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LITANI RIVER AUTHORITY

PRECIPITATION IN THE LITANI RIVER BASIN

AS A FUNCTION OF [redacted] SPACE AND TIME

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REPORT No.1

PRECIPITATION IN THE LITANI RIVER BASIN

AS A FUNCTION OF [redacted] SPACE AND TIME

The climatologist who has a task of giving the spatial distribution of precipitation, i.e. to construct a map of precipitation (izohyetal map), for the certain area and for certain period, must first prepare the needed data using some common statistical procedures. This procedure consist of several steps which will be exposed briefly because they have been applied during the preparation of precipitation data from all stations over the Litani River Basin and its vicinity for the period 1932/33 - 1964/65.

EXAMINATION OF THE HOMOGENEITY OF DATA .-

Obviously, it the first step must be to examine whether the precipitation data are homogeneous in order to avoid those which are strictly false. Namely, as it is well known, the measurement of rainfall is a especialy difficult problem. Changing the method of measurement, the type of instrument, the exposure of raingage (altitude and place) can cause a great discontinuity in the series of date i.e. can cause a break in the homogeneity. If this is, the case, the data in such conditions are useless because they are inacurate and they must be adjusted by means of statistical methods. From this point of view the climatologist needs to examin which variations in the series of measurements are caused by unnatural influences and which ones by variations of weather and climate. Namely, only a series of measurements in which there are discontinuities i.e. which are showing variations caused by the above mentioned unnatural influences is called non-homogeneous and such data must be adjusted and partly or completely eliminated. Numerical serie is homogeneous only if the variations in it are caused by variations of weather and climate.

The examination of homogeneity, which is very important to the quality of the final isohyetal map in the Litani River Basin first encounters a great difficulty. It is not possible to discrimitate between natural and artificial variations in the series

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in question if the measurement of only one station are used. But to solve this problem is not so difficult because it is clear that the variations of weather and climate are not restricted to a single place especially in longer periods as it is the case in the study of the regime of precipitation in the Litani River Basin for which 33 years of measurements have been used. In those cases the trend of the variation is maintained over large regions. Because of that it is possible to examine the homogeneity by comparison with available synchronous data of precipitation for two or more stations.

For the testing of homogeneity there are different satistical methods and criteria. In the case of the precipitation data from the Litani River Basin and vicinity, for the period 1932/33 - 1964/65, the method of statistical mathematics named " method of ratios " have been used and the method of graphical representation of synchronous yearly sums of precipitation at two or more stations.

The first method, which has been used for the testing of homogeneity, is based on the assumption that the ratios between the synchronous amounts of precipitation at two near stations in the same climatic area are much less variable than the rain-fall itself. This ratio can be considered to be quasi-constant from year to year. In connection with this rule every great deviation from the mean value of the ratio, has been considered as a consequence of some unnatural influences and after this consideration all wrong data have been eliminated.

To determine whether or not two or more series of precipitation data in the area of Litani River Basin, are relatively homogeneous the method of graphical representation and comparison of synchronous yearly amounts between all available stations has been used. For this comparison cartisian coordinates with time (years) as abcisa and yearly amount of precipitation as ordinated has been used. In cases where parallel curves showed manifest divergences or convergences, so that quasy parallelism disappeared, nonhomogeneity in the series was surmised and responsible data for it were eliminated. However, it must be said that only really striking disontinuities in the quasi parallelism of curves and great deviations of the ratios from the average values have been taken as consequences of unnatural influences and only responsible data for those were eliminated. The main reason for this procedure was the small number of basic (secular) stations. There were available only 4 stations with full 33 years period of measurements, namely : Beirut, Ksara, Rayak and Hermel. Because of that in some parts of the Litani River Basin, as Northern Bekaa and extreme South, for the examination of homogeneity of data at stations with shorter periods of measurements than 33 years supplementery basic stations Baalbeck and Marjayoun were used. These two stations did not have the full period of measurements as the main basic stations, but in the above mentioned areas they had longer than other stations longer than 20 years (Baalbeck 25 years, Marjayoun 23 years).

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During the examination of the homogeneity of series from 38 stations in the Litani River Basin and vicinity, it was found that there are at some stations some discontinuities in the measurement of precipitation caused by unnatural influences. Especially greater nonhomogeneity was found in the series of measurements from some stations in the mountain areas i.e. at stations with high altitudes. During the examination of these data it was clear that yearly amounts of precipitation are too low for those altitudes and in some cases even lower than at stations in near vicinity but nearer to the sea level. After considering this phenomenon from different points of view it has been concluded that measurements of precipitation at stations in the mountain areas during the winter time were not quite correct because of the snow. The old method of measurement and the type of rain gage used did not give possibility for observers to measure the right amount of precipitation during snowfall. Because of that all data from Karaoun, Cedre and Bcharre stations, which were very incorrect i.e. much lower than we can expect, had to be eliminated. As a result of the examination of homogeneity the following data have also been eliminated.

Kaa-er-Rime 1939/40 - 1958/59 (20 years), El-Kraye 1952/53, 1957/58 - 1962/63 (7), Yammoune 1938/39 - 1949/50 (12), Mansoura 1941/42 - 1945/46 (2), Mejdel Anjar 1938/39 - 1941/42, 1948/49, 1952/53 (6), Joub Jannine 1951/52 (1), Machgara 1938/39 - 1941/42, 1958/59 - 1960/61 (7), Djezzine 1958/59 - 1959/60 (2), Kfar-ez-Zaite 1943/44 - 1944/45 (2).

However, the testing of homogeneity also revealed certain number of incorrect monthly values of precipitation in some years, especially in January and February. The cause of these nonhomogeneities mainly was also measurements of the amount of precipitation during snowfall but in some cases also other unnatural influences.

In connection with the adopted procedure all those incorrect data have also been eliminated.

INTERPOLATION OF MISSING DATA AND REDUCTION TO AN EQUAL PERIOD .-

After, the examination of the homogeneity of available series of measurements and the elimination of all incorrect data, the next step of the statistical procedure was interpolation of missing monthly sums of precipitation and reduction of all series of measurements to the same period - in this case the period 1932/33-1964/65.

The measurements at the various stations in the Litani River Basin and vicinity, were not carried out simultaneously i.e. they had not measurements during 33 yars period. It is well known that series of different periods are not comparable with one another. Namely, it is clear that the changes in the climatic elements with time are so effective especially in the case of precipitation, that a comparison between average values at different places can lead to a reasonable conclusion only if identical periods are considered.

Because stations under consideration didn't have simultaneous measurements the solution of this fundamental problem was found in reducing available series to the same period, namely, the period of years 1932/33 - 1964/65.

For the reduction of data to the same period the statistical method of ratios has been used. Briefly this method is as follows :

A normal (basic) station " A " has been operated for the normal period of " N " years (in our case 33 years). Another station " B " has been operated for " n " years, so during these " n " years simultaneous measurements have been conducted at both stations (A and B). Values which participate in the reduction are :

N = normal period of operation of the basic station " A ".

n = short period of operation of the station B (n < N).

P(A, N) = normal average rain-fall at station "A" during the normal period " N ".

P(B, n) = average rain-fall at station " B " during the short period.

P(A, n) = average rain-fall at station " A " during the short period " n ".

P(B, N) = average rain-fall at station " B " reduced to the normal period " N ".

Unknown value is p(B, N). To get it is need to calculate of the ratios q.

$$\frac{p\ (B,\ n)}{P\ (A,\ n)} = q = \frac{p\ (B,\ N)}{P\ (A,\ N)}$$

Therefore :

$$p\ (B,\ N) = q\ P(A,\ N)$$

This method of reduction, reasonably applied, always yields reasonable results, while the comparison of different periods leads to false inferences. Because of that it has been applied for the reduction all stations in the Litani River Basin and vicinity with shorter period of observation to the period 1932/33 - 1964/65. The basic stations were the same as for the examination of homogeneity i.e. stations which have been operated 33 years. However, as supplementary basic stations, after their own reduction by means of basic stations, Baalbeck, Sarain, Mansoura, Kherbet Kanafar, Marjayoun and Aitaroun were used. In all cases

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when it was possible, the reduction of one station has been done with two basic or supplementary basic stations. One example of the procedure of reduction of station " B ", by two basic stations (A and A1) is given in table 1. It might be useful to mention that the final result in this example P (B, N) is arrived at by calculating the results P (B, N) of the two stations (A and A1) weighted in proportion to their distances from station B.

The minimum years of measurements used for the reduction were five but in some special cases, in the area where data were sparse, period of measurement not longer than 3 or 4 years were also used.

Normally, results of reduction are better in the cases when the period of measurements was longer, but results of reduction of shorter periods can be used also with caution as supplementary data if there is not better choice.

It is needed to mention that the quasi constancy of ratios has been used also for interpolating all missing or false monthly values of precipitation, of course before the step of reduction. One example of the interpolation of missing data is given in " Table 2 ". In this example has been interpolated missing data in January 1944 for Baalbeck by basic station Ksara. After calculation of the ratios between monthly sums of rain-fall for Baalbeck as station " A " and simultaneous monthly sums of rain-fall for Ksara as basic station " B ", statical procedure is as follows :

All unresenable high or low values of ratios (A/B), which deviate from all others must be eliminated as it is case in 1946, 1954 and 1956. After that the next step is calculation of the average ratios dividing their sum by their summarized number ($\sum A/B \; / \; n_{A/B} = \bar{q}$). In given example $n_{A/B}$ is 21 and after dividing with it sum of all 21 ratios, which is 11.98, average ratio $\bar{q}$ is 0,57.

The last step is interpolation of missing data by multiplication available monthly sum of rain-fall in January 1944 for basic station KSARA (B), which is 283 mm. by average ratios 0.57. The result of this calculation is interpolated monthly amount of precipitation for January 1944 at Baalbeck which is 161 mm.

However, according to the climatological rule the maximum missing data can be interpolated either for 4 successive or 6 unsuccessive months in one year.

Numerical results of applying all steps of the above described statistical procedure on data from stations in the Litani River Basin and vicinity, i.e. examination of homogeneity, interpolation of missing data and reduction to the same period, are given in table 3. Values in this table represent statisticaly adjusted average of monthly and yearly amounts of precipitation for 33 years period (1932/33-1964/65). It might be useful to mention that 33 years period was selected as the period to be sunchronous with available hydrological data in the Litani River Basin.

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STATION	ALTITUDE	DISTANCE
A : KSARA	920m.	K.M.
A1: Rayak	920m.	A–B 35 Km.
B : Baalbek	1 150m.	B–C 28 Km.

Table 1 : An example of the statistical method of ratios for the reduction of rain-fall to the same period.

STATION	PERIODE		IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	YEAR
A :	1932/33–1964/65	P(A,N)	2	19	70	114	152	121	77	37	15	tr	0	0	607
	1938/39–1940/41 1943/44–1964/65	Σ nP	40	389	1730	2969	3737	3039	2057	875	403	14	0	0	/
KSARA		n	25	25	25	25	25	25	25	25	25	25	25	25	25
		P(A,n)	2	16	69	119	150	122	82	35	16	tr	0	0	611
A1:	1932/33–1964/65	P(A1,N)	1	17	65	112	156	121	78	36	16	tr	0	0	602
RAYAK	1938/39–1940/41 1943/44–1964/65	Σ nP	14	331	1628	2831	3918	3013	2076	869	405	11	0	0	/
		n	25	25	25	25	25	25	25	25	25	25	25	25	25
		P(A1,n)	1	13	65	113	157	120	83	35	16	tr	0	0	603
B :	1938/39–1940/41 1943/44–1964/65	P(B,n)	1	8	45	70	91	88	58	29	12	0	0	0	402
BAALBEK															
P(B,n) :	P(A,n) = q		0,50	0,50	0,65	0,59	0,61	0,72	0,71	0,83	0,75	0	0	0	0,66
P(B,n) :	P(A1,n) = q'		1,00	0,62	0,69	0,62	0,58	0,73	0,70	0,83	0,75	0	0	0	0,67
P(B,N) =	q P(A,N)		1	10	46	67	93	87	55	31	11	0	0	0	401
P(B,N) =	q' P(A1,N)		1	10	45	69	90	88	55	30	12	0	0	0	400
P(B,N)			1	10	45	68	91	88	55	30	12	0	0	0	400

TABLE 2 : An example of the interpolation of missing data by method of ratios

Station A - Baalbeck
Station B - Ksara

MONTH	JANUARY		
STATION Year	A	B	A/B
1939	56	105	0,53
1940	149	238	0,62
1941	109	194	0,56
1942			
1943			
1944	(161)*	23	
1945	108	164	0,66
1946	35	29	1,20
1947	142	290	0,49
1948	106	134	0,79
1949	104	165	0,63
1950	129	180	0,71
1951	54	86	0,63
1952	30	79	0,38
1953	88	199	0,44
1954	187	180	1,04
1955	11	26	0,42
1956	117	124	0,94
1957	87	187	0,47
1958	113	209	0,56
1959	91	167	0,54
1960	34	92	0,37
1961	70	126	0,56
1962	64	117	0,55
1963	126	161	0,78
1964	34	45	0,76
1965	84	157	0,53
$\sum A/B$			11,98
n A/B			21
$\sum A/B : n_{A/B} = \bar{q}$			0,57

( )* - Interpolated value.

Table 3 : Average of monthly and yearly amounts of precipitation for 33 years period 1932/33 - 1964/65 in the Litani River Basin and vicinity.

No	Station	Altitude in meters	Used period	IX	X	XI	XII	I	II	III	II	V	VI	VII	VIII	Year
1	Hermel	750	1932/33-64/65	tr	9	24	42	53	44	32	23	11	0	0	0	238
2	Yamouneh	1360	1950/51-64/65	5	27	119	152	209	200	186	71	44	3	0	0	1016
3	Chlifa	1000	1943/44-58/59 1960/61-64/65	1	9	57	70	102	78	56	32	15	0	0	0	420
4	Houch ed Dahab	1000	1959/60-64/65	tr	6	44	68	104	90	52	34	14	0	0	0	412
5	Baalbek	1150	1938/39-40/41 1943/44-64/65	1	10	45	68	91	88	55	30	12	0	0	0	400
6	Beit Chama	990	1946/47-56/57	0	10	32	74	98	82	53	24	10	0	0	0	383
7	Houch Seneid	995	1956/57-64/65	1	12	56	86	121	84	58	28	14	0	0	0	460
8	Sarain	1000	1945/46-64/65	1	12	50	91	129	96	68	29	14	0	0	0	490
9	Kaa er Rime	1250	1959/60-64/65	2	28	174	222	318	271	229	85	36	2	0	0	1367
10	Tell Amara	905	1953/54-64/65	1	18	66	113	158	122	77	39	16	tr	0	0	610
11	Hoch el Ghanam	953	1950/51-64/65	1	15	62	113	145	120	79	36	16	0	0	0	587
12	Zahlé	1000	1950/51-64/65	2	19	76	120	172	134	85	40	19	0	0	0	667
13	Rayak	920	1932/33-64/65	1	17	65	112	156	121	78	36	16	tr	0	0	602
14	Ksara	920	1932/33-64/65	2	19	70	114	152	121	77	37	15	tr	0	0	607
15	Chtaura	920	1952/53-64/65	2	22	83	138	192	174	116	49	20	1	0	0	797
16	Taanayel	899	1957/58-64/65	2	21	72	120	176	144	86	34	17	0	0	0	672
17	Anjar	930	1942/43-47/48 1949/50-51/52 1953/54-64/65	tr	12	55	100	128	108	73	33	12	0	0	0	521
18	Mansoura	860	1938/39-40/41 1942/43-44/45 1946/47-64/65	tr	15	73	103	154	117	78	34	11	0	0	0	585
19	Joub Janine	900	1946/47-50/51 1953/54-64/65	3	15	78	115	176	137	89	46	16	2	tr	tr	677

(Table 3 continued)

No.	Station	Altitude in meters	Used period	IX	X	XI	XII	I	II	III	II	V	VI	VII	VIII	Year
20	Kherbt Qanafar	960	1961/62-64/65	2	26	122	165	251	204	166	59	21	10	0	0	1026
21	Qaraoun Barrage	855	1961/62-64/65	1	20	133	191	254	226	139	58	29	0	0	0	1051
22	Machghara	1150	1942/43-55/56 1957/58 1961/62-64/65	2	34	134	207	362	298	203	80	32	tr	0	0	1352
23	Kfar Kouk	1210	1961/62-64/65	1	23	109	144	210	174	132	57	17	0	0	0	867
24	Rachaya	1200	1945/46-64/65	1	24	100	145	206	171	126	60	29	tr	0	0	862
25	Kfar ez Zaite	960	1945/46-64/65	4	29	106	162	252	238	144	85	30	tr	0	0	1050
26	Hasbaya	750	1945/46-64/65	2	22	112	176	249	205	134	71	31	0	0	0	1002
27	Marjayoun	770	1942/43-64/65	2	30	104	149	240	186	120	54	24	1	0	0	910
28	Taibé	600	1949/50-52/53	1	25	59	100	242	134	113	37	6	0	0	0	717
29	Aitaroun	680	1942/43-64/65	1	18	84	137	194	160	106	49	15	tr	0	0	764
30	Ain Ebel	760	1960/61-64/65	tr	20	92	141	186	141	91	48	8	tr	0	0	727
31	Alma Chaab	385	1959/60-64/65	2	23	116	186	208	140	91	26	10	tr	0	0	802
32	El Kasmieh	20	1944/50 1951/52-54/55 1958/59-64/65	3	41	106	138	180	115	88	42	15	tr	0	0	728
33	Djezzine	1000	1932/33-36/37 1939/40-48/49 1950/51-57/58 1960/61-64/65	3	37	140	216	311	251	181	99	35	3	0	0	1276
34	Beirut	91	1932/33-64/65	9	34	140	159	202	159	106	45	17	1	tr	tr	872
35	El Kraye	1000	1932/33 1939/40-51/52 1953/54-56/57 1963/64-64/65	4	57	154	215	337	259	193	115	37	1	tr	0	1372

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SOME REMARKS ABOUT PRECIPITATION IN THE LITANI RIVER BASIN AS A FUNCTION OF TIME .-

In the study of precipitation, it is very important to take into consideration not only the yearly total of rain-fall but also its distribution over the year. As it is seen in Table 3, Lebanon has a tipycally mediteranean regime of precipitation. The dry season of summer and wet season from late autumn to early spring are noticable features of the distribution of precipitation over the year i.e. Lebanon experiences an absolute drought lasting from 5 to 6 months during the warmer part of year and rainy weather during the cool season. The main rain-fall season begins about the end of October or the begining of November. The end of the reliable rain-fall season is in the April or May.

The month of greatest normal precipitation is January, but differences between this month and December and February are not great. It is very usefull to point out that in these three most rainy months 60-65 per cent of the yearly total of precipitation falls.

All rainy months may be classified as follows : DECEMBER - FEBRUARY very humid, MARCH - NOVEMBER humid, APRIL semihumid or semiarid, OCTOBER and MAY arid and JUNE - SEPTEMBER extremly arid when the proportion of the annual total that falls is zero or practically zero.

In order to understand the regime of precipitation in Lebanon it is very usefull to give general breafly outlook on main weather situations under which influence the distribution of rain-fall with time as it is.

The summer is a dry season as a result of the influence of subtropical anticyclons system and prevailing northwesterly very dry winds. As it is stated earlier, during this period of year, practically no rain occurs except scattered light and very rare showers, mosdy in the littoral area, which are not sufficient to interupt dry season.

Most of the yearly ammount of precipitation is a result of influence of cyclons or weather situations when the cold and unstable air mass lies over the eastern Mediteranean i.e. over the warm sea.

In the first case winds of westerly quadrant (south-westerly to north-westerly) in the circulation of the cyclons, develop in the area of Cyprus or move from the west part of Mediterranean towards Near East, cause considerable rain-fall especially in the coastal area of Lebanon and its western slop of mountains.

In second main type of weather situation unstable cold air moves over the warm sea and relatively well heated in land in sunny periods of days and in connection with the convective effect causes heavy rainfall also.

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In both cases unstable humid air is lifted orographically and because of that very heavy clouds and rain may occur.

In connection with above described developement of weather near and over Lebanon normally much of the rain is of the showery type.

PREPARATION OF SUPPLEMENTARY DATA .-

With relatively small number of stations, especially in higher altitudes, with different types of weather situations which affect the area in one mountains county as it is Lebanon, the analysis of spatial distribution of precipitation i.e. drawing the map of isohyetal, might be very complicated. To facilitate the solution of drawing the map of isohyetal it was need to find some supplementary data from new stations which are in operation only one or two years. Climatologicaly it is not correct to use data from stations with short period of measurement. Permited minimum is about 10 years but in this case it was indispensable. The examination of the possibility to benefit those data has been executed by statistical procedure of definition humid, dry and normal years in one longer period measurements of precipitation. For the applying of this method as representative station for the Litani River Basin with maximal 33 years of measurement has been chosen observatorie Ksara. The result of this statistical examination can be seen in Table 4 and Figure 1. Values which participate in this statistical procedure are as follow :

R_1 = yearly totals of rain-fall in order of successive years.

R_2 = yearly totals of rain-fall in order of amounts.

P = probability in per cent.

m = number of order in column 1.

n = number of years (in this case 33).

K = modul's coefficient.

R = average yearly precipitation for available period of measurement (in this case for 33 years period).

From numerical values in Table 4 and graphical presentation of them in Figure 1 has been found that 1964/65 is one average normal humid year. This year is indicated by point sixteen in Figure 1 in the middle of section 35 - 65 per cent which bounds all years with normal amount of rain-fall. The amount of precipitation in that average normal year is 625 mm. and it is given in Table 4 in column 4 under number 16 and in column 3 under number 33.

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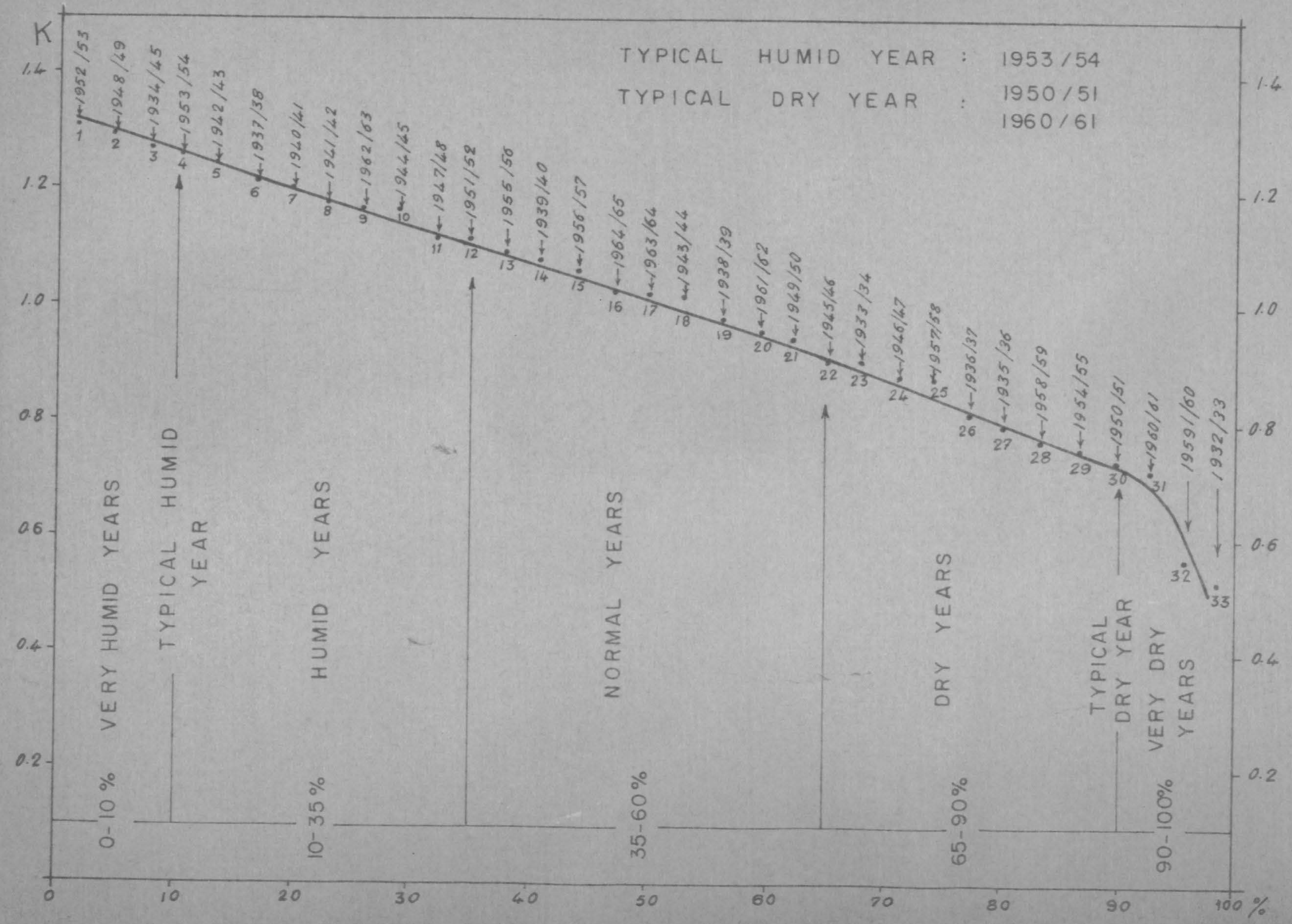
Table 4 : Statistical procedure of the definition humid, dry and normal years in 33 years period 1932/33 - 1964/65.

STATION KSARA

(1)	(2)	(3)	(4)	(5)	(6)
N°	Year	R_1	R_2	$P = \frac{m-0,5}{n}$	$K = \frac{R2}{R}$
1	1932/33	322	799	0,0152	1,311
2	1933/34	552	790	0,0454	1,297
3	1934/35	775	775	0,0758	1,272
4	1935/36	487	771	0,106	1,266
5	1936/37	497	757	0,136	1,243
6	1937/38	737	737	0,167	1,210
7	1938/39	596	733	0,197	1,203
8	1939/40	657	719	0,227	1,180
9	1940/41	733	717	0,258	1,177
10	1941/42	719	715	0,288	1,174
11	1942/43	757	681	0,318	1,118
12	1943/44	618	678	0,348	1,113
13	1944/45	715	664	0,379	1,090
14	1945/46	555	657	0,409	1,079
15	1946/47	535	645	0,439	1,059
16	1947/48	681	625	0,469	1,026
17	1948/49	790	623	0,500	1,022
18	1949/50	575	618	0,530	1,014
19	1950/51	444	596	0,560	0,978
20	1951/52	678	583	0,590	0,957
21	1952/53	799	575	0,621	0,944
22	1953/54	771	555	0,651	0,911
23	1954/55	461	552	0,681	0,906
24	1955/56	664	535	0,712	0,878
25	1956/57	645	533	0,742	0,875
26	1957/58	533	497	0,773	0,816
27	1958/59	468	487	0,803	0,799
28	1959/60	343	468	0,833	0,768
29	1960/61	436	461	0,864	0,756
30	1961/62	583	444	0,894	0,729
31	1962/63	717	436	0,924	0,715
32	1963/64	623	343	0,954	0,563
33	1964/65	625	322	0,985	0,528
		R = 609 m,m.			

FIGURE 1 : DISTRIBUTION OF HUMID, DRY AND NORMAL YEARS IN 33-YEAR PERIOD 1932/33 - 1964/65

STATION KSARA



After above described examination was evident that it is possible to use for the drawing of isohyetals, as supplementary and of course with special carefulness, the amount of rain-fall from stations which have only measurements in 1964/65 hydrological year. Because of better carefulness, all yearly totals of rainfall from those stations have been a little adjusted by basic stations and by means of earlier discribed method of ratios. The result of this adjustment is given in Table 5. Of course it was possible to adjust only yearly totals of rain-fall.

TABLE 5 : Average yearly amounts of precipitation in 33 years period 1932/33 - 1964/65 for supplementary stations which are in operation only during the hydrological year 1964/65.

Station	Altitude in meters	Average yearly amount in mm	Station	Altitude in meters	Average yearly amount in mm.
Ras Baalbeck	840	202	Tyr	5 *	645
Fakie	1.059	267	Nabatie	472 *	914
Ammiq	869 *	780	Deir Zahrani	430 *	955
Tibnine	674 *	802	Doueir	359 *	812
Dahr el Daraji	1.139 *	1.250	Jarjouh	770 *	1.136
Jouaya	269 *	812	Gharife	673	1.019

* : Altitudes are approximate because they have been determined by means of altimeter's method.

Naturally, average yearly amounts of precipitation in Table 5 are approximate but as it will be seen later they are very useful.

DETERMINATION OF GRADIENTS OF PRECIPITATION AND THEIR EXPLANATION.-

For drawing precipitations maps, there are two methods. The first one is the method of drawing isolines by linear interpolation between stations. The second one requests determination of the average gradient of precipitation previously i.e. the determination of the average change of precipitation with altitude. In the case of Lebanon it was not possible to draw isohyetal maps by the first method. It can be used only in flat areas with great density of stations and on map with small scale. In mountanious countries, as in Lebanon, with relatively sparse data of rain fall, as it is the case, and with chose scale of the map 1:200.000°, application of this method can give very bad results i.e. an isohyetal map with a lot of suppositions. The latter method seems to be better and more accurate because it avoids an exaggerated accuracy i.e. a lot of local deviation from one general picture of the distribution of precipitation or some errors in the measurements which was not possible to eliminate during statistical preparation of data. The advantage of this method is that a very small number of stations yield a first approximation.

In the method of gradients, that has been applied to facilitate the drawing of precipitation maps for the Litani River Basin and vicinity, different stations are arranged according to their respective altitudes and amounts of rain-fall on coordinate sistem with altitude as ordinate and amount of rainfall as abcisa. Then elevations and the corresponding amounts of precipitation were averaged by one correlation line from which the average gradient of precipitation can be taken.

Average gradients of precipitation for 33 - Year period, obtained by the above described method can be seen in Appendix I.

As it is stated earlier the orography plays a particularly important role in the distribution of precipitation in Lebanon providing the ascent and descent of prevailing winds from the western quadrant. Because of that the rain-fall distribution over Lebanon is very closely related to orographical conditions.

This great influence gives naturally different gradients in association with exposure of different parts of Lebanon towards prevailing air flow in the lower levels of atmosphere. In Lebanon there are two mountain ranges which are generally parallel and which make right angles with prevailing winds.

During orographic lifting of prevailing winds the heaviest rain-fall occurs on the west side of the Lebanon mountains. It can be seen in Appendix I from correlation lines " I " and " II ". However, because of the similar influence of the moist air origin from the sea there is not a great difference between the amount of rain-fall on the same altitude in this area. Only in the region near Beirut the amount of rain-fall is a little higher (line I) than southerly from it (line II). The average difference is about 120 - 130 mm. It might be useful to mention that the solid parts of correlation lines are fixed by means of available data. The dashed parts where extrapolated theoretically because, unfortunately, there were not, as it is mentioned earlier, data on higher altitudes. It is very difficult to say that rain-fall obviously increases from the bottom of mountains to the top at a uniform rate.

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But the trend of correlation lines in lower levels, fixed by available data, suggest that it is actual especially when it is well known that the air origine from the sea, which is lifted on the western slope of mountains, is very moist.

On the eastern side of the Lebanon mountains, ie. on the leeward slopes, in connection with catabatic winds with " Foehn " effect, the amount of precipitation drops rapidly.

However, in connection with the effect of inercia in lifting, the air continues to ascend after reaching the crest of the mountain for some distance and then begins to descend.

The results of this physical process are the same amounts of precipitation on the eastern side of mountains as on the western side in the higher altitudes near the top. Naturally, because of that, the difference in the amount of rainfall between the bottom and the top will be greater on the eastern side than on the western side of mountains i.e. the gradient of precipitation must be steeper on the leeward slop. This type of gradient is most cummon on the lee sides of mountains..

It can be seen in Appendix 1 if we compare correlation lines for the eastern side of the Lebanon mountains (lines VII, VIII, IX and X) with those for the western side (lines I and II).

Last explanation can't give the answer as to why there are so many correlation lines for the eastern side of the Lebanon mountains.

For this there are two main reasons. The valley of Bekaa is wider in its northern part then in southern. Because of that the possibility for descend air motion towards north is better and in connection with the stronger " foehn " effect in western winds the amount of precipitation decreases in the same direction.

Practically on the extreme south of Bekaa, where two mountains ranges are very near to each other, the westerly air flow passes them without intermediate descend.

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Second reason is associated with the influence of South westerly winds. The Lebanon mountains is perpendicular to the prevailing westerly winds, but not to the prevailing South westerlies. It can even be said that they have nearly parallel directions. Because of that the influence of the moist air in South westerly flow weakens to the North-east direction and the amount of precipitation in connection with this effect, decreases in the same direction. The amount of rain-fall decreases gradually from the South to the North but on the first view it is not possible to see in Appendix I. As it can be seen, between correlation lines VII, VIII, IX and X there are great differences. The reason for this was the impossibility to fix a lot of transition correlation lines without real data of measurements. In connection with the above mentioned explanation the transition in gradients from one area to another must be gradual and without any jumps. It means that the amount of precipitation decreases gradually on the same altitude from the Southern part of the Eastern slop of the Lebanon mountains towards North.

The same situation prevails in the valley of the Litani River - Bekaa and on the Western side of Anti-Lebanon range where the amount of precipitation decreases gradually from South towards North also.

The valley of the Litani River named in arabic Bekaa lying between the Lebanon and Anti-Lebanon ranges, due to " Foehn " effect, receives the Westerly winds with rellatively little moisture. It can be said that Bekaa generally appears as a transition area between the two mountain ranges. The Westerlies are lifted again on the Western slopes of the Anti-Lebanon mountains and precipitation rises again with altitude till the top., in the same way as on the western slopes of the Lebanon mountains. It is quite comprehensible because when two mountains ranges, have the same exposure to the prevailing winds, the distribution of rain-fall on them is similar. But in connection with the smaller amount of moisture, that the air carries after passing over the Lebanon mountains, these slopes receive much less precipitation for the same altitude. Due to the same reason the amount of precipitation over the Eastern part of Bekaa is less than in its Western part.

Above described influence [redacted] can be seen in Appendix I by comparing correlation lines " V " and " VI " for the western side of the Anti-Lebanon mountains and the correlation lines " I " and " II " for the same side of the Lebanon mountains.

At the same time in the extreme Southern parts of the Western side of the Anti-Lebanon mountains i.e. on the Hermon mountain, the amount of rain-fall is very high and very near to that on the Western sides of the Lebanon mountains. This mountain is open to the West and Southwest direction i.e. it is not sheltered by range of the Lebanon mountains. Because of that the effect of upward motion of the moist air is more vigorous than on the windward side of the Anti-Lebanon mountains in Bekaa. As it can be seen from the correlation line III the amount of precipitation on the Western and Southwestern side of the Hermon mountain is less on the same altitude only about 120 - 130 mm. than on the same slope of the Lebanon mountains (correlation line II). But on its northern part in the vicinity of Rachaya and in the Northern part of the Hasbani River, surrounded by mountains and where there is the effect of downward motion of the air, the amount of rain-fall decreases rapidly and it is much less (see correlation line IV).

By means of the above described gradients of precipitation the isohyetal map over the Litani River Basin and vicinity has been drawn. This map is given as Appendix IV. The isohyetal interval is one hundred milimeters. Greater density of isohyetals is not needed. If one wishes to have some intermediate values of precipitation can easily get it by interpolation. Intermediate isohyetals are more or less parallel to drawn isohyetals.

It might be useful to mention that isohyetals cover distances of hundreds of kilometers and they are drawn using a relatively small number of data. With chose distance between than it is possible to avoid a lot of local deviations from the general distribution of precipitation and to avoid some possible errors in the measurement of rain-fall. In connection with the above it can be said that this isohyetal map has been assumed to represent the average of annual distribution of precipitation over the Litani River Basin based on the available precipitation data and theoretical considerations.

ISOHYETAL MAPS FOR THE TYPICAL HUMID AND THE TYPICAL DRY YEAR .-

For hydrological purposes it was also needed to draw isohyetal maps for one typical humid and one typical dry year in the period 1932/33 - 1964/65. The procedure for the definition of these years was the same as was described earlier and given in Table 4 and Figure 1.

As it can be seen in these annexes, the typical humid year was 1953/54 (see Figure 1, point 4). Between two typical dry years - 1950/51 and 1960/61 (see Figure 1, points 30 and 31) with similar total of rain-fall the year 1960/61 has been chosen. The main reason for this was the greater number of stations with available data.

Th procedure for the preparing of gradients and the drawing of isohyetal maps was same as was described earlier in the case of the elaboration of the distribution of precipitation over the Litani River Basin for 33 - year period 1932/33 - 1964/65. The graphical presentation of gradients for the typical humid year 1953/54 is given as an Appendix II and isohyetal map for this year as Appendix V. The same for the typical dry year 1960/61 is given in Appendixes III and VI respectively.

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As it can be seen by comparison of Appendixes I, II and III there are not any great differences between them in the general picture.

Because of that it is not needed to give separate explanations for the last two.

All their characteristics are faily clear from what has already been said for Appendix I. General agreement between them means also that the general trend of variation of gradients is realistic and based on actual physical processes in the atmosphere over Lebanon.

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