Sci. Annals, Fac. Phys. & Mathem., Univ. Thessaloniki, **13**, 381, (1973)

SEQUENCES OF RAIN AND DROUGHT IN THESSALONIKI

by

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(Received, 6.11.1973)

Abstract: *The sequences of rain and drought, during the period* 1930 - 1972 *are being examined on the basis of rainfall data of the MS/AUT and the distribution of same per month, season and year, is concluded.*

Mainly the «Polya» method is applied through which the probability of appearance of a sequence is given as well as the expected number of its repetition during a definite period of time.

INTRODUCTION.

The distribution of sequences of rain and drought in Thessaloniki are examined during the period 1930 - 1972 on the basis of the rainfall observations of the Meteorological Station of the Aristot. University of Thessaloniki (MS/AUT): Annuaire de l'Institut Mètèorologique de Thessaloniki [6].

The gaps in the above observations created by the war and occupation periods, were covered by the respective data of the meteorological station of the german war navy (MS/GWN) which operated during the above periods (LIVADAS and ARSENI - PAPADIMITRIOU [4]).

In order to find the probability of appearance of a sequence of rain or drought as well as the expected number of repetition during a definite period of time, we applied Polya's method (GRISOLLET - GUILMET - ARLERY [3], ABI FARAH [1]).

The sequences of rain or drought in the greek area were dealt with by MARIOLOPOULOS - KARAPIPERIS [5]; those scientists, however, only mentioned statistical data whereas — due to the lack of adequate data — they did not include Thessaloniki in the relevant tables.

I. DEFINITIONS.

As «sequence of rain» is characterized a group of n ($n \geq 1$) successive rainy days. More specifically, as «sequence of rain of grade h_i — h_{i+1} mm» is characterized a group of n (n ≧ 1) successive days during which rainfall was recorded h mm ($h_i \leqq h \leqq h_{i+1}$). Generalizing the term, we characterise as a «sequence of drought» a group of n (n ≧ 1) successive rainless days.

In order to classify a sequence per month, season or year, we applied the following:

— A sequence, all days of which belong to the same month (n ≦ 31) obviously, belongs to this month.
— A sequence part of the days of which belong to one month, and the remaining days to the next month (n ≦ 62):
  (a) Is classified in the month to which belong more than half of its days.
  (b) Is classified in the second month under consideration, when exactly half of its days belongs to the first and the other half to the second month (n = even).
— A sequence the days of which belong to three successive months (n ≧ 30), is always classified under the second of the months under consideration.
— The above apply also in the case where the dates of the sequences are located in the boundaries of two successive seasons or two successive years.

II. Distribution of sequences per month.

The sequences of rain and drought isolated according to the above, are shown (per grade and number of days), for each month, in Table I.

From the above table, which covers the whole period under examination, it is ascertained that the longest rainless period, was recorded during the period from September 1st to October 9th, 1942. In total, during the whole period under consideration, only 9 sequences of drought exceeded, as regards duration, 29 days (in other words, they presented a duration equal or bigger than the average month):

Serial No	Month	Period	Duration	Season
1	August	10/ 8 - 16/ 9/1930	38 days	Summer
2	October	16/ 9 - 16/10/1932	31 »	Autumn
3	May	15/ 5 - 13/ 6/1935	30 »	Spring
4	October	15/ 9 - 21/10/1935	34 »	Autumn
5	September	12/ 9 - 12/10/1940	31 »	Autumn

6	July	9/ 7 - 8/ 8/1941	31 »	Summer
7	September	1/ 9 - 9/10/1942	39 »	Autumn (Max.)
8	July	14/ 7 - 17/ 8/1956	35 »	Summer
9	October	7/10 - 5/11/1965	30 »	Autumn

From the same Table I, it is ascertained as regards sequences of rain per grade, that the duration of none exceeded 11 days.

As we reach the sequences of higher grade, a decrease in number of appearances and duration is recorded. Thus, only 12 sequences of rain of grade $h > 50{,}0$ mm, were recorded during the whole period under consideration; the duration of all sequences did not exceed 1 day.

III. Sequences of rain.

If we do not take into consideration the grade h of rain of the sequences, the duration and number of the sequences of rain are altered in comparison with sequences of rain of grade mentioned in Table I.

The frequency of appearance of the sequences of rain per duration, is shown in Table II.

From the data included in the above table, the curves in Graph I were drawn, in which the frequencies per duration (number of days) of appearance of the sequences of rain are shown by a full line (irrespective of grade) and the total number of days (per duration and sequence) by a dotted line.

Recapitulating, on a total of 15.706 days (period under consideration: 1930-1972), 5.673 days of rain (daily rainfall: $\geqq 0{,}0$ mm) were recorded, distributed in 2.432 sequences of rain. During the same period were recorded respectively: 10.033 rainless days distributed in 2.433 sequences of drought. We may say from the above that the probability of precipitating $\geqq 0{,}0$ mm on a given day of the year is: $p=0{,}36$.

IV. Polya' s distribution

Polya' s distribution (Grisollet-Guilmet-Arlery [3], Abi Farah [1]), brings a modification to the well known Bernoulli' s distribution (in the classical example of the Urn). This presupposes the replacement (after the extraction of a pellet and before extraction of a second) not only of the pellet extracted but in addition of a certain number: μ of pellets (of the same colour as the one extracted), so that after each

TABLE I

Sequences of drought and rain per grade and per month (MS/AUT : 1930 - 1972)

Month	Grade(mm)	n =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	>15
Jan.	0(drought)		76	45	23	18	11	16	7	6	4	1	1	3	—	1	—	2
»	0,0 - 5,0		129	65	19	18	8	6	—	—	1	1	1					
»	5,1 - 20,0		76	12	3	—	1											
»	20,1 - 50,0		14															
»	≧50,1		—															
Febr.	0(drought)		70	42	30	19	11	11	12	6	—	2	—	2	1	1	—	5
»	0,0 - 5,0		130	49	14	12	3	3	2									
»	5,1 - 20,0		55	11														
»	20,1 - 50,0		17															
»	≧50,1		—															
March	0(drought)		72	48	21	17	15	4	6	5	6	4	3	—	4	1	—	2
»	0,0 - 5,0		121	57	27	15	12	3	4									
»	5,1 - 20,0		63	12														
»	20,1 - 50,0		11	2														
»	≧50,1		—															
April	0(drought)		76	59	29	14	13	8	6	6	3	2	5	5	—	1	—	3
»	0,0 - 5,0		135	67	25	9	5	2										
»	5,1 - 20,0		55	9	2													
»	20,1 - 50,0		15	1														
»	≧50,1		1															
May	0(drought)		92	43	32	23	14	11	8	2	1	2	4	5	2	1	—	1
»	0,0 - 5,0		128	60	26	16	4	1	2	1								
»	5,1 - 20,0		61	9	2													
»	20,1 - 50,0		10	1														
»	≧50,1		1															
June	0(drought)		70	44	28	16	17	13	4	13	7	5	—	—	2	1	1	2
»	0,0 - 5,0		137	56	22	4	4	1	—	—	1							
»	5,1 - 20,0		58	8	1													
»	20,1 - 50,0		13	1														
»	≧50,1		2															

TABLE I (Continued)

Month	Grade(mm)	n =	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	>15
July	0(drought)		39	23	23	19	16	11	11	6	3	6	4	—	2	3	5	11
»	0,0 - 5,0		125	36	11	3	2											
»	5,1 - 20,0		36	3														
»	20,1 - 50,0		14															
»	≧50,1		1															
Aug.	0(drought)		24	10	12	15	8	11	7	5	11	1	6	3	2	2	1	24
»	0,0 - 5,0		90	25	11	—	—	3										
»	5,1 - 20,0		21															
»	20,1 - 50,0		8															
»	≧50,1		1															
Sep.	0(drought)		35	28	16	15	12	12	3	8	4	10	4	3	3	2	—	13
»	0,0 - 5,0		105	42	11	5	—	—	1									
»	5,1 - 20,0		46	6														
»	20,1 - 50,0		15															
»	≧50,1		2															
Oct.	0(drought)		52	26	20	17	14	8	3	9	5	5	5	4	—	2	4	6
»	0,0 - 5,0		126	41	16	5	2	—	1	1	1							
»	5,1 - 20,0		71	10	4													
»	20,1 - 50,0		19															
»	≧50,1		2															
Nov.	0(drought)		58	50	30	22	19	10	7	7	2	2	4	—	—	—	—	1
»	0,0 - 5,0		158	53	22	13	3	1										
»	5,1 - 20,0		78	15	3													
»	20,1 - 50,0		21															
»	≧50,1		—															
Dec.	0(drought)		80	45	19	21	12	18	5	5	6	3	1	3	1	—	1	3
»	0,0 - 5,0		133	51	24	16	5	3	2									
»	5,1 - 20,0		85	12	2													
»	20,1 - 50,0		20	2														
»	≧50,1		2															

TABLE II

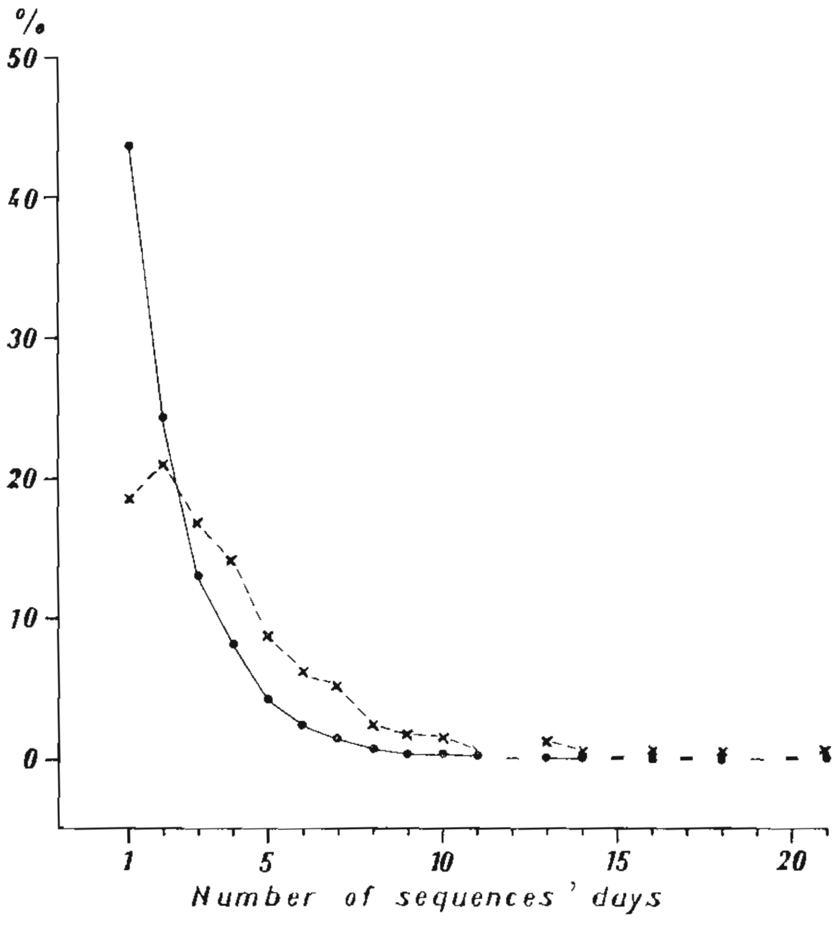
Frequency of sequences per duration and total number of rainy days

(MS/AUT : 1930 - 1972)

Duration of sequence in days (n)	*Frequency of sequences (S)*	%	*Total number of rainy days (n×S)*	%
1	1063	43,71	1063	18,74
2	594	24,42	1188	20,94
3	319	13,12	957	16,87
4	202	8,31	808	14,24
5	100	4,11	500	8,81
6	60	2,47	360	6,35
7	42	1,73	294	5,18
8	18	0,74	144	2,54
9	11	0,45	99	1,75
10	11	0,45	88	1,55
11	2	0,08	22	0,39
12	—	—	—	—
13	5	0,21	65	1,15
14	1	0,04	14	0,25
15	—	—	—	—
16	2	0,08	32	0,56
17	—	—	—	—
18	1	0,04	18	0,32
19	—	—	—	—
20	—	—	—	—
21	1	0,04	21	0,37
Total	2432	100,00	5673	100,01

GRAPH I

Frequency curves of sequences of rain and days of rain (% MS/AUT. 1930-72)



extraction $\mu+1$ pellets he replaced in the Urn, of the same colour as the one extracted. In the case: $\mu=0$, we find again the classical Poisson' s distribution (Conrad and Pollak [2]).

Thus, in Polya' s method there is now a dependence between two successive extractions.

This distribution proves to be satisfactory in order to find the probability of appearance of a sequence of rain or drought of a certain duration as well as the expected number of its appearance in a period of time.

It is well known that in Poisson' s distribution, the probability Px, of x appearances of an event in a series of n observations, for : x=0, 1, 2, . . . i, ... is :

$$P_o = e^{-\bar{m}}, \quad P_1 = \frac{e^{-\bar{m}} \cdot \bar{m}}{1\,!}, \ldots, \quad P_i = \frac{e^{-\bar{m}}\, \bar{m}^{\,i}}{i\,!}, \ldots \tag{1}$$

where : $\bar{m}$ is the mean.

In Polya' s method the probabilities (1) become:

$$P_o = \frac{1}{(1+d)^{\frac{\bar{m}}{d}}}, \quad P_1 = \frac{\bar{m}}{1!\,(1+d)^{\frac{\bar{m}}{d}+1}}, \ldots$$

$$\ldots, \quad P_i = \frac{\bar{m}\,(\bar{m}+d)\ldots[\bar{m}+(i-1)d]\ldots}{i!\,(1+d)^{\frac{\bar{m}}{d}+i}} \tag{2}$$

The above probabilities (2) are simplified (after finding the P_o and on the basis of it), as follows:

$$P_o = \frac{1}{(1+d)^{\frac{\bar{m}}{d}}}, \quad P_1 = P_o\,\frac{\bar{m}}{1+d}, \ldots, \quad P_i = P_{i-1}\,\frac{\bar{m}+(i-1)d}{i(1+d)}, \ldots \tag{3}$$

where: $\bar{m}$ is the mean and the parameter : d (dependence parameter) shows the degree of dependence of an event from the next.

«d» is calculated from the given data through the relation:

$$d = \frac{\sigma^2}{\bar{m}} - 1 \tag{4}$$

where σ^2 is the distribution' s variance.

V. Application of Polya's method on the sequences of rain of the period 1930-1972

From Table II which gives the sequences of rain of the period 1930-1972, we have the following:

During a period of 43 years (15.706 days) were recorded: 5.673 days of rain distributed into 2.432 sequences of rain. From all the above sequences we deduct the first day of each sequence (i. e. from the 5.673 rainy days of the period, 2.432 days are deducted) and we find the remaining 3.241 days, in other words, the total of the subsequent (minus the first) successive days of all the sequences.

The mean (per sequence) of the remaining days is

$$\overline{m} = \frac{3241}{2432} = 1,3326 \text{ days} \tag{5}$$

The other parameters of this distribution are:

— Variance:

$$\sigma^2 = \frac{\Sigma n_i \cdot S_i^2}{N} - \overline{m}^2 = 3,571 \tag{6}$$

where: n_i=the total number of all the sequences of the same duration: $S_i = x_i - 1$=the duration of the sequence (in days) reduced (on the basis of those previously mentioned) by one day, N = the total of the sequences recorded and : $\overline{m}$ = the mean previously mentioned.

— Dependence parameter:

$$d = \frac{\sigma^2}{\overline{m}} - 1 = 1,680 \tag{7}$$

On the basis of the above parameters, the probability of appearance of a sequence of rain of a duration of 1 day, is: $P_o = \dfrac{1}{(1+d)^{\frac{\overline{m}}{d}}} = 0,416$,

i.e. a figure slightly differing from the one infered by the finding of the simple probability:

$$P = \frac{1063}{2432} = 0,437 \left(= \frac{\text{sequences of 1 day}}{\text{number of sequences}} \right) \tag{8}$$

By applying the previous relations, we find the probability of appearance of a sequence of a certain duration as well as the expected number of its repetition (of its appearance) during the period under consideration. The above results are included in the following Table III.

TABLE III

Sequences of rain (MS/AUT : 1930 - 1972) — Polya's distribution

Observed						Calculated by Polya's method sequenees of rain	
Number of days	Number of sequences	Number of days of sequences	n_i	S_i	$n_i \times S_i$	Propability P_i	Expected number $P_i \times N$
1	1063	1063	1063	0	0	0,461600	1117,50
2	594	1188	594	1	594	0,226800	551,58
3	319	957	319	2	1276	0,127230	309,35
4	202	808	202	3	1818	0,074300	180,70
5	100	500	100	4	1600	0,044200	107,49
6	60	360	60	5	1500	0,026590	64,67
7	42	294	42	6	1512	0,016100	39,16
8	18	144	18	7	882	0,009800	23,83
9	11	99	11	8	704	0,006000	14,59
10	11	88	11	9	891	0,003700	9,00
11	2	22	2	10	200	0,002300	5,59
12	—	—	—	11	0	0,001420	3,45
13	5	65	5	12	720	0,000820	1,99
14	1	14	1	13	169	0,000510	1,24
15	—	—	—	14	0	0,000320	0,78
16	2	32	2	15	450	0,000200	0,49
17	—	—	—	16	0	0,000120	0,29
18	1	18	1	17	289	0,000070	0,17
19	—	—	—	18	0	0,000043	0,11
20	—	—	—	19	0	0,000027	0,07
21	1	21	1	20	400	0,000018	0,04
Total	2432	5673	2432		13005		2432,09

VI. Sequences of rain and drought during the various seasons

Finally, in Table IV we gathered the frequence of appearance of sequences of rain and drought during the various seasons of the year.

It is clarified that:

From the total numbers of the sequences of each season, for the rainless periods and the rainy ones, a great difference is ascertained, for all seasons, between the total of the sequences of drought and those of rain. Normally, these two figures should be equal or be different by a unit. The large differences are due to the rules we followed (Par. I), for the classification of a sequence under a month or a season. It is possible, in other words, that a sequence, due to its chronological extent, to belong to a month, covering, however, also quite a number of days of another month.

During all seasons of the year, the sequences of rain of a duration of 1 day, are much greater than the respective sequences of drought.

Conclusions

From all the above mentioned we draw the following conclusions:

—During all the months of the year, (as an average of the period 1930-72), sequences of rain of a duration of 1 and 2 days, are more numerous than the respective sequences of drought.

In case of sequences of a duration of 3 days, with the exception of the months of March and December, all the remaining months record (as an average of the period), sequences of rain inferior or equal (October) to the respective sequences of drought.

In case of sequences of a duration greater than 3 days, all months, (as an average of the period), record sequences of rain inferior to the respective sequences of drought.

—During the whole period under consideration only 9 sequences of drought exceeded in duration the 29 days ($\geqq$ 30 days), with a greater frequence of their appearance during autumn (5 times); during this season a sequence of dronght (39 days) of the maximum duration was recorded: 1/9 - 9/10/1942.

—From the total sequences of rain recorded during the period under consideration, those of a duration of 1, 2 and 3 days, cover the 81,25 % of the total, whereas the number of days of the total of sequences of rain of a duration of 1, 2 and 3 days, covers the 56, 55 % of the total number of rain-days of the period under consideration.

TABLE IV

Sequences of (A) drought and (B) rain per season (MS/AUT : 1930 - 1972)

Number of days	Winter A	Winter B	Spring A	Spring B	Summer A	Summer B	Autumn A	Autumn B
1	221	224	227	275	151	301	146	254
2	133	156	141	186	81	118	108	136
3	71	85	82	95	60	56	66	80
4	57	64	51	63	53	28	54	44
5	35	39	42	23	41	14	47	20
6	45	24	25	17	31	13	28	11
7	24	12	18	17	23	3	13	8
8	17	6	13	4	25	—	24	5
9	10	3	10	4	22	1	12	4
10	6	5	8	2	13	—	15	2
11	3	1	12	—	9	—	12	—
12	8	—	10	—	5	—	7	1
13	2	1	6	—	5	1	3	—
14	3	1	3	—	6	1	4	—
15	1	—	—	—	7	1	4	—
16	—	2	1	—	5	—	3	—
17	1	—	1	—	3	—	2	—
18	2	1	—	—	4	—	1	—
19	3	—	—	—	3	—	—	—
20	1	—	2	—	5	—	—	—

Number of days	Winter A	Winter B	Spring A	Spring B	Summer A	Summer B	Autumn A	Autumn B
21	1	—	2	—	2	—	2	1
22	—	—	—	—	4	—	1	—
23	—	—	—	—	2	—	2	—
24	2	—	—	—	1	—	—	—
25	—	—	—	—	2	—	2	—
26	—	—	—	—	2	—	1	—
27	—	—	—	—	2	—	—	—
28	—	—	—	—	—	—	—	—
29	—	—	—	—	—	—	—	—
30	—	—	1	—	—	—	1	—
31	—	—	—	—	1	—	2	—
32	—	—	—	—	—	—	—	—
33	—	—	—	—	—	—	—	—
34	—	—	—	—	—	—	1	—
35	—	—	—	—	1	—	—	—
36	—	—	—	—	—	—	—	—
37	—	—	—	—	—	—	—	—
38	—	—	—	—	1	—	—	—
39	—	—	—	—	—	—	1	—
Total	646	644	655	686	570	537	562	566

—The sequence of rain of the maximum duration (21 days) was recorded during autumn.

—Refering to the sequences of rain and drought per season and per duration recorded (see Table IV), we ascertain that in the case of sequences of a duration of 1 and 2 days, those of drought are less numerous than the respective sequences of rain, whereas in the case of sequences of a duration ≧ 6 days, the sequences of drought are more numerous than the respective sequences of rain (during all seasons).

—The application of the Polya's method gave remarkable results: through this method, the probability of appearance of a sequence of a certain duraction, during a definite time period as well as the expected number of its repetition during the time period in question, are given with satisfactory accuracy.

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ΠΕΡΙΛΗΨΙΣ

ΕΠΕΙΣΟΔΙΑ ΒΡΟΧΗΣ ΚΑΙ ΑΝΟΜΒΡΙΑΣ ΕΝ ΘΕΣΣΑΛΟΝΙΚΗ

Ὑπὸ

ΒΛΑΔΙΜΗΡΟΥ Ε. ΑΓΓΟΥΡΙΔΑΚΗ

(Ἐργαστήριον Μετεωρολογίας καὶ Κλιματολογίας)

Μελετῶνται τὰ ἐπεισόδια βροχῆς καὶ ἀνομβρίας κατὰ τὴν περίοδον 1930 - 1972, βάσει τῶν βροχομετρικῶν στοιχείων τοῦ ΜΣ/ΑΠΘ, καὶ συνάγεται ἡ κατανομὴ αὐτῶν κατὰ μῆνα, ἐποχὴν καὶ ἔτος.

Κυρίως ἐφαρμόζεται ἡ μέθοδος Polya, διὰ τῆς ὁποίας δίδεται ἡ πιθανότης ἐμφανίσεως ἑνὸς ἐπεισοδίου ὡς καὶ ὁ ἀναμενόμενος ἀριθμὸς ἐπαναλήψεως αὐτοῦ, καθ᾽ ὡρισμένην χρονικὴν περίοδον.