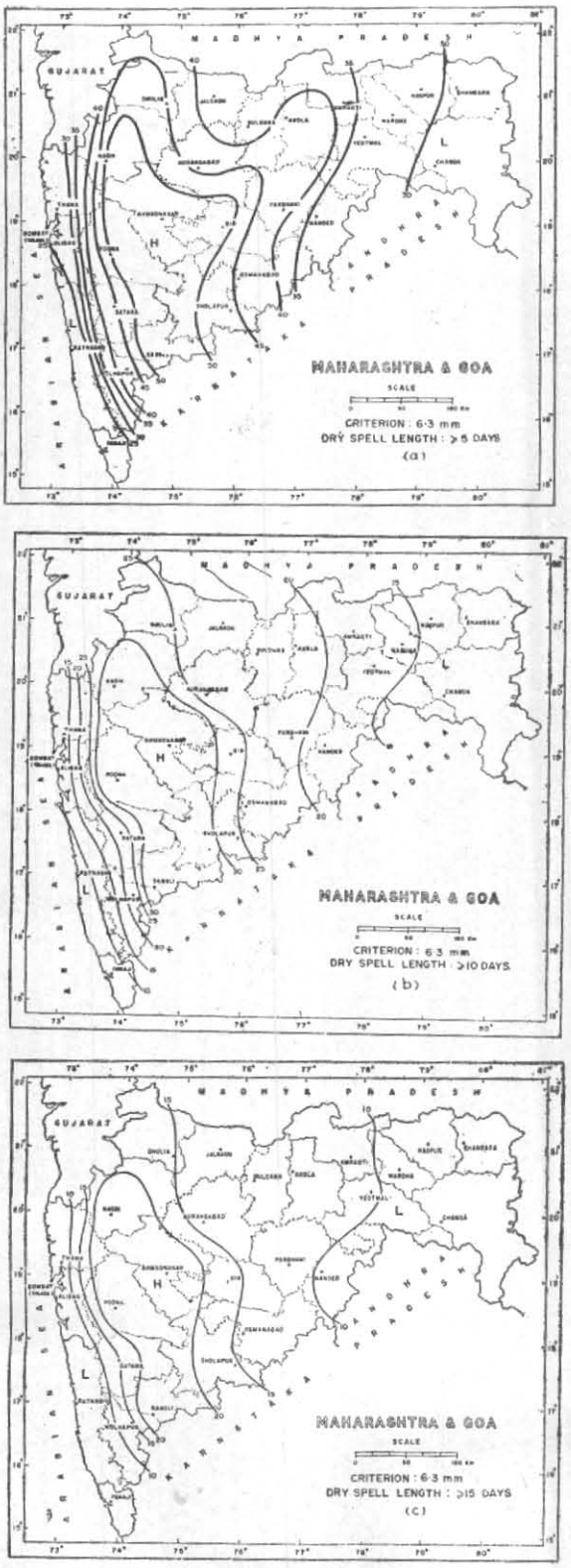
**5. Data presentation**

The frequency of dry spells of lengths 1, 2, .., 24 and $\geqslant 25$ are analysed. For want of space, 12 diagrams for each threshold of rainfall have been presented in Figs. 1 and 2. As the frequencies for different lengths vary greatly, no uniform interval could be maintained in the analysis in drawing the isopleths.

Probability analysis is also made. Probability of occurrence of dry sequences equal to or greater than 5, 10, 15, 20 and 25 are given in Table 3 and or dry sequences equal to or greater than 5, 10, 15




Figs. 3 (a-c)




Figs. 4 (a-c)

are shown in Figs. 3 and 4. The isopleths are drawn at intervals of 5. The probability of spells $\geqslant 20$

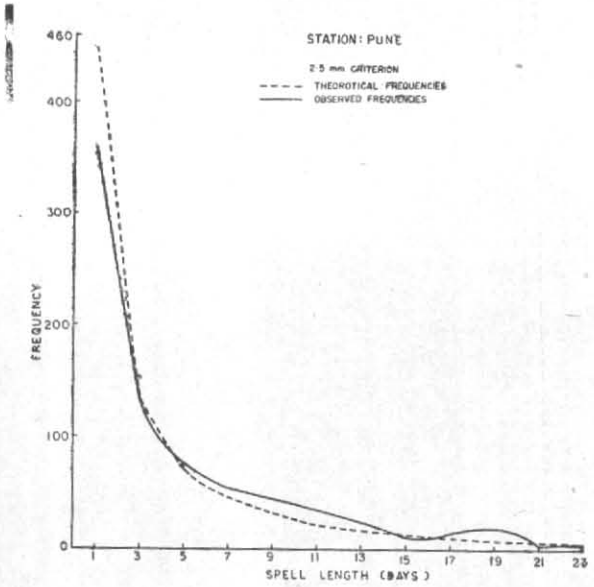



Fig. 5. Observed and theoretical frequencies

days being small, no figures have been presented for this case.

In all the above diagrams, areas possessing highest or lowest values have been marked H or L.

The observed frequencies were fitted to a theoretical distribution which was later utilised to determine the theoretical frequencies. In Table 1, the ratio of number of spells which last atleast $r+1$ days to those which last atleast $r$ days is shown. The observed and computed frequencies have been shown for some of the lengths in Table 2. Illustrations between the computed and observed curves have been presented in Fig. 5 for 2.5 mm rainfall criteria, for Pune

### 6. Past work in the field

In India, study of delineation of drought is comparatively of recent origin. In the earlier work (George *et al.* 1969), drought was studied from two angles, *viz.*, rainfall deficiency and deficiency of available moisture to the crops. Palmer's (1965) method of quantifying drought was later applied to Indian conditions for mapping (George *et al.* 1973). Aridity anomaly indices were later used to measure the extent, intensity and dissipation of agricultural drought (George and Ramasastri 1975 and George *et al.* 1975), adopting correlation technique to study some aspects of drought. As the timing of rainfall or the interval between two rainfall spells is one of the most important reasons of agricultural drought, Raman (1974) has adopted the inter-spell duration to evaluate agricultural drought over Maharashtra.

**TABLE 2**

**Observed and theoretical frequencies of dry day sequences for rainfall less than 2.5 mm per day**

| Station | Spell length in days | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | 3 | | 5 | | 7 | | 9 | | 11 | |
| | O | T | O | T | O | T | O | T | O | T | O | T |
| | (a) **Rainfall less than 2.5 mm per day** | | | | | | | | | | | |
| Thana | 456 | 412 | 90 | 112 | 55 | 52 | 23 | 32 | 20 | 20 | 17 | 18 |
| Colaba | 613 | 556 | 261 | 250 | 52 | 73 | 42 | 42 | 17 | 27 | 14 | 16 |
| Alibag | 599 | 553 | 148 | 147 | 71 | 70 | 26 | 40 | 24 | 25 | 17 | 13 |
| Ratnagiri | 539 | 499 | 114 | 129 | 48 | 60 | 23 | 34 | 21 | 20 | 10 | 22 |
| Jalgaon | 492 | 497 | 116 | 147 | 62 | 75 | 33 | 47 | 34 | 31 | 22 | 22 |
| Nandurbar | 382 | 447 | 139 | 131 | 83 | 70 | 40 | 44 | 39 | 30 | 29 | 22 |
| Nasik | 372 | 446 | 127 | 132 | 78 | 70 | 51 | 44 | 32 | 30 | 23 | 22 |
| Ahmednagar | 289 | 384 | 132 | 116 | 84 | 63 | 37 | 41 | 34 | 29 | 35 | 22 |
| Pune | 360 | 448 | 135 | 133 | 75 | 71 | 54 | 45 | 30 | 31 | 36 | 19 |
| Satara | 363 | 417 | 126 | 122 | 76 | 64 | 41 | 40 | 42 | 27 | 30 | 24 |
| Sholapur | 362 | 500 | 137 | 146 | 84 | 77 | 50 | 48 | 52 | 33 | 36 | 23 |
| Sangli | 385 | 480 | 139 | 141 | 93 | 75 | 51 | 47 | 47 | 32 | 21 | 23 |
| Kolhapur | 427 | 495 | 126 | 140 | 64 | 72 | 57 | 43 | 46 | 29 | 27 | 20 |
| Aurangabad | 461 | 529 | 188 | 153 | 86 | 79 | 62 | 49 | 36 | 33 | 25 | 23 |
| Bhir | 343 | 447 | 130 | 133 | 94 | 71 | 65 | 45 | 47 | 31 | 29 | 23 |
| Osmanabad | 496 | 586 | 169 | 114 | 111 | 58 | 53 | 35 | 39 | 23 | 25 | 16 |
| Parbhani | 479 | 555 | 169 | 159 | 90 | 81 | 11 | 50 | 41 | 33 | 24 | 23 |
| Nanded | 558 | 609 | 160 | 170 | 77 | 86 | 50 | 51 | 26 | 33 | 30 | 23 |
| Buldhana | 518 | 538 | 161 | 153 | 63 | 78 | 49 | 48 | 35 | 32 | 14 | 22 |
| Akola | 448 | 488 | 142 | 143 | 77 | 75 | 62 | 47 | 32 | 32 | 23 | 23 |
| Amraoti | 511 | 547 | 157 | 156 | 80 | 81 | 63 | 49 | 29 | 33 | 26 | 23 |
| Yeotmal | 518 | 566 | 163 | 160 | 97 | 81 | 36 | 49 | 29 | 33 | 20 | 23 |
| Nagpur | 583 | 631 | 204 | 173 | 75 | 85 | 46 | 50 | 31 | 32 | 18 | 21 |
| Wardha | 535 | 575 | 179 | 162 | 82 | 82 | 49 | 49 | 32 | 32 | 22 | 22 |
| Gondia | 631 | 650 | 189 | 175 | 74 | 85 | 39 | 49 | 37 | 31 | 10 | 21 |
| Chanda | 572 | 642 | 195 | 175 | 92 | 86 | 47 | 50 | 27 | 32 | 21 | 21 |

**TABLE 2** (*contd*)

| Station | Spell length in days | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 13 | | 15 | | 17 | | 19 | | 21 | | 23 | |
| | O | T | O | T | O | T | O | T | O | T | O | T |
| | (a) **Rainfall less than 2.5 mm per day** | | | | | | | | | | | |
| Thana | 6 | 9 | 4 | 7 | 6 | 5 | 7 | 3 | 6 | 3 | 3 | 2 |
| Colaba | 8 | 12 | 8 | 8 | 8 | 6 | 7 | 4 | 3 | 3 | 5 | 2 |
| Alibag | 5 | 11 | 4 | 7 | 3 | 5 | 6 | 4 | 5 | 3 | 6 | 2 |
| Ratnagiri | 7 | 9 | 7 | 6 | 7 | 4 | 3 | 3 | 3 | 2 | 2 | 1 |
| Jalgaon | 15 | 18 | 15 | 12 | 9 | 9 | 11 | 7 | 5 | 6 | 6 | 5 |
| Nandurbar | 18 | 16 | 7 | 12 | 12 | 10 | 9 | 8 | 6 | 6 | 6 | 5 |
| Nasik | 21 | 16 | 15 | 13 | 14 | 10 | 9 | 8 | 5 | 6 | 5 | 5 |
| Ahmednagar | 24 | 17 | 21 | 13 | 13 | 11 | 10 | 9 | 10 | 7 | 7 | 6 |
| Pune | 24 | 17 | 12 | 13 | 15 | 10 | 19 | 8 | 4 | 7 | 5 | 5 |
| Satara | 25 | 14 | 12 | 11 | 13 | 8 | 12 | 7 | 5 | 5 | 3 | 4 |
| Sholapur | 24 | 18 | 17 | 13 | 14 | 10 | 3 | 8 | 13 | 7 | 6 | 5 |
| Sangli | 20 | 17 | 14 | 13 | 14 | 10 | 22 | 8 | 7 | 7 | 6 | 5 |
| Kolhapur | 20 | 14 | 9 | 10 | 9 | 8 | 8 | 6 | 6 | 5 | 3 | 3 |
| Aurangabad | 18 | 17 | 16 | 13 | 11 | 10 | 13 | 8 | 3 | 6 | 5 | 5 |
| Bhir | 23 | 17 | 8 | 13 | 12 | 10 | 12 | 8 | 8 | 7 | 4 | 5 |
| Osmanabad | 26 | 14 | 13 | 9 | 11 | 6 | 5 | 5 | 8 | 4 | 3 | 3 |
| Parbhani | 24 | 17 | 12 | 13 | 13 | 10 | 5 | 7 | 6 | 6 | 4 | 4 |
| Nanded | 20 | 16 | 11 | 12 | 11 | 9 | 9 | 7 | 4 | 5 | 2 | 4 |
| Buldhana | 15 | 16 | 15 | 12 | 13 | 9 | 4 | 7 | 4 | 5 | 5 | 4 |
| Akola | 22 | 17 | 21 | 13 | 11 | 10 | 12 | 8 | 6 | 6 | 4 | 5 |
| Amraoti | 19 | 20 | 11 | 12 | 8 | 9 | 6 | 7 | 3 | 6 | 6 | 4 |
| Yeotmal | 15 | 16 | 15 | 12 | 12 | 9 | 5 | 7 | 9 | 5 | 3 | 4 |
| Nagpur | 10 | 15 | 11 | 11 | 8 | 8 | 6 | 6 | 4 | 4 | 0 | 4 |
| Wardha | 16 | 16 | 6 | 12 | 11 | 9 | 5 | 7 | 4 | 5 | 1 | 4 |
| Gondia | 6 | 14 | 12 | 10 | 10 | 7 | 4 | 5 | 6 | 4 | 2 | 3 |
| Chanda | 19 | 15 | 8 | 10 | 5 | 7 | 4 | 5 | 2 | 4 | 6 | 3 |

O = Observed frequency, T = Theoretical frequency.

**TABLE 2** (*contd*)

| Station | Spell length in days: 1 | | 3 | | 5 | | 7 | | 9 | | 11 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | O | T | O | T | O | T | O | T | O | T | O | T |
| | (b) **Rainfall less than 6.3 mm per day** | | | | | | | | | | | |
| Thana | 507 | 486 | 126 | 134 | 62 | 67 | 27 | 39 | 23 | 25 | 22 | 17 |
| Colaba | 426 | 492 | 158 | 141 | 92 | 73 | 41 | 45 | 32 | 30 | 29 | 21 |
| Alibag | 529 | 525 | 146 | 149 | 83 | 78 | 37 | 46 | 33 | 30 | 17 | 21 |
| Ratnagiri | 550 | 553 | 171 | 149 | 67 | 72 | 35 | 42 | 17 | 26 | 22 | 17 |
| Jalgaon | 299 | 382 | 126 | 115 | 62 | 63 | 32 | 41 | 29 | 29 | 25 | 21 |
| Nandurbar | 218 | 329 | 108 | 101 | 71 | 56 | 49 | 37 | 28 | 26 | 31 | 20 |
| Nasik | 187 | 276 | 71 | 86 | 32 | 48 | 36 | 32 | 36 | 23 | 34 | 18 |
| Ahmednagar | 170 | 267 | 81 | 83 | 57 | 47 | 39 | 31 | 27 | 23 | 26 | 17 |
| Pune | 192 | 392 | 84 | 91 | 58 | 51 | 43 | 34 | 27 | 24 | 37 | 19 |
| Satara | 293 | 295 | 101 | 89 | 59 | 49 | 34 | 32 | 41 | 23 | 25 | 17 |
| Sholapur | 219 | 340 | 98 | 104 | 66 | 58 | 33 | 38 | 40 | 27 | 34 | 21 |
| Sangli | 189 | 285 | 93 | 89 | 63 | 50 | 41 | 33 | 26 | 24 | 26 | 18 |
| Kolhapur | 297 | 381 | 143 | 115 | 61 | 62 | 55 | 40 | 36 | 29 | 25 | 21 |
| Aurangabad | 266 | 374 | 120 | 114 | 75 | 62 | 59 | 41 | 38 | 29 | 24 | 22 |
| Bhir | 205 | 316 | 77 | 97 | 73 | 54 | 55 | 36 | 32 | 26 | 34 | 19 |
| Osmanabad | 304 | 409 | 130 | 123 | 83 | 67 | 48 | 43 | 44 | 31 | 34 | 23 |
| Parbhani | 307 | 407 | 129 | 123 | 77 | 67 | 52 | 43 | 45 | 30 | 17 | 22 |
| Nanded | 495 | 560 | 159 | 163 | 86 | 85 | 59 | 53 | 30 | 36 | 32 | 26 |
| Buldhana | 338 | 429 | 139 | 128 | 71 | 69 | 42 | 44 | 34 | 31 | 24 | 22 |
| Akola | 281 | 377 | 134 | 114 | 64 | 62 | 56 | 41 | 37 | 29 | 19 | 21 |
| Amraoti | 308 | 418 | 124 | 125 | 78 | 68 | 53 | 43 | 36 | 30 | 26 | 22 |
| Yeotmal | 400 | 483 | 140 | 143 | 82 | 76 | 53 | 48 | 29 | 33 | 19 | 24 |
| Nagpur | 438 | 534 | 184 | 154 | 80 | 80 | 48 | 49 | 37 | 33 | 31 | 23 |
| Wardha | 375 | 471 | 172 | 139 | 75 | 74 | 52 | 47 | 27 | 32 | 31 | 23 |
| Gondia | 527 | 567 | 185 | 161 | 100 | 83 | 49 | 50 | 37 | 33 | 25 | 23 |
| Chanda | 421 | 528 | 164 | 152 | 101 | 79 | 47 | 49 | 37 | 33 | 31 | 23 |

**TABLE 2** (*contd*)

| Station | Spell length in days: 13 | | 15 | | 17 | | 21 | | 19 | | 23 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | O | T | O | T | O | T | O | T | O | T | O | T |
| | (b) **Rainfall less than 6.3 mm per day** | | | | | | | | | | | |
| Thana | 7 | 12 | 4 | 9 | 6 | 6 | 5 | 5 | 6 | 4 | 3 | 3 |
| Colaba | 14 | 15 | 9 | 12 | 11 | 9 | 9 | 7 | 5 | 5 | 5 | 4 |
| Alibag | 12 | 16 | 11 | 11 | 6 | 8 | 4 | 6 | 5 | 5 | 4 | 4 |
| Ratnagiri | 10 | 12 | 7 | 8 | 11 | 6 | 2 | 4 | 4 | 3 | 1 | 2 |
| Jalgaon | 12 | 16 | 17 | 13 | 16 | 10 | 12 | 8 | 10 | 7 | 5 | 6 |
| Nandurbar | 25 | 15 | 16 | 12 | 13 | 10 | 12 | 8 | 11 | 7 | 9 | 6 |
| Nasik | 14 | 14 | 17 | 11 | 15 | 9 | 14 | 8 | 10 | 7 | 8 | 6 |
| Ahmednagar | 21 | 14 | 15 | 11 | 11 | 9 | 14 | 8 | 17 | 7 | 8 | 6 |
| Pune | 23 | 15 | 17 | 12 | 16 | 10 | 18 | 8 | 13 | 7 | 6 | 6 |
| Satara | 25 | 13 | 14 | 10 | 11 | 8 | 17 | 7 | 13 | 6 | 9 | 5 |
| Sholapur | 30 | 16 | 18 | 13 | 14 | 10 | 12 | 9 | 11 | 7 | 12 | 6 |
| Sangli | 24 | 15 | 19 | 12 | 14 | 10 | 16 | 8 | 19 | 7 | 12 | 6 |
| Kolhapur | 31 | 17 | 6 | 13 | 14 | 10 | 11 | 8 | 8 | 7 | 8 | 5 |
| Aurangabad | 15 | 17 | 30 | 13 | 14 | 11 | 16 | 9 | 9 | 7 | 11 | 6 |
| Bhir | 17 | 15 | 10 | 12 | 20 | 10 | 14 | 9 | 12 | 7 | 7 | 6 |
| Osmanabad | 25 | 17 | 19 | 14 | 17 | 11 | 13 | 8 | 13 | 7 | 9 | 6 |
| Parbhani | 20 | 17 | 10 | 13 | 20 | 11 | 14 | 9 | 14 | 7 | 4 | 6 |
| Nanded | 27 | 19 | 17 | 14 | 17 | 11 | 14 | 9 | 10 | 7 | 5 | 5 |
| Buldhana | 13 | 17 | 18 | 13 | 18 | 10 | 7 | 8 | 8 | 7 | 4 | 5 |
| Akola | 25 | 16 | 23 | 13 | 12 | 10 | 10 | 9 | 7 | 7 | 2 | 6 |
| Amraoti | 17 | 17 | 13 | 13 | 5 | 11 | 10 | 8 | 5 | 7 | 8 | 6 |
| Yeotmal | 24 | 18 | 15 | 14 | 15 | 11 | 8 | 8 | 9 | 7 | 3 | 5 |
| Nagpur | 21 | 17 | 9 | 13 | 11 | 10 | 11 | 8 | 3 | 6 | 1 | 5 |
| Wardha | 20 | 17 | 13 | 13 | 16 | 10 | 9 | 8 | 5 | 7 | 4 | 5 |
| Gondia | 6 | 17 | 12 | 12 | 14 | 9 | 8 | 7 | 4 | 6 | 6 | 4 |
| Chanda | 19 | 17 | 25 | 13 | 6 | 10 | 8 | 8 | 4 | 6 | 3 | 5 |

O=Observed frequency T=Theoretical frequency.

**TABLE 3**

**Probability of occurrence of dry sequences (in percentage)**

| | Spell length in days equal to or greater than | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Rainfall < 2.5 mm/day | | | | | Rainfall < 6.3 mm/day | | | | |
| | 5 | 10 | 15 | 20 | 25 | 5 | 10 | 15 | 20 | 25 |
| **Konkan** | | | | | | | | | | |
| 1 Thana | 22.0 | 11.1 | 6.3 | 3.5 | 1.0 | 23.9 | 11.4 | 6.1 | 3.7 | 1.2 |
| 2 Colaba | 20.6 | 9.7 | 5.4 | 3.0 | 1.7 | 29.9 | 14.3 | 7.4 | 4.0 | 2.4 |
| 3 Alibag | 20.2 | 8.8 | 5.0 | 3.2 | 0.9 | 27.6 | 11.9 | 6.1 | 4.0 | 1.3 |
| 4 Ratnagiri | 18.9 | 7.8 | 4.3 | 2.1 | 0.5 | 21.7 | 9.5 | 5.0 | 2.4 | 0.8 |
| **Madhya Maharashtra** | | | | | | | | | | |
| 5 Jalgaon | 29.7 | 16.0 | 8.7 | 5.0 | 1.7 | 38.1 | 22.7 | 14.0 | 8.8 | 2.9 |
| 6 Nandurbar | 33.2 | 16.5 | 9.5 | 6.1 | 2.1 | 46.0 | 26.4 | 16.4 | 10.7 | 7.0 |
| 7 Nasik | 36.4 | 18.1 | 9.5 | 4.4 | 1.2 | 53.2 | 34.1 | 21.6 | 12.6 | 4.3 |
| 8 Ahmednagar | 42.5 | 23.7 | 13.3 | 7.4 | 2.3 | 52.4 | 33.8 | 22.8 | 16.5 | 5.3 |
| 9 Pune | 38.0 | 19.6 | 9.4 | 3.4 | 0.9 | 51.9 | 32.5 | 20.3 | 11.8 | 3.9 |
| 10 Satara | 35.4 | 17.3 | 8.2 | 2.8 | 0.6 | 42.4 | 24.4 | 15.0 | 8.2 | 2.1 |
| 11 Sholapur | 36.5 | 16.9 | 7.4 | 3.8 | 0.9 | 47.1 | 28.5 | 15.7 | 9.4 | 2.9 |
| 12 Sangli | 36.7 | 17.1 | 8.8 | 3.8 | 0.8 | 52.0 | 32.3 | 21.4 | 14.1 | 4.4 |
| 13 Kolhapur | 32.0 | 12.5 | 5.5 | 1.8 | 0.4 | 41.7 | 22.2 | 12.9 | 7.0 | 1.7 |
| **Marathwada** | | | | | | | | | | |
| 14 Aurangabad | 31 6 | 14.3 | 7.7 | 3.7 | 1.2 | 44.4 | 23.5 | 14.7 | 8.0 | 2.3 |
| 15 Bhir | 39.0 | 18.7 | 9.5 | 4.9 | 1.5 | 51.3 | 29.2 | 17.4 | 9.7 | 3.0 |
| 16 Osmanabad | 29.2 | 12.4 | 5.4 | 2.8 | 0.8 | 41.7 | 22.0 | 12.3 | 6.7 | 1.9 |
| 17 Parbhani | 31.3 | 13.3 | 6.4 | 3.0 | 0.9 | 41.0 | 20.8 | 13.0 | 7.2 | 2.0 |
| 18 Nanded | 26.9 | 11.8 | 5.5 | 2.8 | 1.0 | 32.6 | 15.7 | 8.6 | 4.6 | 1.4 |
| **Vidarbha** | | | | | | | | | | |
| 19 Buldhana | 27.9 | 13.2 | 7.2 | 4.4 | 1.5 | 35.8 | 20.3 | 11.8 | 6.7 | 2.2 |
| 20 Akola | 32.7 | 16.3 | 8.7 | 4.7 | 1.5 | 42.4 | 22.3 | 13.8 | 8.1 | 2.6 |
| 21 Amraoti | 28.9 | 13.6 | 6.8 | 4.1 | 1.4 | 38.8 | 19.9 | 11.3 | 7.5 | 2.5 |
| 22 Yeotmal | 27.4 | 13.1 | 6.7 | 3.8 | 1.3 | 34.1 | 17.8 | 10.1 | 5.7 | 1.8 |
| 23 Nagpur | 23.3 | 9.7 | 5.0 | 2.9 | 1.0 | 30.7 | 14.1 | 7.5 | 4.1 | 1.3 |
| 24 Wardha | 26.8 | 11.6 | 6.3 | 3.4 | 2.4 | 34.1 | 17.9 | 9.6 | 5.2 | 1.9 |
| 25 Gondia | 22.4 | 8.7 | 5.2 | 2.9 | 0.9 | 27.3 | 11.4 | 7.2 | 4.0 | 1.2 |
| 26 Chanda | 22.8 | 8.9 | 4.7 | 2.9 | 0.9 | 29.9 | 14.3 | 7.3 | 4.4 | 1.4 |

**7. Fitting a theoretical distribution**

With a view to interpret the effect of persistence on the sequence of dry spells, it is necessary to determine the sequences of different lengths expected from theoretical considerations and then estimate the unknown parameters. In this study, the hypothesis that the longer a dry spell lasts, the higher the probability that the following day will also be dry was assumed.

Denoting $S_r$ by number of dry sequences which last atleast $r$ days, we, therefore, have

$$S_r+1/S_r = P(r)$$

where $P(r)$ is the probability, a sequence of $r$ dry days will be following by another dry day and is an increasing function of $r$.

The ratio $S_r+1/S_r$ was calculated and for 10 values ($r=1, 2, \ldots, 10$) of the observed frequency of dry spells presented in Table 1. From the table it is seen that this ratio gradually increases, in general, for both the criteria of rainfall. For rainfall less than 2.5 mm per day criteria, for the spell length 1 to 10, the increase is from 0.71 to 0.90, the corresponding values for the second criteria being 0.80 to 0.93 respectively. This recurrence relationship is the logarithmic distribution and can be represented by

$$f_r+1 = (r/r+1)q.\ f_r$$

where $f_r$ = number of drys pells of exactly $r$ days duration, $q=1-p$ and $0<q<1$. Now as $S_r+1/S_r$ or $P(r)$ increases with $r$, $f_r+1/f_r$ must also increase with $r$, this being the characteristic feature of logarithmic distribution. Frequency $f_r$ is given by

$$f_r = N\frac{-1}{\log_e(1-q)} \times \frac{q^r}{r} \quad \text{for } r \geqslant 1$$

where $N$ = total number of dry spells.

For each case, the logarithmic distribution was fitted by equating the observed mean to the theoretical mean given by

$$\text{Theoretical mean} = \frac{-1}{\log_e(1-q)} \times \frac{q}{(1-q)}$$

and the values of $q$ determined from Table 1 of Williamson and Bretherton (1964) paper.

The theoretically obtained frequency for various dry spells are depicted in Table 2. In general, for most of the stations the computed values were closer to those observed for different spells.

This was also confirmed by testing the goodness of fit on computing the $\chi^2$.

**8. Characteristic features of the analysis**

8.1. *Analysis of frequencies*

(1) *Rainfall less than 2.5 mm per day* — Analysis of frequencies of spells of dry days of different lengths reveal some interesting characteristics. Whereas for dry days of spells upto 6 days, the dry land zone of the State has the least frequency, Konkan and east Vidarbha in contrast possess comparatively higher frequencies. This means that dry spells of shorter duration are less frequent over Madhya Maharashtra and adjoining Marathwada, but are more frequent in the remaining parts of the State. The pattern undergoes a reversal thereafter when over Konkan and Vidarbha the frequencies of spells of higher length diminish and higher frequencies appear over eastern parts of Pune, Sangli and Satara districts, western parts of Sholapur district, Ahmednagar district, parts of Nasik district and adjoining parts of Marathwada. This high frequency area initially appears over Sholapur, Sangli and adjoining districts and later spreads northwards. With the increase in the length, strong gradient appear over the Western Ghats. Moreover, though different parts of the areas of higher frequencies spread over Madhya Maharashtra and adjoining Marathwada for higher length, highest frequencies could, in many cases, be located over Ahmednagar district and its surrounding areas. This will imply that over these areas, particularly Ahmednagar district, may receive rainfall less than 2.5 mm for continuous long spell.

(2) *Rainfall less than 6.3 mm per day* — The observations for this criterion were similar to that for 2.5 mm criterion. For lower lengths of dry spells, low frequencies were observed for Madhya Maharashtra while comparatively higher frequencies were observed over eastern parts of Vidarbha and Konkan.

This means that, chances of getting rainfall less than 6.3 mm for continuous period of 5 to 6 days are rare for Madhya Maharashtra and adjoining Marathwada.

In contrast on large number of occasions dry spells exceeding 6 days may be expected over this area.

8.2. *Probability distribution*

The above analysis based on observed frequency distribution gives a fair indication of the areas in which continuous dry spells and hence drought may be expected. It, however, does not show, in how many years a drought condition may be expected over a locality by chance. As has been mentioned, occurrence of drought is a random phenomenon and the likelihood of its occurrence by mere chance may be quantified by the probability distribution. For this purpose, the probability of occurrence of dry spells of various lengths was worked out and presented in Table 3.

For first threshold value, probabilities of occurrence of dry spells equal to or more than five days was highest (40 per cent) over Ahmednagar district and adjoining areas, meaning thereby that in two years out of five, this areas may experience dry spells equal or more than 5 days in length. Over Madhya Maharashtra as a whole, the probability exceeded 35 per cent. For large spells also areas of highest probabilities were

found located around Ahmednagar. Thus for dry spells equal to or more than 10, 15 and 20 days in this area the probability exceeded 20, 10 and 5 per cent respectively. In the second category of dry day for obvious reasons, probability of occurrence of dry spells should be more for corresponding length than that in the first category. Thus for dry spells 5 days, the highest probability was 50 per cent occurring over Madhya Maharashtra, *i.e.*, every second year we may expect dry spells equal to or more than 6.3 mm. The probability diminishes with higher lengths although highest probability was confined more or less to the same area. Thus, for dry days equal or exceeding 10, the probability was 30 per cent for 15 days, 20 per cent and 15 per cent for 20 days or more.

The probabilities were lowest in both categories of dry days, for any length over coastal belt and Vidarbha.

### 9. Summary

The frequencies of sequences of dry days based on certain minimum amount of rainfall, having bearing on agriculture, have been advanced as a drought discriminant in the country. A theoretical function, *viz.*, logarithmic distribution has been established and by computing the parameters in the model, it was believed, it may be possible to evaluate drought conditions, both in time and space.

It may, however, be emphasised that the occurrence and severity of agricultural drought depends on the length of the dry sequences, in combination with moisture content, soil texture and moisture holding capacity of the soil, type, stage and water use pattern of the crop. The results of the study may not be considered, in isolation, but may be synthesized with the above factors for a realistic evaluation of drought.

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### References

George. C.J. and Kalyanasundaram, V., 1969, Use of monthly rainfall deciles for assessing agricultural drought, India met. Dep. Pre-publ. Sci. Rep. No. 96.

George, C. J., Ramasastri, K. S. and Rentala, G. S., 1973, Incidence of droughts in India, India met. Dep., Met. Monograph Agrimet. No. 5/1973.

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

George, C. J., Abhyankar, V. P. and Rentala, G. S., 1975, Areal extent of drought of southwest monsoon in India, *Indian J. Met. Hydrol. Geophys.*, **26**, 2, pp. 199-202.

Palmer, Wayne C., 1965, Met. Drought—Res. Paper No. 45, U. S. Dep. of Commerce, Weath. Bur.

Raman, C.R.V., 1974, Analysis of commencement of monsoon rains over Maharashtra State for Agricultural planning, India met. Dep. Pre-publ. Sci. Rep. No. 216.

Williamson, E. and Bretherton, M. M., 1964, Tables of the logarithmic series distribution, *Annual Math. Stat.*, **35**, pp. 284-98.