Sci. Annals, Fac. Phys. & Mathem., Univ. Thessaloniki, 13, 347, (1973)

PRECIPITATION IN THESSALONIKI

by

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(Received 6.11.1973)

Abstract: *Rain and its various parameters in Thessaloniki (MS/AUT) are examined for the period : 1930 - 1972.*

It is ascertained that the mean annual rainfall is 476,74 mm and the mean annual variation of rain shows a double fluctuation with primary maximum and minimum in December and August respectively.

The cyclonic activity during the winter period and the lack of it in summer are the main causes in the shaping of the above maximum and minimum.

The seasonal distributions of precipitation are examined as well as their duration (both in days and hours), the intensities and other rainfall parameters.

From the examination of the annual rainfall and the annual numbers of rainy days in the area under examination during the period under consideration, a trend of increase is ascertained which is connected with the increase in population and the expansion of the city during the same period.

INTRODUCTION

Rain and its various parameters in Thessaloniki are being examined.

The above subject was dealt with by the scientists: ALEXANDROU [1], MARIOLOPOULOS [6,7] MARIOLOPOULOS - KARAPIPERIS [8], KYRIAZOPOULOS [4], LIVADAS - PAPADIMITRIOU [5]; the total of the papers in question refer to more general studies of the greek area or the area under examination, where the element of rain participates with the same weight as the other elements. The basic source of the material used was the series of the «Annuaire de l'Institut Météorologique»: OBSERVATIONS METEOROLOGIQUES DE THESSALONIKI [10] of the MS/AUT. This data covers the period 1930 - 1972; a gap is noted during the war and occupation (November 1940 - July 1945). This was covered by the meteorological station of the german navy (MS/GWN) * which operated for tbe grea-

* During the occupation, the MS/AUT operated defectively during a certain period of time. From tbe correlation of values of the MS/AUT and the respective

ter part of the above period at a distance of 1000 m. S of the MS/AUT (LIVADAS - PAPADIMITRIOU [5]) on the one hand and on the other hand with the help of the respective observations of the meteorological stations of the Sindos Cotton Research Institute and that of the American Farm School, by application of the regression equation

$$X = \overline{X} + \frac{\Sigma xy}{\Sigma y^2} (Y - \overline{Y})$$

Thus, a 43 year series of full observations on rain has been completed.

It should be noted that the MS/AUT from the date it was founded (1930) up to December 31, 1958 was operating on a site located about 230 m. W of the site it occupies since January 1, 1959 to this date. For the connection of the two periods of precipitation observations, in the above two locations, we correlated the observations on rain made in 1970 simultaneously on the two sites. The amounts observed at the old site (AUT_1) and the new one (AUT_2), are:

Month	J	F	M	A	M	J	J	A	S	O	N	D	Year
AUT_1	32.1	43.3	74.6	5.2	53.5	48.4	99.6	3.3	11.0	38.5	5.9	31.5	447.9
AUT_2	31.8	43.7	72.3	5.9	52.8	49.3	92.7	3.2	10.8	36.3	5.6	34.4	438.8

and the correlation coefficient was found equal to: $r = +0{,}998$.

I. ANNUAL VARIATION OF RAIN.

It shows a double fluctuation with principal maximum in December and principal minimum in August. The rainfall of the rainiest month is more than three times (3,98) that of the driest month; the latter shows a rainfall of $<$ 30,0 mm (14.5 mm).

The secondary maximum - minimum are noted during May and February respectively. The monthly values of the period varied between: 166,2mm (Dec. 1935) and: 0 mm (rainless, Sept. 1942). The annual values of the period varied between: 639.9 mm (1937) and 264.2mm (1932) respectively, with mean annual precipitation of 476,74 mm. The relation between rainfall of the rainiest and driest years of the period is: 2,42.

The variability coefficient of the monthly rainfall appears bigger

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of the MS/GWN made on rainfall (January 1943-June 1944), the correlation coefficient found was : $r = 0{,}93$.

Notice

From 1891 to 1925 various meteorological stations operated in different locations within the city of Thessaloniki : Austrian, Bulgarian, Greek High School and other (ALEXANDROU [1], MARIOLOPOULOS [6,7], KYRIAZOPOULOS [4], presenting a dissimilarity as regards time period, location, hours and observation instruments.

TABLE I

Precipitation data of Thessaloniki (MS/AUT : 1930 - 1972).

Month	$\overline{H}$	*Year*	μ	*m*	*H*	$\pm \sigma$	$\pm e$	*C.V.* (%)	*P.C.* (%)	*V* +	*V* —	$\underline{H}$	*Year*
J	111.0	1951	39.9	—	44.39	24.4	3.7	54.9	110.1	7.43		9.7	1932
F	114.0	1954	31.7	—	36.96	27.4	4.2	74.1	100.8		1.99	0.1	1945
M	94.1	1936	38.2	M.T.	38.95	24.5	3.7	62.3	96.7		0.24	1.9	1943
A	120.6	1938	30.1	7.5	39.19	28.6	4.4	72.9	100.5		4.37	3.6	1935
M	111.9	1963	37.3	—	43.56	29.5	4.5	67.7	92.5	6.26		0.2	1962
J	133.3	1957	29.2	29.2	37.30	25.4	3.9	68.8	95.6	5.00		3.6	1944
J	118.3	1972	23.3	—	32.30	30.9	4.7	95.6	80.1	17.76		0.0	1948
A	58.8	1945	10.5	M.T.	14.54	14.5	2.2	99.7	35.9		16.79	0.0	1950,61
S	125.1	1967	16.9	—	31.33	30.5	4.6	97.3	80.2		16.92	0	1942
O	133.6	1955	43.2	32.1	48.25	33.0	5.0	68.3	119.8		3.85	0.0	1969
N	136.4	1937	43.0	M.T.	52.10	32.7	5.0	62.7	133.5		5.77	7.0	1970
D	166.2	1935	49.3	—	57.87	41.2	6.3	71.1	143.6		13.48	0.8	1972
Year	639.9	1937	486.2	—	476.74	89.6	13.7	53.2				264.2	1932

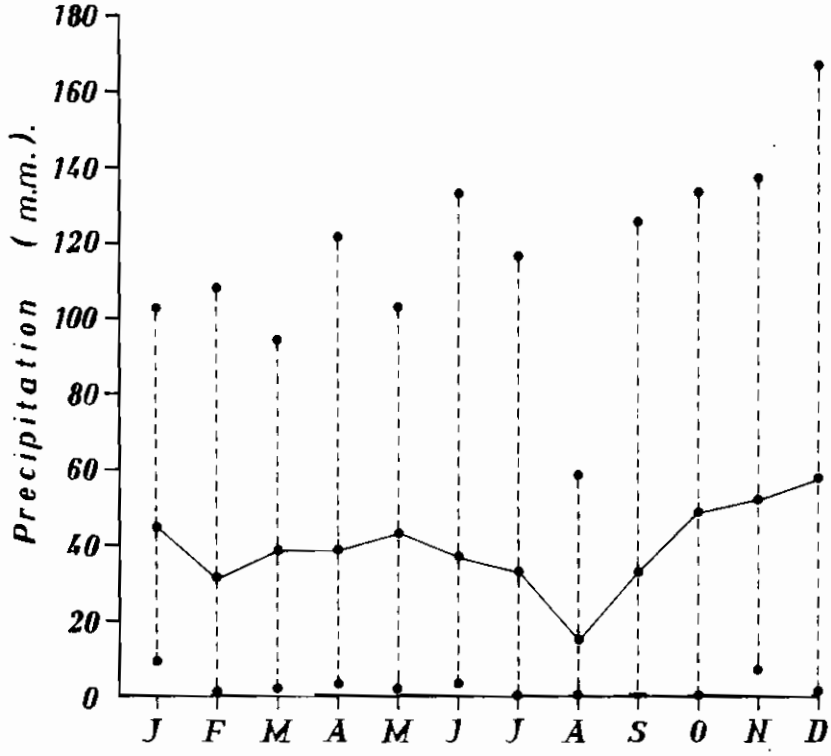
Symbols

$\overline{H}$: Maximum monthly rainfall (mm)
μ : Monthly rainfall (median)
m : Monthly rainfall (mode)
H : Monthly rainfall (mean)
$\pm \sigma$: Standard deviation
$\pm e$: Standard error
C.V. : Coefficient of variability
P.C. : Pluviometric coefficient
V : Variation
$\underline{H}$: Minimum monthly rainfall (mm)

during the warm period (July - August - September) considering that the very few intense precipitation of this season are particularly accentuated, and stand out among the, as a rule, small or nearly non - existent summer precipitation. On the contrary, the pluviometric coefficients, as it is easily understood, appear bigger during the cold period (maximum during December), considering that their order of

DIAGRAM I

Mean annual variation of precipitation in Thessaloniki (M.S/A.U.T: 1930-1972, M.A.P: 476,74 mm).



magnitude follows the order of magnitude of each month rainfall.

Out of the frequencies distribution of the deviations of the monthly values from the mean value (for each one month) it is ascertained that, notwithstanding the fact that the majority of values is smaller than

the respective mean value, no monthly value is noted between $H - 3\sigma$ and $H + 3\sigma$.

Four significant deviations ($> H + 3\sigma$) were noted as regards monthly values whereas none was noted in yearly values.

Approximately half (47 %) of the total of monthly values varies between: 0 — 29.9 mm. Especially August shows values of which the 86 % give rainfall: $<$ 29.9 mm. whereas the month of December covers

TABLE II

A. Distribution per grade of monthly rainfall (MS/AUT : 1930 - 1972).

Grades (mm)	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Total Abs. val.*	*%*
0 - 29.9	15	20	19	21	19	23	25	37	24	13	16	11	243	47.0
30.0 - 59.9	14	13	16	13	11	12	10	6	14	16	12	15	152	29.4
60.0 - 89.9	12	8	7	5	10	7	6		2	9	9	7	82	15.8
90.0 - 119.9	2	2	1	3	3		2		2	4	4	6	29	5.6
120.0 - 149.9				1		1			1	1	2	3	9	1.7
≧150.0												1	1	0.2
Total	43	43	43	43	43	43	43	43	43	43	43	43	516	99.7

B. Distribution per grade of annual rainfall (MS/AUT : 1930 - 1972).

Grades (mm)	260	320	380	440	500	560	620	680	Total
Distribution	3	4	5	13	11	5	2		43
%	7	9	12	30	26	12	5		101

by its values the whole scale of grades, showing a value: $>$ 150.0 mm (166,2 mm). On the total of monthly values of the period, 75 % do not exceed 60,0 mm

The distribution of the annual values per grades appears skewed to the left, whereas 50 % of the total of values do not exceed 450,0 mm.

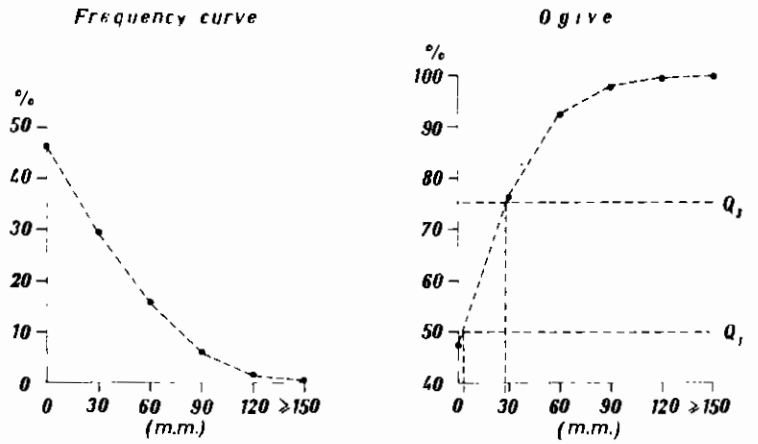
II. SEASONAL VARIATION OF RAIN.

From the mean seasonal rainfall of the period, it is ascertained that winter gives 29 % of the mean annual rainfall, autumn 28 %, spring 26 % and summer follows with a great difference (18 %).

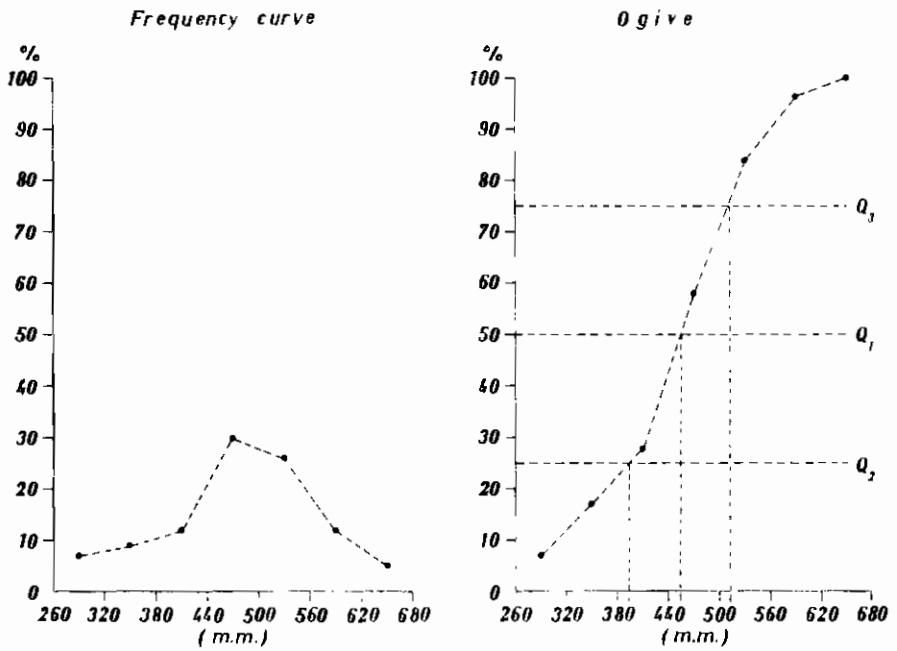
Although summer comes last as regards rainfall as an average of the period, the absolute summer maximum (175,7 mm, 1943) exceeds the mean winter precipitation by 36,5 mm.

DIAGRAM II

(a) Monthly Precipitation (M.S/A.U.T.: 1930–1972).



(b) Annual Precipitation (M.S/A.U.T.: 1930–1972).



The grades 80,0 - 120,0 and 160,0 - 200,0 mm, concentrate the 51 % of the total of the winter precipitation. The same percentage (51 %) of spring precipitation concentrates in the grade 80,0 - 160,0 mm.

TABLE III

Seasonal rainfall data (MS/AUT : 1930 - 1972).

								Percentage (%)					
Season	*Max. (1)*	*Year (2)*	*H (3)*	*μ (4)*	*m (5)*	*Min. (6)*	*Year (7)*	*h (8)*	*H (9)*	*μ (10)*	*m (11)*	*Max. (12)*	*Min (13)*
Wi.	273.8	1969	139.2	138.0	205.8	41.6	1967	1.54	29	29	33	62/69	9/67
Sp.	243.9	1936	121.7	120.8	—	24.1	1947	1.32	26	26	38	41/65	5/47
Su.	175.7	1943	84.1	84.1	—	11.4	1954	0.92	18	18	18	34/43	3/54
Au.	259.9	1955	131.7	131.9	—	20.6	1969	1.45	28	28	M.T.	43/55	5/69

Symbols

H : Mean
μ : Median
m : Mode
h : The mean seasonal rainfall divided by the actual number of days of each season (Wi. 90.25 days, Sp. 92 days, Su. 92 days, Au. 91 days).

Explanation

Columns: (10) - (13) resulted as follows:
The percentage of each seasonal rainfall was taken for each year, as to the respective annual, and followed the selection of: μ = median, m = mode, max. = maximum (the denominator indicates the year) and min. = minimum (the denominator indicates the year).
Column (9) resulted from the percentage of mean seasonal rainfall as to the mean annnal rainfall.

The majority of summer precipitation (70 %) fluctuates between 40,0 - 120,0 mm. Finally, the 35 % of the autumn precipitation concentrate on the 80,0 - 120,0 mm grade.

III. NUMBER OF RAINY DAYS.

Obviously, the rainfalls observed in a place are functions of also the duration of precipitation as well. A relative indication of the duration of precipitation is also the number of rainy days. We speak about «relative indication», because the number of rainy days does not express absolutely the duration of rain, since one day of rain is classified as such one if during that day was observed precipitation ($\geqq$ 0,0 mm)

either of 1 minute or 24 hours duration. Thus, reasonably, the curve expressing the mean annual variation of the number of rainy days does not resemble necessarily with that of the mean annual variation of rainfall in a location, as an average of the same period. The main dif-

TABLE IV

Distribution per grade, of seasonal rainfall (MS/AUT : 1930 - 1972).

(A) Absolute values.

Season	0	40	80	120	160	200	240	280(mm) Total
Wi.	0	7	11	8	11	4	2	43
Sp.	1	9	11	11	10	0	1	43
Su.	6	12	18	5	2	0	0	43
Au.	2	3	15	12	7	3	1	43
Total	9	31	55	36	30	7	4	172
(B) Percentage (%) (For each season).								
Wi.	0	16	26	19	26	9	5	101
Sp.	2	21	26	26	23	0	2	100
Su.	14	28	42	12	5	0	0	101
Au.	5	7	35	28	16	7	2	100
(C) Percentage (%) (For each grade).								
Wi.	0	23	20	22	37	57	50	
Sp.	11	29	20	31	33	0	25	
Su.	67	39	33	14	7	0	0	
Au.	22	10	27	33	23	43	25	
Total	100	101	100	100	100	100	100	

ference in this case between the above curves consists in the appearance of the third extreme values of the number of rainy days (March: maximum, April minimum). As an average of the period all months show rainy days less than half of their number of days. The absolutely maximum number of rainy days of all months of the whole period was observed in March (26 rainy days, 1961) whereas September, in one case, showed not even one single rainy day (rainless, 1942).

The months of July - August - September show the greatest variability as in the case of rainfall (see Table I).

As regards the mean, per seasons, values of rainy days for the period, winter and spring have almost the same number (39 and 38 rainy days respectively). The maximum number of rainy days was noted in winter of 1954 (58 rainy days: 68 % of its total number of days). In the summer of 1946 only 10 rainy days were recorded.

TABLE V

Data on number of rain-days (MS/AUT : 1930 - 1972).

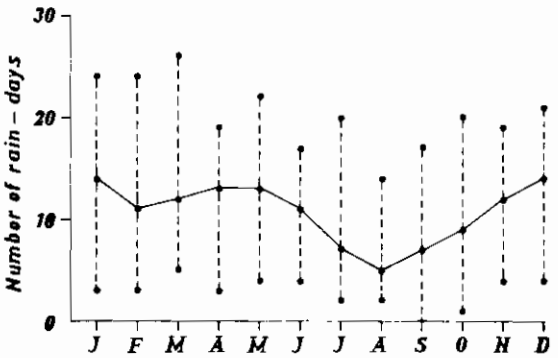
Month or Season	*Max.*	*Year*	μ	*m*	*M*	$\pm \sigma$	$\pm e$	*C.V.* %	*Min.*	*Year*
(A) Per month										
J	24	1972	14	M.T.	14,4	4.6	0.7	31.9	3	1932
F	24	1942	11	M.T.	11.2	5.0	0.8	44.6	3	1934
M	26	1961	12	M.T.	13.0	5.2	0.8	40.0	5	1945,53
A	19	1972	13	13	12.1	3.5	0.5	28.9	3	1947
M	22	1957,63	13	13	13.3	4.3	0.7	32.3	4	1942
J	17	1930	11	11	10.5	2.9	0.5	27.6	4	1932
J	20	1972	7	4	7.2	3.6	0.6	50.0	2	1946,48
A	14	1955	5	6	5.1	2.6	0.4	50.9	2	M.T.
S	17	1949	7	M.T.	7.3	3.9	0.6	53.4	0	1942
O	20	1951	9	8	10.3	4.3	0.7	41.7	1	1965
N	19	1954,56,62	12	12	12.4	4.0	0.6	32.2	4	1967
D	21	1930	14	17	13.7	4.0	0.6	29.1	4	1972
Year	168	1972	131	M.T.	130.5	17.1	2.6	13.1	98	1932
(B) Per season										
Wi.	58	1954	38	38	39.3	7.9	1.2	20.1	25	1949
Sp.	51	1960	39	M.T.	38.4	7.4	1.1	19.2	21	1935
Su.	41	1972	21	20	22.8	6.1	0.9	26.7	10	1946
Au.	47	1955	30	26	30.0	7.6	1.2	25.3	13	1965

The mean annual value of rainy days (130,5 days) does not exceed the 36 % of the total of days of the mean year (365,25 days), whereas the absolute extreme values are: maximum 168 rainy days (1972: 45 % of the days of the year) and minimum: 98 rainy days (1932: 27 % of the days of the year). It should he noted that the mean of these two extreme values of the number of rainy days of the year, slightly differentiate from the mean annual value of the period (133.0 and 130,5 rainy days respectively).

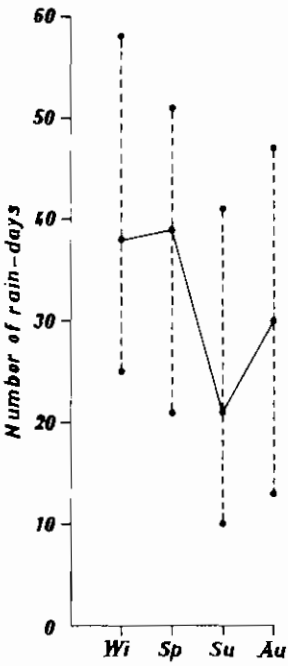
D I A G R A M III

Mean annual (a) and seasonal (b) variation of rain-days number (M.S / A.U.T. : 1930-1972)

(a) Annual



(b) Seasonal



The 34 % of the total of the monthly values shows rainy days varying between 11 - 15 days. The month of March covers the whole scale of grades marking (as mentioned before) in one case 26 rainy days

TABLE VI

Distribution of number of rain-days per grade (MS/AUT : 1930 - 1972).

(A) Per month

Number of days	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Total*	%
0 - 5	2	8	2	2	1	2	17	25	15	4	2	1	81	15,7
6 - 10	4	10	13	11	11	18	18	17	20	20	11	9	162	31,4
11 - 15	21	17	12	23	19	22	7	1	6	13	19	17	177	34,3
16 - 20	12	6	12	7	10	1	1	0	2	6	11	15	83	16,1
21 - 25	4	2	3	0	2	0	0	0	0	0	0	1	12	2,3
26 - 31	0	0	1	0	0	0	0	0	0	0	0	0	1	0,2

(B) Per season.

Number of days	*Wi.*	*Sp.*	*Su.*	*Au.*	*Total*	%
0 - 10	0	0	1	0	1	0,5
11 - 20	0	0	19	3	22	12,7
21 - 30	6	6	19	19	50	29,0
31 - 40	22	20	3	17	62	36,0
41 - 50	10	16	1	4	31	18,0
51 - 60	5	1	0	0	6	3,4

(C) Per year.

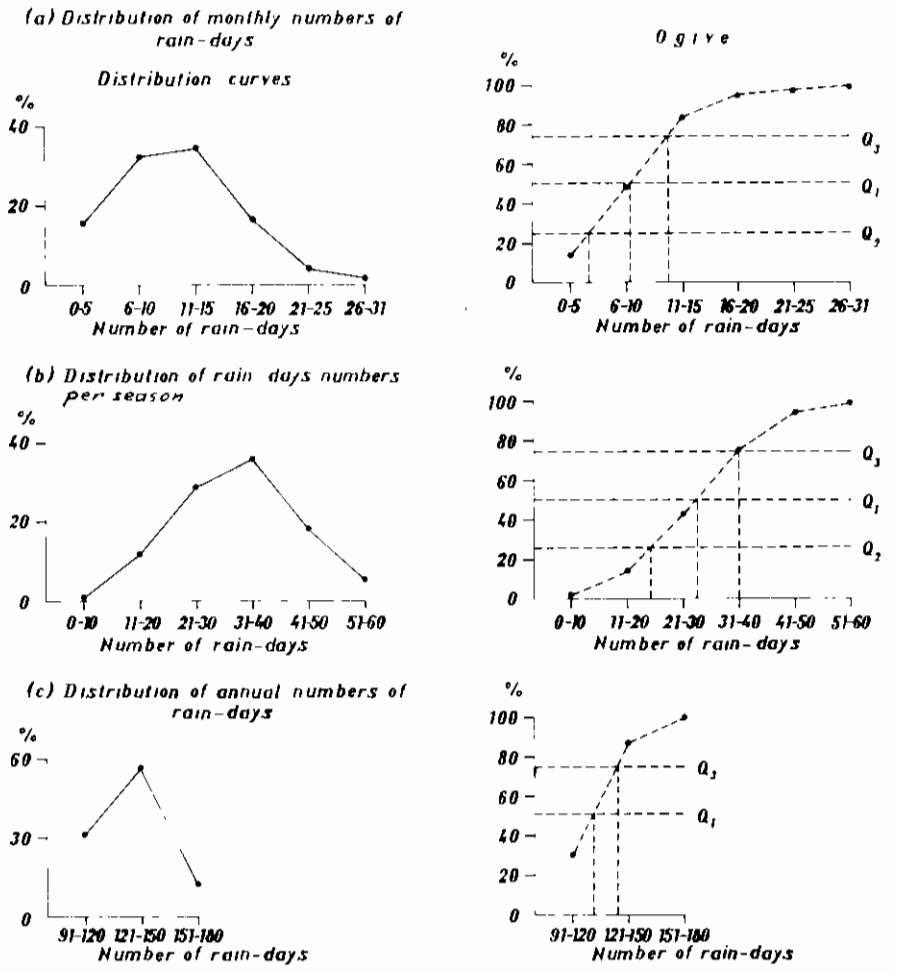
Number of days	*Frequency*	%
0 - 30	0	0
31 - 60	0	0
61 - 90	0	0
91 - 120	13	30
121 - 150	24	56
151 - 180	6	14

wehreas the month of August is restricted only to the 3 first grades of the scale.

From the distribution of standard deviations, it is ascertained that all months, during the whole period, mark an important concentration

DIAGRAM IV

Distribution curves of rain-days number per grade
(M.S/A.U.T. 1930–1972)



of their values in the class: $M \pm \sigma$ ($\geqq 63$ %). With the exception of April and July, all other months show more negative deviations than positive.

As regards the seasonal values of rainy days, once again an important concentration of values in the class $M \pm \sigma$ ($\geqq 63$ %) is noted. In this case with the exception of spring the other seasons show more negative than positive deviations.

Finally, the annual values show a concentration of their deviations in the class: $M \pm \sigma$ equal to the 65 % of the total and more positive than negative deviations.

IV. DURATION OF PRECIPITATION.

As mentioned in the heginning of the previous paragraph, the numher of rainy days constitutes a relative indication of the duration of precipitation. In this case we deal with the actual duration of precipitation, in other words, for each month we add hours and minutes during which we had precipitation.

TABLE VII

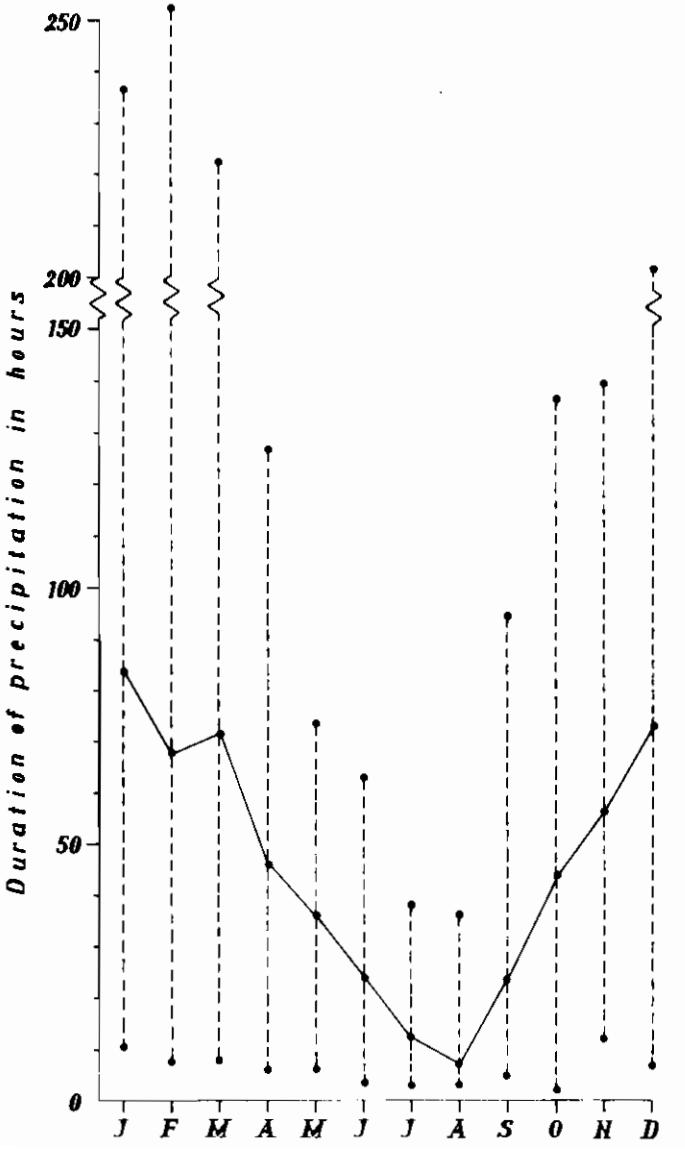
Duration of precipitation in hours (MS/AUT : 1930-39, 1947-72).

Month	*Maximum values*		*Mean*	*Minimum values*	
	Duration (hours)	*Year*	*Duration (hours)*	*Duration (hours)*	*Year*
J	234.33	1954	83.75	10.08	1932
F	250.33	1954	67.22	7.33	1966
M	220.08	1969	72.37	8.17	1938
A	126.83	1938	45.53	5.25	1935
M	73.92	1963	36.63	6.00	1962
J	62.92	1930	22.48	2.50	1938
J	38.08	1970	11.60	0.25	1948
A	37.58	1955	7.33	1.00	1934
S	93.08	1960	21.31	1.17*	1954*
O	135.15	1972	44.34	0.58	1965
N	139.58	1956	57.68	11.55	1972
D	212.83	1962	74.65	5.17	1972
Year	990.25	1954	544.89	267.58	1950

* Table I shows the month of September 1942 as rainless, whereas this Table shows as minimum duration of precipitation of the period, September recorded : 1.17 h. This is due to the fact that this table was drawn on the basis of data of the period : 1930 - 39, 1947 - 72, not including the year 1942.

DIAGRAM V

Annual variation of the duration of precipitation
(M.S / A.U.T. : 1930-39, 1947-72)



The above values as an average of the period, show a double fluctuation with principal maximum - minimum in the months of January - August respectively and secondary maximum - minimum in the months of March - February respectively. The absolute maximum - minimum

TABLE VIII

Frequency distribution per grade of duration of precipitation (hours) MS/AUT : 1930-39, 1947-72.

(A) Monthly values.

Grades (hours)	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Total*	%
0 - 24	1	9	6	7	11	22	30	35	24	10	5	4	164	37.9
24 - 48	8	7	7	16	15	12	6	1	9	11	13	6	111	25.6
48 - 72	9	8	9	7	9	2			1	10	8	8	71	16.4
72 - 96	6	6	5	1	1				2	2	4	9	36	8.3
96 - 120	7	1	5	4						2	5	6	30	6.9
120 - 144	2	1		1						1	1	1	7	1.6
144 - 168		2	3									1	6	1.3
168 - 192														
192 - 216	1	1										1	3	0.6
216 - 240	1		1										2	0.4
240 - 264	1	1											2	0.4
Total	36	36	36	36	36	36	36	36	36	36	36	36	432	99.4

(B)Annual values.

Grades (hours)	240	360	480	600	720	840	960	1080	*Total*
Frequency (absol. val.)	4	10	12	3	6	0	1		36
Frequency (%)	11	28	33	8	17	0	3		100

values are noted in February 1954 (maximum 250,33 h) and in July 1948 (minimum 0,25 h). We clarify in this case that whereas in Table I, September 1942 appears as rainless, Table VII shows minimum duration of its precipitation in 1954: 1,17 h.

This is due to the fact that, as regards the precipitation duration values, the period under examination was restricted to the years 1930 - 1939, 1947 - 1972, and consequently the year 1942 is not taken into consideration.

Out of the total of 432 months of the period, 412 (95,1 %) show precipitation (for each one month) of a duration 120 hours; during the months of July and August in no case precipitation of a $>$ 48 hours duration each were recorded.

Concerning the annual precipitation, their total yearly duration they did never show during the whole period under consideration precipitation of a total duration of 1080 hours; as regards maximum frequency, this is noted in the 400 - 600 h. grade of rains.

V. MAXIMA HOURLY AND DAILY PRECIPITATION - INTENSITIES - REPETITION PERIODS.

Hourly and daily rainfall as well as intensities present both theoretical interest (as being connected to atmospheric instability) and a practical interest considering that they become regulative factors of vital sectors of human activity (Agriculture: destructive rains, City Planning: floods, sewerage, Transportations: blockage of roads, and other). It should be noted that in also this paragraph (as in the previous one) the period under consideration is limited to the years: 1930 - 1939, 1947 - 1972.

(a) Hourly rainfall

Having taken into consideration the extreme values between which fluctuated the maximum hourly values during each month, during the period under consideration, the following Table IX was drawn.

TABLE IX

Largest and smallest values of maximum hourly precipitation per month (MS/AUT: 1930-1939, 1947-1972)

	Month	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	Year
Max.	Largest	13,3	15,0	17,5	27,3	42,2	32,5	47,3	16,3	40,8	30,7	17,6	12,9	47,3
	Smallest	0,9	0,3	0,9	1,1	0,1	2,1	0,0	0,0	0,0*	0,0	1,2	0,4	0,0

* See footnote of Table VII and clarification on page above.

From the above maxima, the largest value is recorded in the month of July whereas the smallest value is recorded in December and (with a slight difference) in January. The maximum of July: 47,3 mm/h, as compared to the other rainfall conditions of the area under examination, is quite remarkable, considering that it is inferior to the maximum mean monthly value (December: 57, 87 mm, Table I) by hardly 10,57 mm. and constitute about the 1/10 of the mean annual precipi-

tation of the area under consideration.

Out of the per grade distribution of frequencies, interesting conclusions are drawn, as we will see furtheron. At this stage we only note that 94,2 % of the months of the period under consideration, recorded maximum hourly rainfall ≦ 17,9 mm/h. Bigger than 17,9 mm/h

TABLE X

Frequency distribution per grade of maxima hourly precipitation (MS/AUT : 1930-39, 1947-72).

Grades (mm)	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*	%
0.0 - 5.9	26	27	27	24	16	15	16	22	21	19	17	24	254	58.8
6.0 - 11.9	9	7	8	8	10	11	9	7	9	11	13	9	111	25.7
12.0 - 17.9	1	2	1	2	6	6	4	7	2	2	6	3	42	9.7
18.0 - 23.9				1	2	3	3		1	3			13	3.0
24.0 - 29.9				1			3		2				6	1.4
30.0 - 35.9						1				1			2	0.5
36.0 - 41.9					1				1				2	0.5
42.0 - 47.9					1		1						2	0.5
Total	36	36	36	36	36	36	36	36	36	36	36	36	432	100.1

maxima are recorded during the whole period, only in the months: April - July and September - October, in other words during spring and autumn.

The descending series of the frequency per grade of the maxima hourly precipitation, for all months (last column of Table X) is given through the curves in Diagram VI (VI_A: linear coordinates, VI_B: semilogarithmic coordinates) and their mathematical expression is:

$$y = e^{-0.87x+6.37} \quad (1)$$

where: y = frequency and x = the serial number of the grade under consideration.

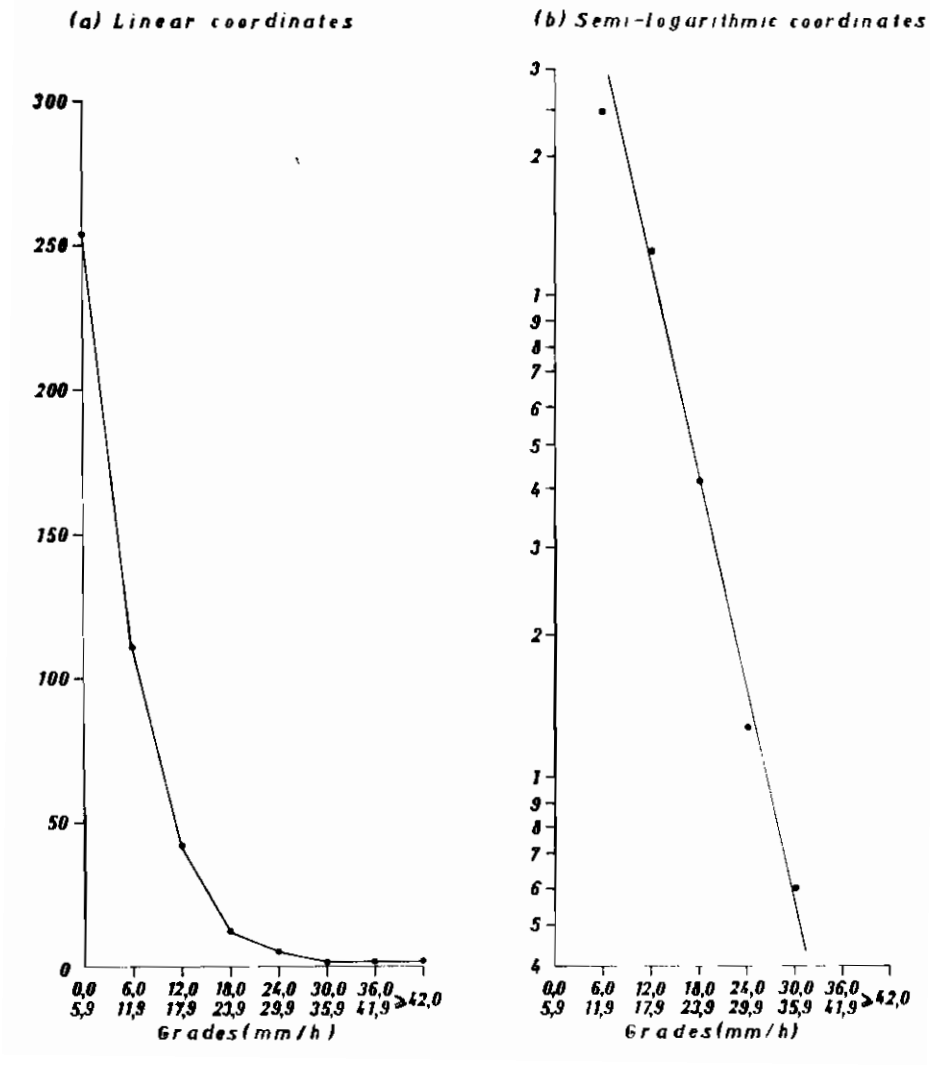
(b) Maxima daily precipitation.

In order to examine the maxima daily precipitation, material was gathered covering the whole period 1930 - 1972. Thus, we found that 54,8 % of all months of the period recorded daily precipitation not exceeding 15,0 mm/24h, whereas 95,8 % recorded daily precipitation not exceeding 40,0 mm/24h, in other words, precipitation smaller than the hourly maximum of the previous paragraph.

Out of the last column of Table XI, curves (A : linear coordinates,

DIAGRAM VI

Frenquency curves per grade of maxima hourly precipitation
(M.S/A.U.T. : 1930-39, 1947-72)



B : semilogarithmic coordinates) were given in Diagram VII, the mathematical expression of which is

$$y = e^{-0,92x+6,76} \quad (2)$$

where y = frequency and x = the serial number of the grade under consideration.

TABLE XI

Frequency distribution per grade of maxima daily precipitation (MS/AUT : 1930 - 1972).

Grades (mm/24h)	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Year*	%
0.0 - 14.9	22	21	25	25	21	22	25	32	27	21	19	23	283	54.8
15.0 - 29.9	19	19	11	13	17	15	7	9	8	9	19	11	157	30.4
30.0 - 44.9	2	2	6	3	3	4	8	1	4	11	5	5	54	10.5
45.0 - 59.9		1	1	2	1	2	3	1	4	2		3	20	3.9
≧ 60.0					1							1	2	0.4
Total	43	43	43	43	43	43	43	43	43	43	43	43	516	100.0

Note: L. ALEXANDROU[1] in: «The Climate of Thessaloniki» (page 57 - Maxima of rain 24 hours), reports 24 hours maxima recorded, greater than those we mention. (April: 74,1, May 90,0, July: 72,6, November: 82,5); these values pertain to years prior to these considered in this study and to meteorological stations which operated in various sites within the city of Thessaloniki.

(c) Intensities

With the material on hand, we were able to cover, as regards intensity, the periods: 1930 - 1940 (October) and 1946 (May) - 1972. The maxima intensities recorded during the above periods are given in Table XII below.

The maximum intensity was recorded in July (July 15, 1972) where in 5′ time 19,0 mm were recorded, a quite important amount of water for the area under examination, when taking into consideration its other rainfall conditions.

However, on the basis of more general criteria, the intensities of MS/AUT included in Table XII may be considered as not important.

(d) Repetition periods.

When studying the maxima precipitations of a location not only the amount and duration of precipitation are important. Equally important (if not more) is tbe knowledge of the time period intervening between two precipitation of a given amount: hi mm or greater than that.

DIAGRAM VII

Frequency curves per grade of maxima daily precipitation (M.S/A.U.T.: 1930–1972)

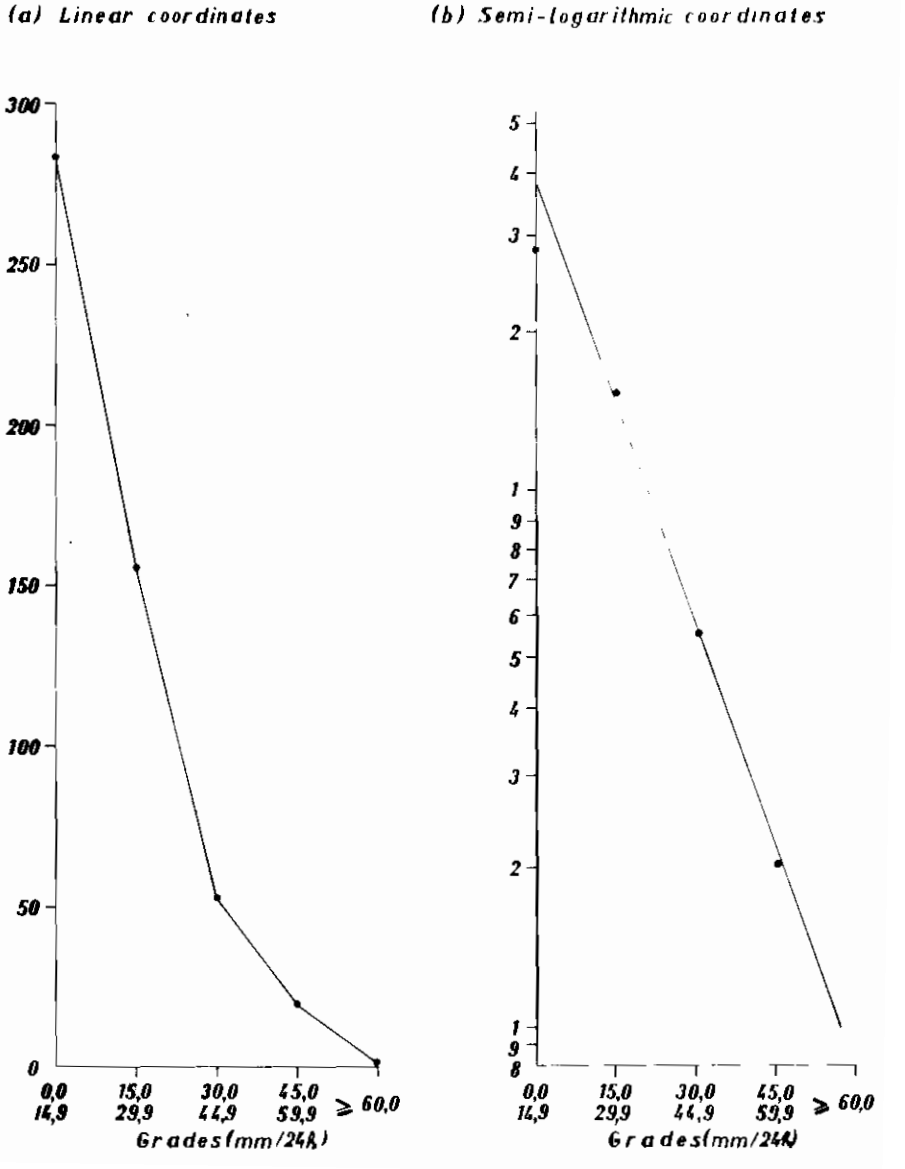


TABLE XII

Significant intensities recorded in Thessaloniki (MS/AUT).
(1930 - 1940 Octob., 1946 May - 1972).

	J	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*Maximum*
(A) PER 5'.													
Amount	3,2	5,1	16,2	5,1	9,0	10,0	19,0	6,3	9,7	9,4	7,0	8,4	19,0
Day	19	13	1	5	30	2	15	5	30	2	20	5	15.7.1972
Year	1952	1938	1951	1951	1965	1956	1972	1940	1967	1957	1956	1946	
(B) PER 10'.													
Amount	4,7	6,1	16,5	9,0	13,8	18,1	24,3	12,0	19,2	13,0	8,0	8,6	24,3
Day	19	13	1	5	6	21	15	5	30	2	5	5	15.7.1972
Year	1952	1938	1959	1951	1934	1940	1972	1940	1967	1957	1961	1946	
(C) PER 15'.													
Amount	8,0	7,2	16,7	10,8	19,4	19,2	27,6	13,9	23,5	13,6	9,5	8,8	27,6
Day	19	13	1	5	6	21	15	5	30	2	5	5	15.7.1972
Year	1952	1938	1959	1951	1934	1940	1972	1940	1967	1957	1961	1946	
(D) PER 20'.													
Amount	8,3	10,7	17,0	11,8	25,9	20,1	38,0	15,1	29,7	14,6	11,1	9,1	38,0
Day	19	13	1	5	6	2	15	5	30	2	5	5	15.7.1972
Year	1952	1938	1959	1951	1934	1956	1972	1940	1967	1957	1961	1946	
(E) PER 30'.													
Amount	8,4	11,8	17,3	12,8	29,8	29,0	47,3	15,6	37,4	15,2	16,3	9,5	47,3
Day	19	13	1	5	6	2	15	5	30	2	5	5	15.7.1972
Year	1952	1938	1959	1951	1934	1956	1972	1940	1967	1957	1961	1946	

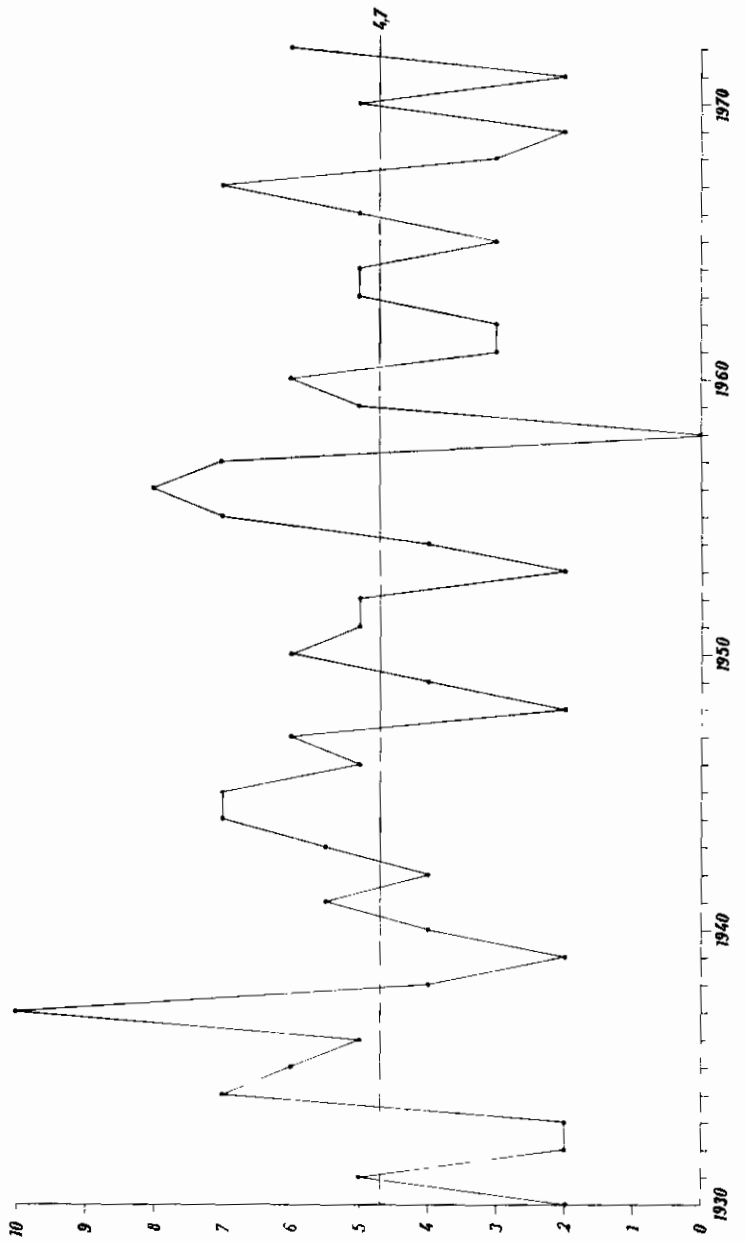
TABLE XIII

Frequency of daily precipitation ≧ 2,00 mm in Thessaloniki (MS/AUT : 1930 - 1972).

Year	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*	*A*
1930							1		1				2
1931	1	1		1						2			5
1932						1			1				2
1933		1						1					2
1934	1				2	1				1	2		7
1935	2		1								1	2	6
1936		1	1	1			1			1			5
1937		1	1	1		1	1			2	3		10
1938		1		1						1		1	4
1939				1		1							2
1940							2				1	1	4
1941	1	2		1		1	1						6
1942						1	1				2		4
1943		1		1		2			1		1		6
1944		1		1			1		1	1	1	1	7
1945								1	2	1		3	7
1946	1		1		1					1		1	5
1947		2							1	1		2	6
1948						1			1				2
1949					1				1		2		4
1950	1		1			1				1		2	6
1951	1			1			1	1		1			5
1952	1	1					1					2	5
1953				1			1						2
1954		2									2		4
1955	1		1				1	1	1	2			7
1956		1	2			1				1	1	2	8
1957		1				2				3	1		7
1958													0
1959			1		1					1		2	5
1960									2		2	2	6
1961					1						1	1	3
1962						1						2	3
1963	1	1	1		1			1					5
1964			1		2		1		1				5
1965				1	1	1							3
1966	1							1		1	1	1	5
1967			2		1		2		2				7
1968					1				1		1		3
1969			1									1	2
1970			1		1	1	2						5
1971							1				1		2
1972		1		1	1		2			1			6
Total	12	18	15	12	14	16	20	6	16	22	23	26	200

DIAGRAM VIII

Frequency of cases per annum of daily precipitation ≥ 20 mm (M.S/ALIT.: 1930–1972)



In this case we examine the repetition period of daily precipitation of a given amount and above.

Specifically, in Table XIII were included the daily precipitation of the period 1930 - 1972 the height of which was ≧ 20,0 mm.

From Table XIII we find that, as an average of the period, 4,7 cases of daily precipitation ≧ 20,0 mm (more specifically, 47 cases within a decade) are recorded per annum. Diagram VIII was based on the data of Table XIII.

TABLE XIV

Frequency of daily precipitation ≧ 50,0 mm in Thessaloniki (MS/AUT : 1930 - 1972).

Year	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
1934					60/1							
1935									← (18 months) 52/1			
.....												
1938		← (27 months) 57/1										
.....												
1942			← (50 months) 54/1									
1943						← (13 months) 51/1						
1944							← (12 months) 51/1					
1945					← (9 months) 58/1							
.....												
1947									← (27 months) 51/1			
.....												
1952									← (59 months) 64/1			
.....												
1954	← (13 months) 53/1											
.....												
1956			← (27 months) 56/1									
1957			← (11 months) 51/1									
.....												
1961		← (46 months) 54/1										
.....												
1967							← (75 months) 50/1					
.....												
1972		← (54 months) 54/1										

Finally, in the above Table XIV are included the cases of daily precipitation the amount of which was ≧ 50,0 mm.

Out of this table, Table XV was drawn from which it is concluded that between two daily precipitation of $\geq 50,0$ mm intervenes a time interval, as an average of the period, of 31,5 months ($>$ 2,5 years).

TABLE XV

Intervals (in months) between daily precipitation $\geq$ 50.0 mm (MS/AUT : 1930 - 1972).

S/N	*Precipitation (in whole mm)*		*intervals (in months)*
1	May 1934	60,0 *mm*	18
2	December 1935	52,0 »	27
3	April 1938	57,0 »	50
4	July 1942	54,0 »	13
5	September 1943	51,0 »	12
6	October 1944	51,0 »	9
7	August 1945	58,0 »	27
8	December 1947	51,0 »	59
9	December 1952	64,0 »	13
10	February 1954	53,0 »	27
11	June 1956	56,0 »	11
12	June 1957	51,0 »	46
13	May 1961	54,0 »	75
14	September 1967	50,0 »	54
15	April 1972	54,0 »	
Total			441
Mean			31,5

VI. TRENDS

From the annual values of rainfall in Thessaloniki during the period 1930 - 1972 (Table XVI, 2nd column) we form their time series by the polygonic line (a) of Diagram IX, of which we examine the general trend. To this effect we applied three of the more usually applied methods, the results of which do not differ greatly; they prove (all three methods) that, for the period under consideration, there exists a trend of increase in rainfall with the progress of time in the area under examination. The mathematical expression of the lines interpreting the general trend of the rainfalls under consideration, are:

(a) Semi - averages method (Diagram IX, curve (b)):

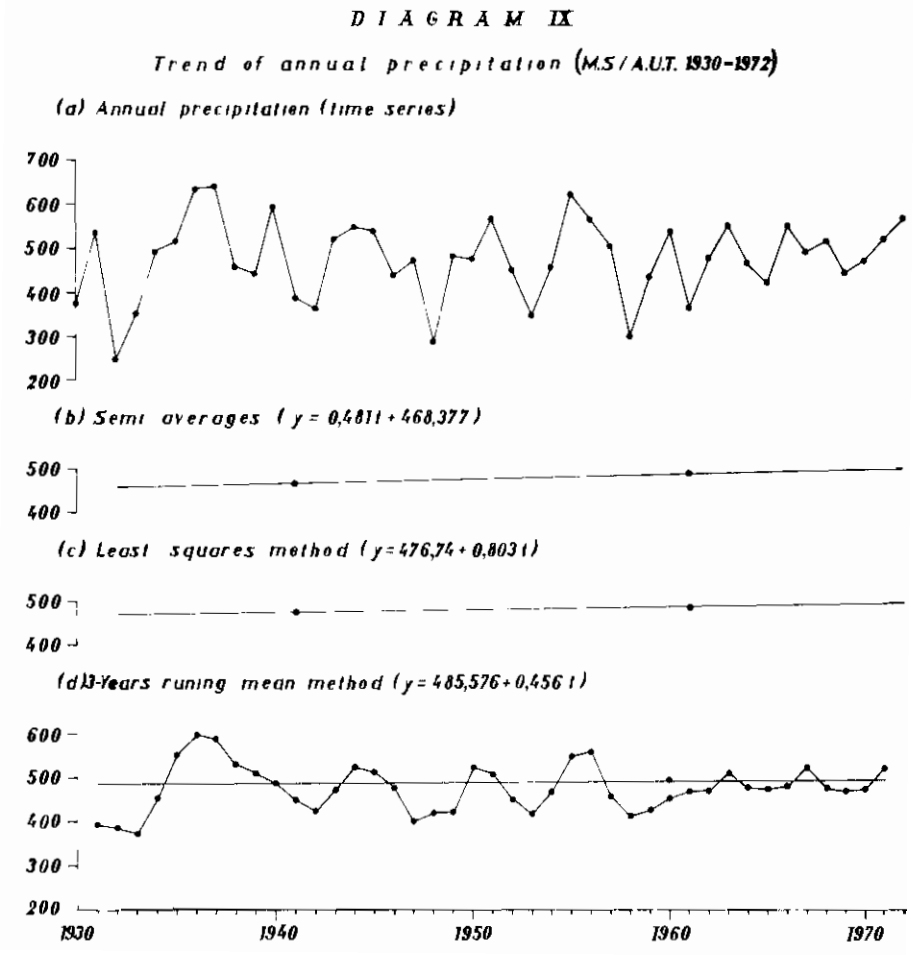
$$y = 0,481t + 468,377 \quad (3)$$

(b) Least squares method (Diagram IX, curve (c)):

$$y = 0,803t + 476,74 \quad (4)$$

D I A G R A M IX

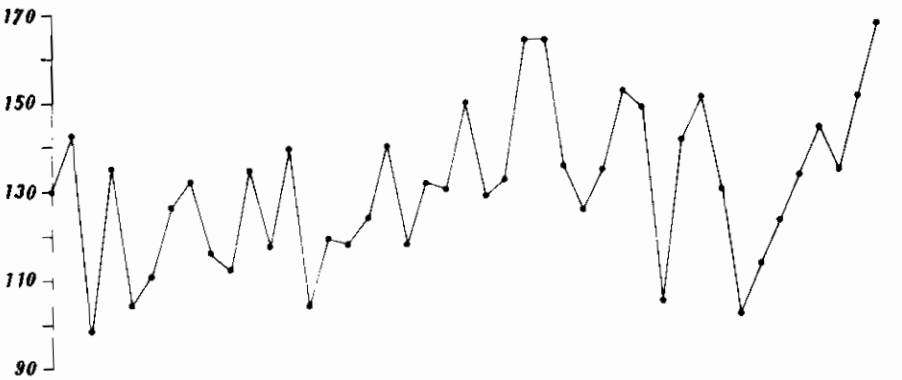
Trend of annual precipitation (M.S / A.U.T. 1930-1972)



D I A G R A M X

Trend of annual values of rain-days number (MS/AUT:1930-72)

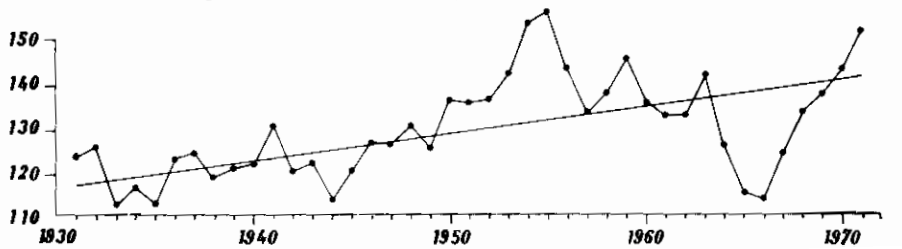
(a) Annual values of rain-days number



(b) Semi averages (y = 0,855 t + 107,735)

(c) Least square method (y = 119,604 + 0,518 t)

(d)3-Years runing mean method (y = 118,450 + 0,550 t)



(c) 3 - years running mean method (Diagram IX, curve (d)):

$$y = 0{,}456t + 485{,}576 \quad (5)$$

where : y = rainfall and t = statistical order of dates.

Of the three above methods, method (b) gives the quicker increase of rainfall with time.

Applying the same procedure in the case of the number of rain-days per annum, of the same as above period, and the same area, we have respectively the mathematical expressions of their general trend, i.e.

(a) Semi - averages method (Diagram X, curve (b)):

$$y = 0{,}855t + 107{,}735 \quad (6)$$

(b) Least squares method (Diagram X, curve (c)):

$$y = 0{,}518t + 119{,}604 \quad (7)$$

(c) 3 - years running mean method (Diagram X, curve (d)):

$$y = 0{,}550t + 118{,}450 \quad (8)$$

CONCLUSIONS

From all the above mentioned we draw the following conclusions:

— The intense cyclonic activity over the area under examination during winter, is the principal cause of winter precipitation.

On the other hand, the lack of cyclonic disturbances during the warm period as well as the low temperature of the sea during this season (in relation to those of the surrounding lands) provoke, more or less, a stability of air masses, which have as result the important reduction (or even cessation) of precipitation during the period in question. Sometimes these stability conditions change, due to sudden invasion of colder air masses from greater latitudes, in height (phenomena: upper trough or col pool) with as result the creation of thundering conditions with showers.

Thus, the mean annual variation of rain in Thessaloniki, presents a double fluctuation with principal maximum in December (winter for the area under consideration) and principal minimum in August (summer for the area under consideration). Secondary maximum and minimum are observed in May and February respectively.

— As regards rain, September may be listed under the warm period of the year for the area under consideration (same as in cloudiness: ANGOURIDAKIS [2]) considering that rainfall of this month slightly differs from that of July. Furthermore, we note that September

is the only month of the period under consideration during which, in one case, uo rain-day was recorded (September 1942).

— The absolute maximum monthly rainfall during the whole of the period under consideration, was recorded in December 1935 (166,2 mm) and the absolute minimum, as mentioned before, in September 1942 (0 mm).

— The absolute maximum and minimum annual rainfall were recorded in the years: 1937 (max. 639,9 mm) and 1932 (min. 264,2 mm).

— A «good» to «strong» concentration of values of monthly precipitation in the class: $\overline{H} \pm \sigma$ is recorded whereas the few cases of significant deviations (always to the right of the mean value: $> \overline{H} + 3\sigma$), take place during the warm period mainly due to heavy rainfalls of this season. As regards the annual values of rainfall, no significant deviations were recorded during the whole period. It should be noted that in the case of monthly values of rainfall, negative deviations (values included in the class: $\overline{H}$, $\overline{H}-3\sigma$) are, as a rule, more than the positive (slewed to the left), whereas the opposite happens in the case of annual values of rainfall (skewed to tbe right).

— From the distribution of the monthly rainfall of the period, we find that: more than the 3/4 (76,4 %) of the total of the monthly rainfall have not exceeded 60,0 mm. Especially the month of August in no case during the whole period exceeded 60,0 mm.

— Approximately half of the annual rainfalls of the period (51 %) fluctuated between 320,0 and 500,0 mm.

— It is ascertained that precipitation of the warm period (spring + summer) are, as a rule, smaller than the respective of the cold period (winter + autumn), a characteristic feature of mediterranean precipitation.

— From the rainfalls recorded during the various seasons we find that winters holds the first place with autumn following (though there isn't but a slight difference between these two seasons).

— The maximum frequency for all seasons and for the whole period is recorded under the grade: 80,0 - 120,0 mm. of rain (55 cases on a total of 172); follows the grade: 120,0 - 160,0 mm of rain (36 cases on a total of 172).

— The maximum number of rain - days per month ($h \geqq 0,0$ mm) was recorded in March 1961 (26 rain - days) and the minimum during September 1942 which was a rainless month, whereas in Au-

gust for the whole period of 43 years, no more than 15 days of rain were recorded.

— If we examine the duration of precipitation in hours, we find that the mean annual variation of duration per month precipitation presents a double fluctuation with principal maximum in January and principal minimum in August. The secondary maximum and minimum are recorded in the months of March and February respectively.

The absolute maximum monthly duration of precipitation in hours is recorded in February 1954 (250h 20′ of rain) whereas the absolute minimum is recorded in September 1942 which was a rainless month (see footnote Table VII).

In the months of July and August, in no case during the whole period, more than 48 total hours of rain were recorded for each, one, whereas the maximum frequency for all months was recorded under the grade: 0 - 24h (37,9 %).

Only 4,3 % of the total of months of the period recorded precipitation of a total duration per month of $>$ 120h.

From the distribution of the duration in hours of the annual precipitation in Thessaloniki, we find that 33 % on the total of years of the period recorded precipitation of a duration fluctuating between 480h and 600h.

Only 3 % of the total of years of the period under consideration recorded precipitation the total duration of which in hours fluctuated between 960h and 1080h.

— The maximum hourly precipitation in Thessaloniki during the periods 1930 - 1939 and 1947 - 1972 was recorded in July 1972 (July 15, 1972): 47,3 mm/h, in other words a remarkable amount for the area under examination when taking into consideration the other rainfall conditions of the area.

During the cold period (November - March) as well as in August, the maxima hourly precipitation (during the period mentioned in the beginning of this paragraph) did not exceed 17,9 mm. This is quite clear considering that during winter the large monthly amounts of rain are a result of the, as a rule, long duration precipitation of small intensity; for the month of August the actually recorded monthly amounts of rain are small or rather zero. On the contrary, during the remaining months of the year, heavy and of rather short duration precipitation are recorded mainly of orographic origin.

— The 54,8 % of the total of months of the period under consideration in Thessaloniki, recorded maximum daily rainfall $\leq$ 14,9 mm, whereas only May, in one case, recorded maximum daily precipitation $>$ 60,0 mm.

It should be clarified that L. ALEXANDROU [1], reports maximum daily rainfall in Thessaloniki, greater than those we mention; however, these values pertain to previous years than those considered in the present study.

— The intensities recorded during the period 1930 - 1940 (October) and 1946 (May) - 1972 cannot be considered as important when seen within the frame of precipitation in the Mediterranean; however, taking into consideration the remaining rainfall conditions of the area, those recorded in July 15, 1972: 19,0 mm/5′, 24,3 mm/10′, 27,6 mm/15′, 38,0 mm/20′, 47,3 mm/30′, are quite important for Thessaloniki.

— We ascertained in Thessaloniki as an average of the period 1930 - 1972:

(a) Daily precipitation $\geq$ 20,0 mm take place every 79,8 days (47 times during a decade).

(b) Daily precipitation $\geq$ 50,0 mm take place every 2,5 years approximately (every 31,5 months).

— Finally, from the examination of the annual rainfall and the annual number of rain-days in Thessaloniki, for the period under consideration, the following are concluded:

A trend of increase of rainfall in the city of Thessaloniki, was proved by all three methods used. A quite reasonable cause of such increase is the influence of the city. In fact, J. GRIFFITHS [3] and J. MURRAY MITCHELL JR. [9] report as probable causes for the increase in precipitation, the expansion and the increased activities of the city. They have reservations, however, since there are no long series of rainfall observations, so that they may be able to found their conclusions on more data.

In this study, the period under consideration without being long enough, allows one to discern qnite clearly the above mentioned increase. Such increase, with fluctuation periods from 2 to 6 years (periods between two successive maxima or two successive minima), follows the expansion of the city of Thessaloniki and the growth of its industrial and transportation activities.

More specifically, from 1958 and on, when Thessaloniki begun to show signs of building intense growth, the fluctuations of an-

nual rainfall became more dense and of a smaller width, with more clear and intense the general trend of increase.

The annual values of the number of rain-days in the city of Thessaloniki during the same as above period, give the same picture.

Thus, we may say that:

— The increase of the nuclei of condensation (polluted air - habitants: 1.000.000) contributes definitely to the creation of condensation conditions and consequently: cloud formation.

— The increase in the covering of the city by concrete or other similar stuff (covering of dwellings with concrete, paving of roads with asphalt, and other) facilitate the updraft due to mechanical reasons (overheating) which, especially for the area under consideration, being assisted by the neighbouring sea and the amphitheatric structure of the city, contributes to the condensation of air masses due to elevation, which in turn reinforce the actually existing precipitation.

— Finally, the factor «friction» (on the continuously expanding building area of the city) compels the elevation of the coming air masses due to the reduction of the velocity of their lower layers with the same as the preceding result.

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Material:

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ΑΙ ΒΡΟΧΟΠΤΩΣΕΙΣ ΕΙΣ ΤΗΝ ΘΕΣΣΑΛΟΝΙΚΗΝ

Ὑπὸ

Β. ΑΓΓΟΥΡΙΔΑΚΗ καὶ Π. ΜΑΧΑΙΡΑ

(Ἐργαστήριον Μετεωρολογίας καὶ Κλιματολογίας)

ΠΕΡΙΛΗΨΙΣ

Μελετῶνται ἡ βροχὴ καὶ αἱ διάφοροι παράμετροί της εἰς τὴν Θεσσαλονίκην (ΜΣ/ΑΠΘ), διὰ τὴν χρονικὴν περίοδον: 1930 - 1972.

Διαπιστοῦται ὅτι τὸ μέσον ἐτήσιον βροχομετρικὸν ὕψος εἶναι: 476,74 mm, ἡ δὲ μέση ἐτησία πορεία τῆς βροχῆς, ἐμφανίζει διπλῆν κύμανσιν μὲ κύρια μέγιστον - ἐλάχιστον κατὰ Δεκέμβριον - Αὔγουστον ἀντιστοίχως.

Ἡ κυκλωνικὴ δρᾶσις κατὰ τὴν χειμερινὴν περίοδον καὶ ἡ ἔλλειψις αὐτῆς κατὰ τὴν θερινὴν τοιαύτην, εἶναι τὰ κύρια αἴτια διαμορφώσεως τῶν ἀνωτέρω μεγίστου καὶ ἐλαχίστου.

Ἐλέγχονται αἱ ἐποχικαὶ κατανομαὶ τῶν βροχοπτώσεων, ὡς καὶ αἱ διάρκειαι αὐτῶν (τόσον εἰς ἡμέρας, ὅσον καὶ εἰς ὥρας), αἱ ραγδαιότητες καὶ ἄλλαι βροχομετρικαὶ παράμετροι.

Ἐκ τῆς μελέτης τῶν ἐτησίων βροχομετρικῶν ὑψῶν καὶ τῶν ἐτησίων ἀριθμῶν ἡμερῶν βροχῆς, εἰς τὴν ὑπὸ μελέτην περιοχὴν κατὰ τὴν θεωρουμένην περίοδον, διαπιστοῦται μία τάσις αὐξήσεως, συνδεομένη μὲ τὴν αὔξησιν τοῦ πληθυσμοῦ καὶ τὴν ἐπέκτασιν τῆς πόλεως κατὰ τὴν αὐτὴν περίοδον.